NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Improving
Fox Management Strategies
in Australia

Glen Saunders and Lynette McLeod

DEPARTMENT OF AGRICULTURE, FISHERIES AND FORESTRY

The European red fox was introduced into Australia in the 1870s for recreational hunting. Their subsequent spread was rapid and they are now responsible for environmental and agricultural impacts valued at over $200 million per annum.

Despite greater public awareness about feral cats, foxes are considered to be Australia's greatest predation threat to the survival of native fauna – particularly relevant given their recent introduction to Tasmania.

Foxes are also widely regarded as a major threat to lamb production, although it is important to recognise that many factors involved in poor lambing percentages are inconspicuous, whereas damage inflicted by predators is usually highly visible.

There have been surprisingly few scientifically-rigorous studies to confirm or refute many of the perceived impacts of foxes on agriculture and the environment. The need for further impact and cost–benefit studies is a common theme in this review.

Over the past decade there has been a dramatic increase in the use of 1080 fox baits, and whilst the continuing trend toward coordinated regional fox baiting should be encouraged, it is also important to ensure that such baiting is conducted effectively, particularly considering that recent surveys suggest that fox impacts may be increasing in many areas.

This report provides a comprehensive review of fox management strategies along with impacts and monitoring techniques. This includes a critical appraisal of past research studies and ongoing fox management programmes. A key finding is that problems with the experimental design and analysis of research and management has sometimes hindered progress in defining fox impacts and determining the best approach to reducing these impacts.

This report offers a set of key recommendations for consideration by research agencies, land managers and policy-makers to improve and harmonise approaches to measuring and managing fox impacts.

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Bureau of Rural Sciences
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Author affiliations:
Glen Saunders and Lynette McLeod, New South Wales Department of Primary Industries — Vertebrate Pest Research Unit

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Foreword

The European red fox was introduced into Australia in the 1870s for recreational hunting. Their subsequent spread was rapid and closely linked to that of rabbits; to the extent that both species are now widespread in Australia south of the Tropic of Capricorn. Tasmania was once free from the threat of foxes, but this has changed with their recent illegal introduction and an eradication campaign is under way.

Foxes possess a number of attributes that have allowed them to successfully colonise a diverse range of habitats in Australia — including rangeland, alpine, coastal and urban environments. Foxes are opportunistic predators and scavengers with no specialised food requirements. They show considerable variation in behaviour, population density, reproduction and diet between different habitats. Although breeding only occurs once per year and litter size is relatively small, cub survival is high. Foxes have few natural predators in Australia and disease is not a major mortality factor.

Despite greater public awareness about feral cats, foxes are considered to be Australia's greatest predation threat to the survival of native fauna. Foxes are also widely regarded as a major threat to lamb production. However, there have been surprisingly few scientifically rigorous studies to confirm or refute many of the perceived impacts of foxes on agriculture and the environment. The need for further impact and cost–benefit studies is a common theme in this review.

Historically, fox control was based on strychnine baiting and labour intensive approaches such as trapping, shooting and even 'fox drives'. There have also been attempts by some governments to encourage fox control through bounty schemes, but these have widely been regarded as unsuccessful in reducing fox impacts.

Factors which hinder the effective management of foxes include their wary and secretive nature which makes it difficult to assess population densities. Foxes are mobile animals and will actively fill any territory vacated by other foxes that have been removed through control programmes. Hence the effect of fox control over small areas will be rapidly negated by reinvasion.

Over the past decade there has been a dramatic increase in the use of 1080 fox baits. This has largely been driven by government agencies and landholder groups promoting regional approaches to fox management. The increasing availability of manufactured bait has also improved the convenience of fox baiting. Whilst the continuing trend toward coordinated regional fox baiting should be encouraged, it is also important to ensure that such baiting is conducted effectively. This requires employment of correct bait type, placement and timing, tailored to the local situation. Poor fox control results may discourage land managers from continuing control, but are often due to poor selection and implementation of available control techniques and strategies. Monitoring the success of fox control programmes and resultant changes in fox impacts is critical to determine the effectiveness of different approaches in different areas and to allow continual refinement of regional fox management programmes.

This report provides a comprehensive review of fox management strategies along with impacts and monitoring techniques. This includes a critical appraisal of past research studies and ongoing fox management programmes. A key finding is that problems with the experimental design and analysis of research and management has sometimes hindered progress in defining fox impacts and determining the best approach to reducing these impacts. Defining fox impacts and the effectiveness of control approaches is essential to justify public and private expenditure on management.

This report offers a set of key recommendations for consideration by research agencies, land managers and policy-makers to improve approaches to measuring and managing fox impacts. The report is a timely follow-up to the 1995 Bureau of Rural Sciences publication, *'Managing vertebrate pests: foxes'*, given the dramatic increase in published research and coordinated fox baiting programmes since this was released. These documents are part of a series of pest management guidelines prepared by the Bureau of Rural Sciences over the past decade through its administration of the National Feral Animal Control Programme — a Natural Heritage Trust initiative. Others in the series include guidelines for managing feral horses, rabbits, feral goats, feral pigs, rodents, carp, wild dogs and pest birds.

Dr Colin J. Grant
Executive Director
Bureau of Rural Sciences

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Acronyms and Abbreviations

ACO	Authorised Control Officer (New South Wales)
APVMA	Australian Pesticides and Veterinary Medicines Authority
DAFWA	Department of Agriculture and Food Western Australia
DEC	Department of Environment and Conservation (Western Australia – previously Department of Conservation and Land Management)
DEFRA	Department for the Environment, Food and Rural Affairs (United Kingdom – previously Ministry of Agriculture, Fisheries and Food; MAFF)
DEW	Department of the Environment and Water Resources (Australian Government previously Department of the Environmnet and Heritage)
DPIFM	Department of Primary Industry, Fisheries and Mines (Northern Territory)
DPIW	Department of Primary Industries and Water (Tasmania)
DSE	Department of Sustainability and Environment (Victoria)
DWLBC	Department of Water, Land and Biodiversity Conservation (South Australia)
NPWS	National Parks and Wildlife Service (New South Wales)
NRMB	Natural Resources Management Board (South Australia)
NSW DPI	New South Wales Department of Primary Industries
PAPP	para-aminopropiophenone
QDPIF	Queensland Department of Primary Industries and Fisheries
RLPB	Rural Lands Protection Board (New South Wales)
SFE	Synthetic Fermented Egg
TAP	Threat Abatement Plan
w/w	by weight

Glossary

1080: sodium fluoroacetate – an acute metabolic poison without antidote; particularly toxic to canids.

Adaptive management: a systematic process for continually improving management policies and practices by monitoring and learning from the outcomes of ongoing operational programmes.

Affiliative behaviour: behaviour that promotes cohesion between individuals.

Anthelmintic: the expulsion or destruction of internal parasitic worms.

Anxiolytic: compound which relieves anxiety.

Asymptote: a straight line that continually approaches a given curve but does not meet it at any finite distance.

Bait aversion: where a target animal learns to avoid a poison bait usually after having ingested a sub-lethal dose and becoming sick.

Bait caching: the removal of a bait from its original site and concealment at another site for consumption at another time.

Bait take: the total number of baits removed (not necessarily consumed) during a baiting programme, usually expressed as a proportion of the total available baits.

Battue: the organised beating or driving of game from cover, to be killed by hunters.

Canids: animals in the family Canidae, including dogs, foxes and wolves.

Corvids: birds in the family Corvidae, including crows, ravens and magpies.

Critical weight range species: animals that have a mean adult weight range between 35 and 5500 grams, argued to be more prone to extinction from predation and environmental disturbance than animals outside this range.

Dasyurids: animals in the family of carnivorous marsupials Dasyuridae, including quolls, dunnarts, antechinuses, planigales and the Tasmanian devil.

Edge effect: effect of the juxtaposition of contrasting environments on an ecosystem, used commonly in conjunction with the boundary between natural habitats, especially forests, and disturbed or developed land. Edge effects are especially pronounced in small habitat fragments where they may extend throughout the patch.

Electroencephalograph: the neurophysiologic measurement of the electrical activity of the brain.

Emetic: causes vomiting.

Factorial experiment: a statistical study in which each observation is categorised according to more than one factor, therefore allowing for study of the effect of each factor on the response variable as well as the effect of the interaction between factors on the response variable.

Fecundity: the number of offspring produced by an organism in a given time.

Free-feeding: a practice where non-toxic baits are laid for a certain period before the commencement of a toxic baiting programme.

Hair tubes: a tube device with patches of adhesive surface used for sampling animals' hair, usually used in conjunction with an attractant, or in areas of high target animal traffic.

Immunocontraception: the stimulation of the immune responses (antibody production and cell-mediated immunity) in the target animal against its own reproductive hormones, gamete proteins or another protein essential to reproduction, to induce sterility.

Indices/index: a measure which is correlated with a value but is not an actual estimate of that value.

Juvenile: the young of an animal, that is not fully developed or sexually mature.

***k*-adapted:** species with a low rate of reproduction so invest heavily in fewer offspring, each of which has a better chance of surviving to adulthood. Usually associated with stable environments where populations tend to expand to the maximum number of individuals that the habitat can support.

LD_{50}: the quantity of poison or lethal dose that will kill 50% of treated animals.

Line transect counts: a method of population sampling where the observer progresses through the area following a straight line of known length (transect) recording each animal, noting the distance of the animal from the observer when spotted and its angle relative to the transect.

Macropods: animals in the Macropodidae superfamily, including kangaroos, wallabies, bettongs and potoroos.

Mesopredator: a middle-rank predator in a food web.

Microsatellite loci: the chromosomal position of highly repetitive DNA base sequences of less than 15 base pairs, usually repeated 10 to 100 times without interruption. One of the types of satellite DNA used for verifying identity.

Mortality collars: radiotelemetry collars fitted to individuals that change signal pulse rate when no movement is detected for a set period of time indicating death of the individual.

Multiple regression analysis: a statistical method for estimating the conditional expected value of a variable given the values of more than one covariate (predictor variable).

Natal dens: dens used during breeding.

Necropsy: post-mortem examination of an animal.

Nil tenure: an approach used in pest animal management programmes that involves the removal of all land tenure issues from the planning stage to focus on the problem in a holistic manner, rather than on the basis of land ownership.

Point transects: a method of population sampling where the observer stands at a given position and counts the number of animals seen. Generally all detections are recorded, regardless of distance from the point, however they can be restricted to a fixed distance.

Poisson distribution: a discrete probability distribution that expresses the probability of a number of events occurring in a fixed period of time if these events occur with a known average rate, and are independent of the time since the last event.

Predacide: a substance or mixture of substances intended for preventing, destroying, repelling, or mitigating mammalian predators.

Quadrat: a defined plot of land selected for the study of plants and animals within it.

***r*-adapted:** species that produce many offspring, each of which is unlikely to survive to adulthood. Usually associated with unstable or unpredictable environments.

Radiotelemetry: a technique used to study animal movements by using a small portable radio transmitter (radio-collar) which emits a known frequency signal that can be received using a special antenna.

Raptors: a term for all birds of prey from several families, including eagles, falcons, harriers, kites, hawks, buzzards and owls.

Riparian: relating to or situated on the bank of a river or other body of water.

Sandplots/sandpads: an area of flat ground prepared by raking to remove sticks, rocks and any other debris then spread with sieved sand or soil to cover the surface with a coating of relatively fine material that allows for a clear impression of animal footprints.

Scat: faeces.

Seroconversion: the development of detectable antibodies (proteins which are produced by the immune system to neutralise foreign objects) in the blood serum as a result of infection or other stimulation of the immune response system.

Stratified sample: is a statistical method of grouping a population into relatively homogeneous subgroups (stratums). Then random or systematic sampling can be applied within each stratum to improve the representativeness of the sample by reducing sampling error.

Strip transect: a method of population sampling where the observer progresses through the area following a straight line of known length (transect) recording each animal within a fixed distance (strip) from the transect.

Sylvatic: involving one or more wildlife species.

Sympatry: the occurrence of organisms in overlapping geographical areas, but without interbreeding.

Taste aversion: where an animal learns to dislike or avoid a particular food or drink because of its taste, smell or other characteristics.

Ultrasound scanning: use of low frequency to internally investigate an animal without surgery, used for counting foetuses.

Wald statistic: used in the Wald statistical test. Typically used to test whether an effect exists or not between two nominal (named) or ordinal (ranked) variables.

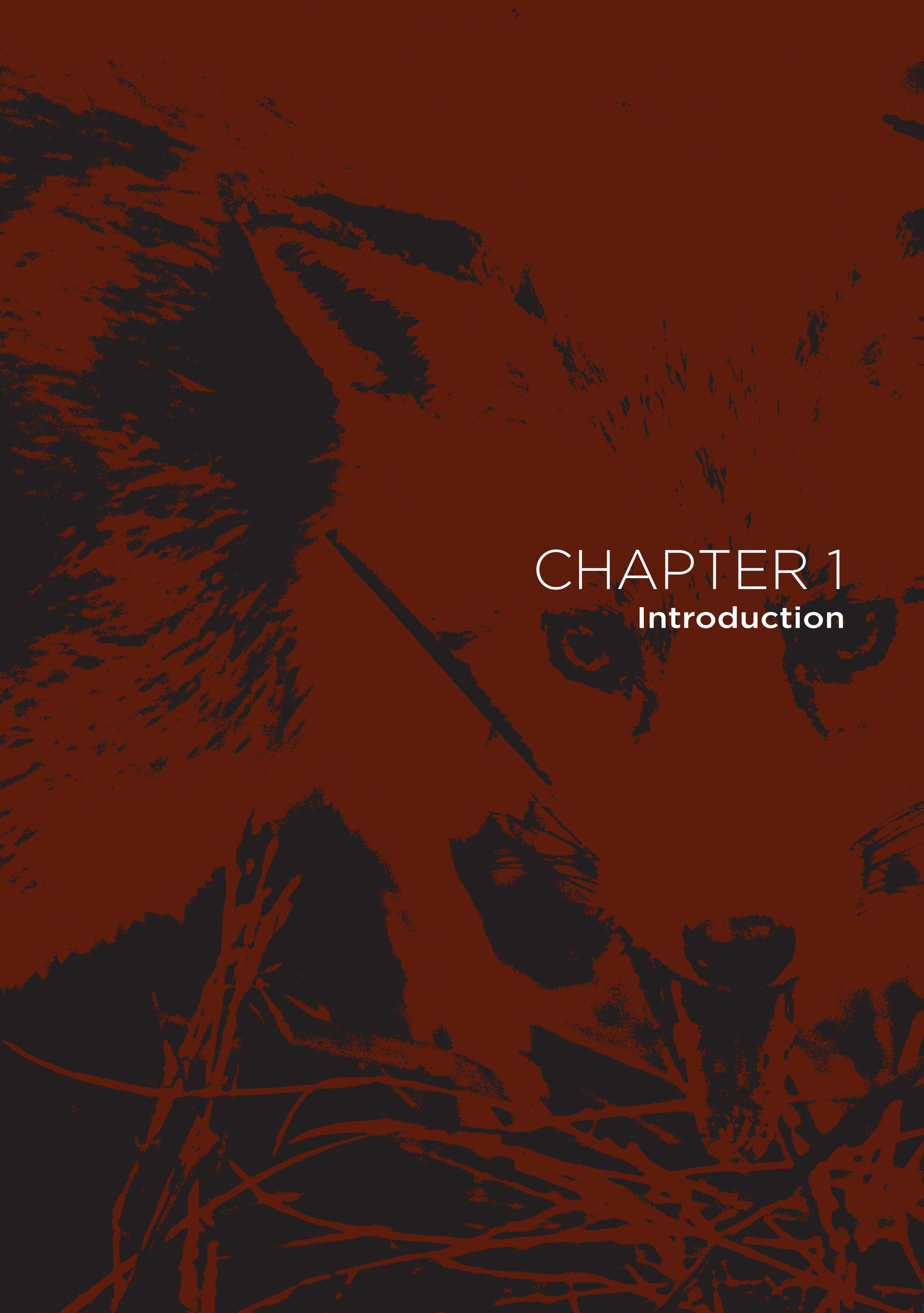
ZP (zona pellucida): a layer of glycoprotein that surrounds the plasma membrane of a mammalian egg cell. It develops as a jelly coat around the primary oocyte and is surrounded by the granulosa cells.

Key Recommendations

1. The objective of fox control programmes is to reduce the impacts of fox predation, not to reduce fox populations *per se*. The effectiveness of fox control programmes should be measured in terms of the response of the threatened population or in the economic return via increased agricultural production, not just by the change in fox abundance.
2. With its inherent ability to rapidly establish new territories over both short and long distances, the fox is perfectly adapted to compensate for any form of population reduction. Experimental, broadscale evaluations of population reductions from lethal baiting suggest high rates of success. However, the resources, duration and care that go into experimental control programmes are generally much greater than occurs during routine fox control programmes which often achieve lesser fox population reductions. There needs to be more assessment of routine fox control programmes to ensure that baiting recommendations achieve sufficient fox population reductions in 'real world' situations.
3. In the absence of reliable information, there is a particular need to re-evaluate the efficacy of conventional baiting programmes, especially on agricultural lands. Such evaluations should consider the way baits are deployed and the reasons why land managers choose to engage or otherwise in group baiting programmes.
4. A robust understanding of density:damage relationships for foxes in both agricultural and conservation landscapes remains elusive. This in turn hinders more definitive bioeconomic decision making. Deriving such relationships will require costly experimental evaluations. Nonetheless, opportunities and innovations for examining such relationships should not be overlooked in ongoing fox research programmes.
5. Aerial baiting of foxes has been successful in Western Australia. Differences in landscape, land ownership, density of human habitation and tolerance of native species to 1080 suggest that implementation of this strategy in south-eastern Australia may be problematic but warrants further consideration.
6. Consumption of sub-lethal doses of 1080 because of the combined consequences of bait caching and decay of 1080 has potentially important implications in the development of bait aversion. Research should be done to determine whether this is a real cause of concern and/or how it can be averted.
7. The continued use of any vertebrate pesticide cannot be guaranteed. The research and development required to register an additional toxin to 1080 for foxes are probably not commercially justified. Public funding will therefore be important if such alternatives are to be developed. Additional methods of fox control should also be subject to ongoing research.
8. The broadscale shooting of foxes is once again becoming popular. Large numbers of animals are being shot, with no documentation of the resultant changes in production values or the remaining fox numbers. The cost-effectiveness of this technique (and minimum shooting area and intensity required for sustained population control) needs to be further researched if its use continues to expand to the detriment of conventional baiting strategies.

9. In carnivores, death from 1080 is typified by severe central nervous system disturbance, convulsions, hyper-excitability, vocalising and ultimately respiratory failure. Although these symptoms can be distressing to an observer and may be associated with pain and distress, signs of convulsions, mental disorientation and unconsciousness do not necessarily mean that 1080 poisoning is inhumane – i.e. it is possible that animals are not experiencing conscious pain or distress due to the effect of 1080 on the nervous system. Regardless, it is appropriate to investigate other toxins which might be viewed by the public and animal welfare groups as being more humane.
10. The use of analgesic, sedative or anxiolytic agents combined with 1080 has also been proposed as a means to decrease or limit the perceived suffering that may be associated with 1080 poisoning. This is an area that requires research, particularly in assessing the field efficacy of incorporating analgesics with 1080 baits. Cost factors need also be considered. If the use of analgesics becomes a reality (and/or a requirement) of fox baiting, non-commercial preparation of baits may become redundant because of restrictions on the handling and use of such chemicals. This will have cost–benefit implications but might also bring more uniform standards into fox bait production.
11. Perceptions of the lack of humaneness of pest animal control techniques can hinder the research and development of more cost-efficient (and humane) means of controlling fox and other pest animal populations. There is an urgent need for national acceptance of standard operating procedures for all techniques currently employed in pest animal management. This would include the phasing out of inhumane control techniques such as steel jaw traps and strychnine.
12. As the fox is generally a secretive animal that is often present at low densities, obtaining accurate estimates of its abundance still remains a challenge. Complete enumeration is rarely possible for foxes (or any other wildlife species). Further experimentation with density estimates is required so that the accuracy and application of indices can be better interpreted. Studies that incorporate a variety of measures should be encouraged, and obtaining estimates by line transect counts and DNA sampling needs to be further investigated under Australian conditions.
13. There is a need to be concerned for 'at risk' or endangered native wildlife in circumstances where cats are present and foxes are controlled. This particularly applies where rabbits co-occur and where resources are limited in time by drought. The relationship between cats and foxes and the implications of mesopredator release requires further research. If conclusive evidence is available that cats will become a significant problem following the control of foxes, strategies that address the simultaneous control of both species must be considered. In some circumstances, such as in arid parts of Australia, the urgency for such action is already apparent.
14. There is a need to place fox baiting in the broader context of lamb production issues (e.g. nutrition). The full benefits of fox baiting may not be realised until issues such as nutrition, shelter, and the timing of lambing are resolved.
15. The recent introduction of foxes to Tasmania highlights the priority, with legislative support, of maintaining the fox-free status of other key islands around Australia such as Kangaroo Island. The Tasmanian situation is a potential environmental disaster and every effort should be taken to ensure foxes are eradicated from this State.

16. Given that resources are increasingly limited, greater emphasis on prioritising actions taken against foxes is required. Prioritisation should begin with identifying what impacts foxes are likely to be having and where these impacts are likely to occur. The PESTPLAN process provides a useful guide for private-land managers in setting priorities for control at a regional scale. In New South Wales, priority areas for control for the conservation of biodiversity have been established under the New South Wales Fox Threat Abatement Plan. A similar approach may be warranted in other jurisdictions.



CHAPTER 1
Introduction

1. Introduction

The red fox (*Vulpes vulpes*) is the most common and widespread member of its genus, which includes 11 other species worldwide (Clutton-Brock et al. 1976). It occurs naturally throughout most of North America, Europe and Asia, and parts of northern Africa (Lloyd 1980), and was first introduced to Australia in 1845 (Rolls 1969). Its success is attributable to its highly adaptable, unspecialized lifestyle with no specific habitat requirements (Corbet and Harris 1991). The fox's value as a furbearer and game animal, its predatory behaviour as a pest of livestock, and its role in the spread of rabies have made it the subject of intense study throughout the world.

The fox has long been recognised as a serious threat to populations of Australian wildlife (Marlow 1958, Finlayson 1961, Priddel 1989, Short and Milkovits 1990, Friend 1990, Kinnear et al. 2002). Because native Australian fauna did not evolve with foxes they have few fox-specific strategies for avoiding predation. Furthermore, the fox's impact on wildlife has probably been exacerbated by habitat fragmentation and modification since European settlement (Mansergh and Marks 1993). The fox is also increasingly being seen as an important livestock predator, although the results of studies to determine the extent of this impact have been highly variable (Saunders et al. 1995; Greentree et al. 2000). One positive impact is the role played by foxes in the regulation of rabbit populations; this role is thought to be important, but only at low to medium rabbit densities (Pech et al. 1992).

In 2004 foxes were estimated to cost the Australian agricultural industries and the environment more than $227 million (McLeod 2004). The most commonly used fox control techniques are lethal baiting, shooting, trapping, den fumigation, den destruction and exclusion fencing (Saunders et al. 1995). Fertility control through immunocontraception has been investigated as an alternative or supplementary means of fox control (Bradley et al. 1998), as has chemical fertility control (Marks et al. 1996). Other measures such as the use of guard animals have been promoted in recent years (Olsen 1998) but are not yet fully evaluated in Australia. Figure 1.1 shows the proportional uses of different fox control strategies, based on New South Wales data.

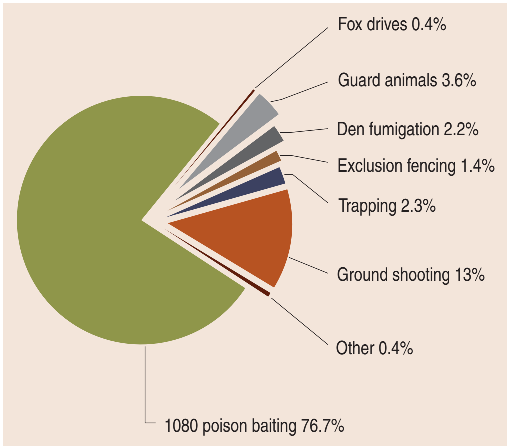


Figure 1.1 *Proportional use (percentage of control effort) of fox control techniques in NSW (after West and Saunders 2003).*

The scale of problems involving fox predation, ranging in size from a small poultry shed to a large national park or agricultural region, can determine the most appropriate means of fox control or, conversely, the effectiveness of control in individual situations. For example, aerial baiting would be the most cost-effective strategy over large areas, whereas the use of guard dogs would be suitable only on a property basis. Similarly, the use of fertility control would be of little benefit in protecting small-scale enterprises. Measurements of cost-effectiveness and efficacy for each control technique are useful in deciding the most appropriate strategy.

The strategies and techniques used in agricultural protection have mostly been determined by the biology of the livestock being protected, rather than by the biology of the fox. As such, these techniques have been used on a reactionary or short-term basis, with little consideration for sustained fox population and impact reduction. Conservation management strategies focus on alleviating fox predation on wildlife species by culling foxes from an area using poisoned baits and exclusion fencing (Kinnear et al. 1988; Burbidge and Friend 1990). By necessity, such control effort needs to be sustained.

'Foxes cost Australian agriculture and the environment more than $227 million in 2004.'

The profile of the fox as a pest animal has undergone a dramatic change over the last decade with its promotion as a major threat to the environment and agriculture by government agencies, conservation groups and companies that manufacture fox baits. This change has also occurred partly in response to the withdrawal of commercial harvesting operations with the collapse of the fur trade. Accompanying this elevation of public perception has been an exponential increase in fox control activities, particularly lethal baiting.

The Australian Government has developed national guidelines for the coordinated management of vertebrate pests, including the fox (see Saunders et al. 1995). In addition to specifically considering fox management practices, these guidelines also review the principles and strategies of pest animal management. Current pest management strategies need to emphasise management of the whole system rather than separate elements, and to focus on reducing detrimental impacts rather than just pest numbers (Braysher 1993).

Predation by the fox is listed as a 'key threatening process' under Schedule 3 of the recently repealed Commonwealth *Endangered Species Protection Act 1992*. As a requirement of this listing, a national Threat Abatement Plan (TAP), intended to coordinate efforts to minimise the impact of foxes on native wildlife, has been prepared by the Department of the Environment and Water Resources (Environment Australia 1999). This plan must be reviewed at intervals of no more than five years with such a review currently in progress. The objectives and actions delivered by the TAP provide guidelines for funding support made available under the control of Natural Heritage Trust.

The TAP makes various recommendations, including the need to develop and use innovative and humane control methods for fox management. The Commonwealth *Environment Protection and Biodiversity Act 1999* provides a framework for the environmental assessment and approval of actions that are likely to have a marked impact on matters of national significance. Therefore, fox control activities may come under the scrutiny of the Federal Minister for the Environment and Water Resources.

Similar legislation is being enacted in some States. For example, in New South Wales, the *Threatened Species Conservation Act 1995* also requires the preparation and implementation of a State TAP for foxes (NSW National Parks and Wildlife Service 2001). This document includes the specific objective of ensuring that fox control programmes are effective in minimising the impacts of fox predation on threatened species. The New South Wales TAP points out that there are insufficient resources to control all areas where there is conflict between foxes and native fauna, so managers need to use existing resources and technologies more efficiently to achieve the desired outcomes.

The fox is distributed widely across the Australian mainland, with the exception of the wet tropics. This distribution was mostly achieved within 100 years of its introduction to central Victoria (Jarman 1986). It is likely that the northernmost limits change with seasonal conditions (Saunders et al. 1995), although Edwards et al. (2004) suggest that some northerly movements are becoming permanent. For example, foxes were rarely encountered in the Tanami Desert in the 1970s and 1980s but are now relatively common as far north as Tennant Creek (Paltridge and Southgate 2001; Edwards et al. 2004).

Despite recent intensive control efforts, the fox is still found in high numbers throughout most of this distribution. For the fox, human 'predation' has long been the most important cause of death both in Australia and across its natural distribution, and the species has adapted well to this situation. A study of fox populations with and without the influence of hunting found that genetic variability in non-hunted populations was almost absent and significantly lower than in hunted areas (Frati et al. 2000). The fox probably evolved under the pressure of a community of larger predators (Cavallini 1996). Hunting (and other forms of control) may increase the genetic variability in fox populations by partly mimicking the effects of natural predation; this may be why numerous persecution campaigns and hunting have failed to eradicate foxes from large areas (Frati et al. 2000).

This review presents details of current fox management practices and of some successful fox management programmes (at various scales), measured in terms of reductions in fox numbers and recovery of prey species. Government-sponsored fox control initiatives such as 'Western Shield' (Section 13.5) concentrate primarily on the protection or recovery of native prey. It is hard to place a value on biodiversity and to determine the degree of value-adding that government expenditure in this area creates. As outlined in TAPs for the fox, provided that fox control is well targeted and properly prioritised in terms of the available resources, successful conservation outcomes can be achieved. The matrix approach described by Dickman (1996b) is particularly useful in this process. What needs to be evaluated more critically is the cost-effectiveness of private investment in fox control based on production values.

Unfortunately, there have been few unequivocal reports on the evaluation of fox control, and there is a reliance on anecdotal information to sustain the notion that ongoing campaigns against the fox throughout Australia produce positive cost–benefits. Evidence of the impact on production values is often based on historical observations, which may need to be re-affirmed in the light of today's agricultural practices. There is also a bias in that those scientific evaluations that are available have been conducted mostly by government agencies with access to relatively high levels of resources and (in some cases) using management approaches that are not representative of routine control programmes.

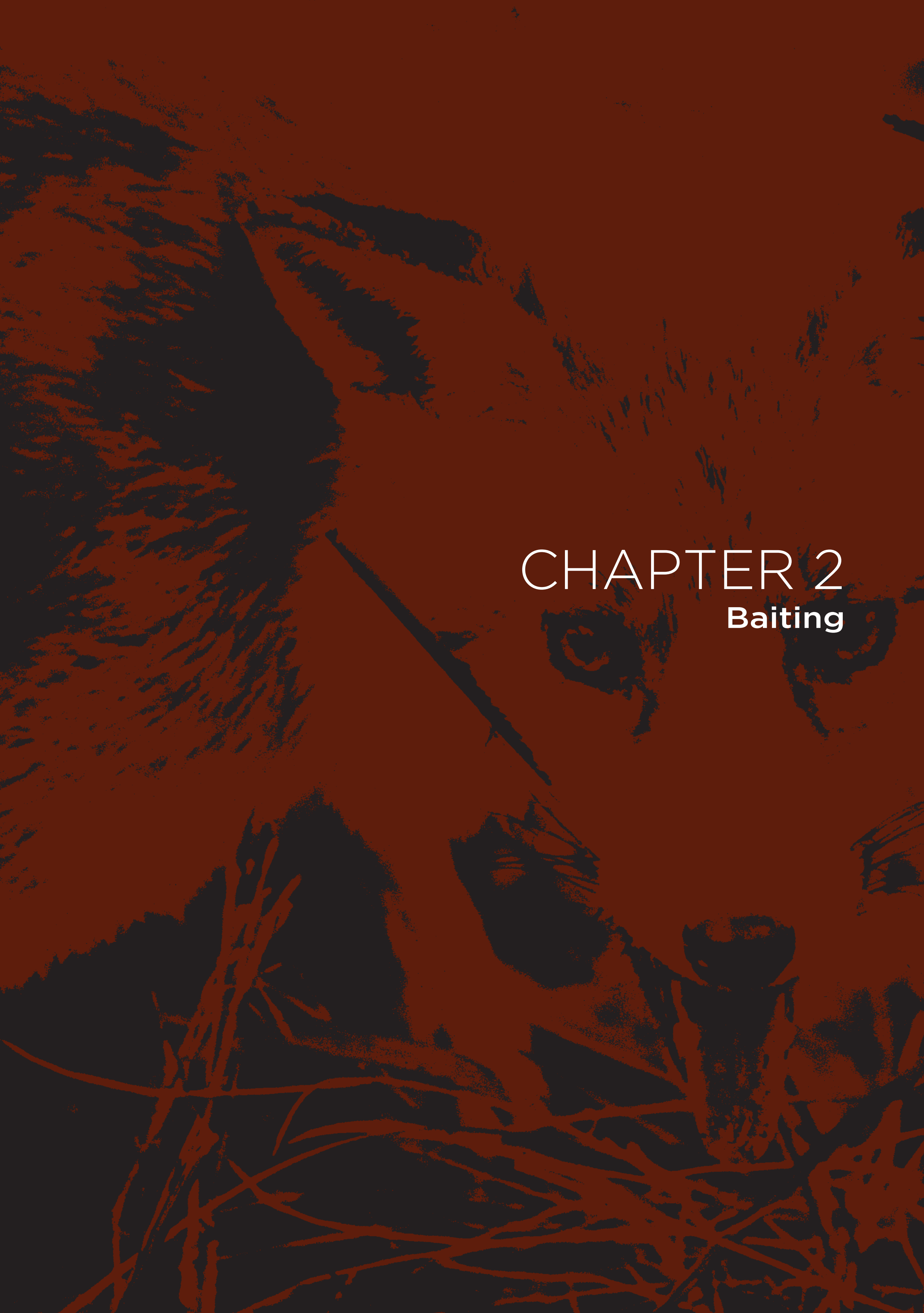
It is questionable how well these evaluations reflect the outcomes of the majority of fox control programmes conducted by private land managers, either in isolation or as part of group campaigns. They also tend to concentrate on the extent of population reduction rather than impact reduction, perhaps rightly based on the assumption that anything approaching 80%–90% control will result in significant reductions in impact. Similarly, there are no estimates of the likely regional impact of fox predation in the complete absence of any control measures. Compensatory mechanisms (such as increased litter size and dispersal) are thought to cancel out the longer-term influence of fox control programmes, and some fox populations might regulate their own numbers regardless of the influence of external control measures.

Braysher (1993) highlighted the need to continually reassess management strategies because of the changing expectations and goals of pest management. New approaches to pest management are being built around five interrelated steps (Olsen 1998):

- Define the problem in terms of pest damage.
- Determine objectives.
- Identify and evaluate management options.
- Implement a management plan.
- Monitor and evaluate the outcome (including, if necessary, redefining the problem).

Consistent attempts to promote the need to manage vertebrate pests on the basis of 'damage not numbers' appear to be failing, and there is still an alarming lack of monitoring of impact as a means of measuring success. This problem is shared equally by pest animal controllers and researchers. Caughley and Sinclair (1994) point out that wildlife control campaigns in many countries share a common characteristic: the original reason for the existence of a management action is forgotten and then the action (reducing population density) becomes the objective. A pest management strategy should always start with the question 'Why is the pest a pest?' and should seek to address the underlying weaknesses in ecosystems and/or agronomic practices that have allowed organisms to reach pest status (Lewis et al. 1997).

Since *Managing Vertebrate Pests: Foxes* (Saunders et al. 1995) was published, there have been many advances in our knowledge of foxes, particularly related to their management. This review attempts to document these advances, with emphasis on control techniques, monitoring techniques and legislation as they affect control. In some cases a historical perspective is provided to help explain the evolution of these advances.



CHAPTER 2
Baiting

2. Baiting

Key issues

- *With its inherent ability to rapidly establish a new territory over both short and long distances, the fox is perfectly adapted to compensate for any form of population reduction. It is therefore critical to assess the desired outcomes over time of a baiting programme so that the coverage of bait achieves the necessary levels of control.*
- *Experimental, broadscale evaluations of population reductions from lethal baiting suggest high rates of success. However, the resources, duration and care that go into these experimental studies are usually much greater than that associated with routine landholder control programmes. More evaluations of the latter are needed to determine the 'real world' reduction in fox populations that can be expected from recommended baiting strategies.*
- *In the absence of reliable information, there is a need to re-evaluate conventional baiting programmes conducted in eastern Australia, especially on agricultural lands, and with particular emphasis on the way baits are deployed.*
- *Attractiveness and hence location of fox baits can be enhanced by including synthetic compounds. First establish the need to make existing baits more attractive and then test the effect of including additional attractants under field conditions.*
- *Anecdotal and research evidence shows that continuous scent trails should not be dragged between fox baits.*
- *Free-feeding can have negative consequences on toxic bait uptake and cost-effectiveness in conventional control programmes. It should only be done where other issues, such as the identification of non-target risks, are being addressed, or to assess populations.*
- *Studies that compare the rates of consumption of different types of baits should not use bait removal (uptake) alone as an index of consumption. Rates of bait caching should be incorporated in measurements of bait uptake where they are used to derive population indices.*
- *Although regional variations may exist, most commonly used fox baits are readily consumed by foxes and are unlikely to be less preferred to naturally occurring food items. However, saturation of an environment with a seasonally abundant source of easily acquired food could make baits less desirable to foxes.*
- *The potential for foxes to regurgitate bait materials once toxic effects are experienced may need to be considered if this becomes an important source of non-target risk.*
- *The potential for cached baits to be moved large distances from bait lines must be considered when assessing non-target risk.*
- *Caching may result in monopolisation of bait lines and bait aversion through consumption of sub-lethal doses. Where caching is thought to be occurring (e.g. continuous and multiple bait take), the baiting strategy (and possibly the bait type) should be modified.*
- *Food preference plays a role in bait caching. There is a lack of information on how dietary preferences relate to bait preferences, particularly in relation to seasonal changes in diet, and in turn on how this affects caching behaviour.*
- *The full consequences of burying fox baits, although mandatory in most of eastern Australia, has not been scientifically assessed. Similarly, it has not been properly shown that mound baiting improves the effectiveness of fox baiting.*

- *Although foxes are known to cache fresh baits, the palatability of baits that have been buried for extended periods is not known. If these baits are neither palatable nor readily found, issues such as the development of bait aversion may not be important.*
- *The effectiveness of a baiting operation should be improved by taking advantage of the peak demands for food by foxes, although this has not been experimentally tested.*
- *Studies of energy demands and reserves show that the optimal month to bait foxes is at the crossover point from energy depletion to gain (November).*
- *Recommendations for optimal baiting strategies based on seasonal changes in behaviour and food supply are conflicting. There may be enough information available in the literature to address this issue through modelling.*
- *Aerial baiting is about one-third the cost of ground baiting, provided that a big enough area is treated. Foxes will take longer to encounter baits applied randomly from the air, although this does not appear to affect overall baiting effectiveness. Aerial application should also reduce the extent of multiple bait take, although this has not been tested.*
- *Aerial baiting has been successful in Western Australia. Differences in landscape, land ownership, human habitation and tolerances of native species to 1080 suggest that implementation of this strategy in eastern Australia may be a problem but warrants further consideration.*
- *There are numerous cost–benefit factors that need to be taken into account when considering optimal baiting strategies. These must be given equal weighting to the many biological factors that can influence likely outcomes.*

Historically, baits derived from major fox dietary items have been used to deliver toxicants to both harvest and control wild fox populations (Lloyd 1980; Linhart 1993). Baits have been used to deliver experimental antifertility agents in North America (Linhart 1964; Allen 1982) and more recently, various bait types have been developed to deliver oral rabies vaccines throughout Europe, North America and the Middle East (Bachmann et al. 1990; Guittre 1990; Linhart et al. 1997 a and b; Cliquet and Aubert 2004; Thulke et al. 2004).

In Australia, lethal baiting is considered to be the most effective method of fox control. Strychnine was the first recommended toxin used in fox baits, but since the late 1960s, sodium monofluoroacetate (compound 1080) has been the poison of choice. Meat has been the preferred substrate for baits because of its palatability to foxes and relatively high target specificity (Kinnear et al. 1988).

'Lethal baiting is still considered to be the most effective method of fox control in Australia.'

A variety of bait types are used in Australia, including fowl heads or wings, fresh and dried pieces of meat, offal, lamb tongues and the commercially produced Foxoff® (Animal Control Technologies) and De-Fox™ (Paks National Pty Ltd). Foxoff® baits are rectangular, semi-soft tablets available in two sizes: 30 grams and 60 grams. They are based on meat meal and contain animal fat, preservatives, binding agents and some proprietary flavour enhancers (Saunders et al. 1995). De-Fox™ is a 22-gram sausage-shaped bait, made from 80% liver and 20% kangaroo meat.

In Western Australia, the Department of Agriculture and Food manufactures a dried-meat bait (mostly kangaroo) for foxes that is used extensively and effectively across the State. On a smaller scale, the NSW National Parks and Wildlife Service (NPWS) also produce a dried-meat bait. The Western Australian Department of Environment and Conservation (DEC) has developed its own manufactured bait (Pro-bait®) made from minced kangaroo meat, pork fat and dog food flavour enhancer, bound together with a salami-style binder and dried (N. Marlow, DEC, pers. comm. 2005). Eggs are also occasionally used as bait substrates (Twigg et al. 2001).

The effectiveness of lethal baiting relies on the ability of the target animal to find a bait (attractiveness of bait) and then consume it (palatability of bait) (Allen et al. 1989; Linhart et al. 1997a). Once bait is found by a fox it is not necessarily consumed on the spot but can be left in place or cached for possible later consumption. Caches can also be found by other foxes or non-target species (see Section 2.7), or left to decay in the ground. Bait is offered to foxes as an alternative food source. Foraging behaviour can be influenced by the food choices available in the environment and by the energy demands of foxes throughout the year. Baiting effectiveness can thus be also influenced by time. Overlaying these behavioural influences on the effectiveness of baiting is a series of logistical considerations involved in bait delivery. These include the method of application, timing, frequency, bait density, coverage and cost. Taking all of these into account creates a complicated matrix of factors that can influence the outcome of a lethal baiting programme.

2.1 Attraction to baits

Various methods have been used to attract a target animal to a bait site, including the use of visual and auditory cues, odorous chemicals and 'draw baits' such as carcasses or other food. In North America, a novel practice, especially when baiting in heavy snow cover, was to insert a feather into baits to make them more visible to foxes (Linhart 1964).

Foxes depend strongly on olfactory cues for locating food and communicating (Storm et al. 1976; Henry 1977) and odorous compounds have long been used to draw foxes to control devices such as traps and baits (Fagre et al. 1981; Turkowski et al. 1983). These odorous attractants can be coated on, incorporated in, or placed near the bait or control device. They mainly consist of pheromonal or food odours.

Researchers have discovered complex inter-relationships between certain odours and behaviour in predators. In addition to attracting a predator, some odorous lures can elicit specific behavioural responses such as biting or rolling (Phillips et al. 1990; Kimball et al. 2000). Seasonal trends have been found in the attractiveness of many of these odorous lures, mainly because of the effects of pheromones in breeding (Steelman et al. 1998; Saunders and Harris 2000).

In overseas studies, synthetic fermented egg (SFE) product (an artificial attractant), fox anal sac secretion and fox urine have been found to be highly attractive to foxes (Macdonald 1977; Albone et al. 1978; Whitten et al. 1980). Saunders and Harris (2000) tested a variety of chemical attractants for foxes, in a series of pen trials in England. Although no outstanding substance (i.e. one that elicited a significant response at all times of the year) was identified, the response to some of the chemicals (SFE and valeric acid) led the authors to conclude that the incorporation of an attractant in baits was worth further field investigation.

'Foxes depend strongly on scent for locating their food and communicating, so scent lures may be used to attract foxes to baiting stations.'

There have been a number of published Australian studies on attractants. These initially concentrated on dingoes and wild dogs (*Canis familiaris dingo, C. f. familiaris* and hybrids) (Jolly and Jolly 1992; Mitchell and Kelly 1992), but Hunt et al. (2005) reported on the recent development and testing of a synthetic SFE for foxes and wild dogs. In trials conducted in the southern highlands of New South Wales, the application of SFE to bait stations was shown to significantly increase site visitation (measured using sandplots) by both wild dogs and foxes. This product has now been released as a commercial product in Australia, under the trade-name FeralMone™ (Animal Control Technologies). There are mixed anecdotal reports and scientific results regarding the use of FeralMone™, and a recent large-scale study in the Western Australian rangelands found that there was no increase in wild dog visitation or bait take at plots treated with FeralMone™ (Thomson and Rose 2005).

Artificial attractants such as SFE have not been widely used in fox baiting in Australia, even though their use is recommended (Korn and Lugton 1995; Bloomfield 1999). The recent release of FeralMone™, which comes in a user-friendly aerosol can and is widely available, now allows land managers to test the effectiveness of such attractants in their local area at low cost.

Carcasses are sometimes used as 'draw stations' for trapping foxes (Bubela et al. 1998; Kay et al. 2000) but are not commonly used for fox baiting. Moseby et al. (2004) reported that auditory lures were successful in attracting foxes to bait stations in arid regions of South Australia. These types of lures were easier to maintain than olfactory lures and offered a consistent output without the need for continual refreshment.

A practice that is commonly used in Australia to hasten bait location and uptake is the dragging of a scent or lure trail using an animal carcass (e.g. Korn and Lugton 1995; Anon 1999a; Bloomfield 1999). Greentree (2000) reported on a study designed to compare bait uptake between dragged and non-dragged bait lines. Although no significant difference was detected in bait uptake after three weeks, results were not presented for shorter time periods. Since the purpose of using scent trails is to hasten bait uptake in the short term, the results of this study were inconclusive.

In a series of bait trials where baits were laid without the use of scent trails, Staples and McPhee (1995) reported that foxes found 40%–90% of bait stations within 8–28 days of establishment. These results are very general and, again, provide inconclusive evidence. Despite the lack of strong experimental evidence supporting the cost-effectiveness of scent trails, this practice continues to be used. In Western Australia, continuous scent trails are not recommended (Anon 2001).

'Do not drag continuous scent trails between fox baits – it tends to encourage multiple take of baits by individual foxes.'

In recent years, the use of scent trails has been suspected from anecdotal evidence to encourage multiple uptake of baits (and presumably caching) by individual foxes (Staples and McPhee 1995; Priddel and Wheeler 1997; Bloomfield 1999). As a consequence of these observations, dragging in a continuous line between all bait stations is now not recommended.

Pre-baiting or free-feeding is a practice where non-toxic baits are laid for a certain period before a toxic fox-baiting programme is commenced. Free-feeding has been used in field trials to attract foxes to a specific site (point of control pre-baiting) to either hasten subsequent toxic bait uptake (Saunders et al. 1997) or obtain indices of fox abundance (Thompson and Fleming 1994; Dexter and Meek 1998). Landscape pre-baiting is a practice where non-toxic baits are spread across an area remote from the actual control points. The idea is that animals are attracted to the area and become habituated to the scent associated with a non-lethal reward; lethal baits can then be placed using the same scent (Hunt 2005).

'Free-feeding can have a negative effect on uptake of toxic baits and cost-effectiveness of control programs.'

Free-feeding is not a common practice in current baiting strategies in most States, although in Victoria and New South Wales it is recommended to use free-feeding in conjunction with sandplots to assess the risk to local non-target animals, particularly quolls, before poison baits are offered (Bloomfield 1999; NSW National Parks and Wildlife Service 2001). Although free-feeding has been suggested by some authors (Thompson 1994; Thompson and Fleming 1994; Dexter and Meek 1998; Hunt 2005) as a way of increasing the effectiveness of a fox-baiting programme, this has not been experimentally verified. The procedure adds to the cost of control, requiring more resources and labour, and is usually used only for conservation purposes.

Free-feeding patterns in most pest animal control programmes tend to start off with low rates of bait take, eventually reaching a plateau of maximum take. Provided that lethal fox-baiting programmes are long enough, the same plateau is reached with toxic baits without the additional demand on labour. A potential problem of free-feeding as a means of attracting foxes is that foxes could become satiated before the lethal baits are offered and thus could be more likely to cache the lethal baits. Gentle (2005) confirmed this in his study.

Free-feeding could also predispose non-targets to take lethal baits, particularly when it is hard to determine whether non-targets are present (or when this is simply not done). Additionally, the presentation of non-toxic bait for periods before toxic bait can pre-condition animals to consuming the non-toxic bait, and if the cues are different for the toxic baits, consumption of the toxic bait may be reduced. There is evidence that this has occurred in foxes (Gentle 2005).

2.2 Bait consumption

Although odour attractants or lures may enhance bait discovery, this does not necessarily increase bait ingestion (Allen et al. 1989; Linhart 1993). Bait palatability is an inherent characteristic that induces an animal to consume the bait as food (Allen et al. 1989). Despite the distribution of many millions of fox baits for oral rabies vaccination of foxes in Europe and North America, and for lethal control of foxes in Australia, there are few published papers on the development of baits and bait preference, mostly because of the desire to protect commercial interests (Linhart et al. 1997a). Linhart (1964) tested eight different fox bait types to evaluate their suitability to deliver an anti-fertility drug and found that no bait type was consumed preferentially. Saunders and Harris (2000) also tested a variety of bait types on captive urban foxes and concluded that foxes showed no clear preference for any particular bait type. In many cases, bait preference is based on user requirements such as cost and availability, rather than the aim of maximizing consumption by foxes. Figure 2.1 shows the relative use of different bait types throughout New South Wales in 2002.

There are several published Australian studies on bait uptake by foxes (e.g. Thompson and Fleming

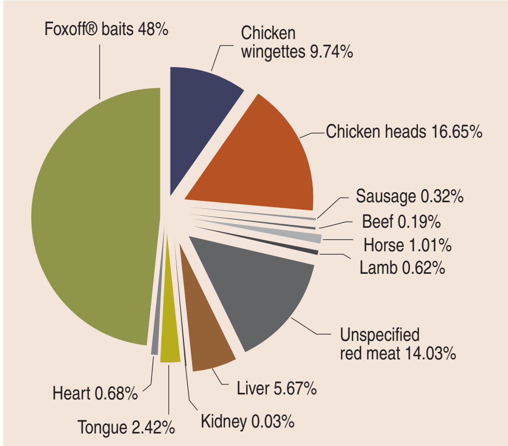


Figure 2.1 *Proportional use of bait types to control the impacts of foxes in NSW (after West and Saunders 2003).*

1994; Marks and Bloomfield 1999a; Thomson and Algar 2000; Thomson et al. 2000), but there is a lack of conclusive information on bait preferences in the Australian literature. Kinnear et al. (1988) reported that meat was highly palatable to foxes, but that under wet conditions chicken eggs were a more reliable vehicle for delivering 1080. Although this study stated that one of its objectives was to determine the types of bait most palatable to the fox, the experimental procedure and results were not detailed and the conclusion seemed highly anecdotal. Both red kangaroo and emu meats are thought to be preferred baits for foxes in western New South Wales, but again, no experimental confirmation is available (I. Lugton, NSW DPI, pers. comm. 2000).

One of the apparent problems in identifying a preferred bait is the reliance on subjective assessments. Bait removal (uptake) over time as a measure of bait preference/palatability is not necessarily a conclusive measure of bait preference, because even if a bait has been removed it may not necessarily have been consumed. Examples of this discrepancy between uptake and consumption are highlighted in studies by Körtner et al. (2003), where 19 of 20 baits that were removed from the bait station by spotted-tailed quolls (*Dasyurus maculatus)* were found intact a short distance away, and Thomson and Kok (2002), who reported that a small number of baits were moved from the bait station area and just dropped, largely intact, on the ground surface. There may also be geographical variations in preference, depending on the availability and range of alternative foods as well as the previous baiting history.

Van Polanen Petel (2001) tested the preference of captive foxes for three types of baits (Foxoff®, beef-liver and dried beef-liver) and reported a significant preference for the beef-liver bait over the other two types. Although observations on captive animals in pen trials are useful indicators, field trials are necessary to determine whether behavioural responses of free-ranging animals are similar (Saunders and Harris 2000). Van Polanen Petel (2001) also tested bait preference in a field situation using two bait types (dried beef-liver and Foxoff®) offered as a paired choice, utilising transmitters to determine the fate of baits. The liver bait was eaten more often and cached the least.

'Some studies suggest that foxes have a preference for liver-based baits, but others suggest a preference for synthetic meat-based baits.'

Both Fleming et al. (1992) and Staples and McPhee (1995) report unpublished field studies that compared the uptake of different types of baits by foxes, but they, too, used bait removal (uptake) as a measure of bait preference/palatability. Fleming et al. (1992) reported on the commercial fox bait, D-K9, which consisted of a sausage containing meat, green dye, lure chemicals and a tablet of 1080. This bait was field tested along with three other types of bait (chicken heads, meat and liver) but no details were given of the experimental procedure. Foxes were found to remove this bait at about the same rate (23%) as chicken heads (25%), and at a significantly higher rate than either meat (10%) or liver (12%).

Further development and commercialisation of the D-K9 bait did not proceed because commercial funding was discontinued (P. Fleming, NSW DPI, pers. comm. 2005). Staples and McPhee (1995) tested the uptake of manufactured Foxoff® baits, along with a variety of other bait types (horse meat, beef, mutton, lamb tongue, chicken heads and liver) in a series of trials across a wide range of habitats in Victoria. The overall uptake of the manufactured bait was similar to that of most other meat bait types.

The consumption and palatability of the newly developed Pro-bait® (Department of Environment and Conservation, WA — DEC) was compared with those of dried-meat baits in a series of field experiments (Marlow 2000). Unlike other Australian bait preference studies, this study used bait markers and destructive sampling of the population to determine the uptake of each bait type. The rate of consumption of dried-meat baits was significantly higher than that of the Pro-bait® (when the data were pooled, uptake was 82% for the dried meats and 71% for Pro-bait®). About half of the sampled foxes were found to have ingested both baits. It is not known whether this difference in uptake is entirely due to the preference for dried-meat baits over the Pro-bait®, or whether other factors such as the longevity of Pro-bait® influenced the results (Marlow 2000).

Further trials revealed that Pro-bait® lasted longer in the field than dried meat baits. Seven different flavour enhancers were presented to foxes in the field and the chicken flavour enhancer was significantly preferred. This flavour enhancer was added to Pro-bait® and the uptake trials using biomarkers and destructive sampling were repeated. There was no significant difference between the uptake of dried meat baits and Pro-bait®.

Trials on captive individuals of chuditch and brush tailed phascogales indicated that these two species were potentially at risk from Pro-bait® (Martin et al. 2002. However, toxic Pro-bait® was delivered to wild populations of chuditch and brush tailed phascogales and no individual of either species was killed so these baits are now endorsed for operational use at all 'Western Shield' sites (N. Marlow, DEC, pers. comm. 2006).

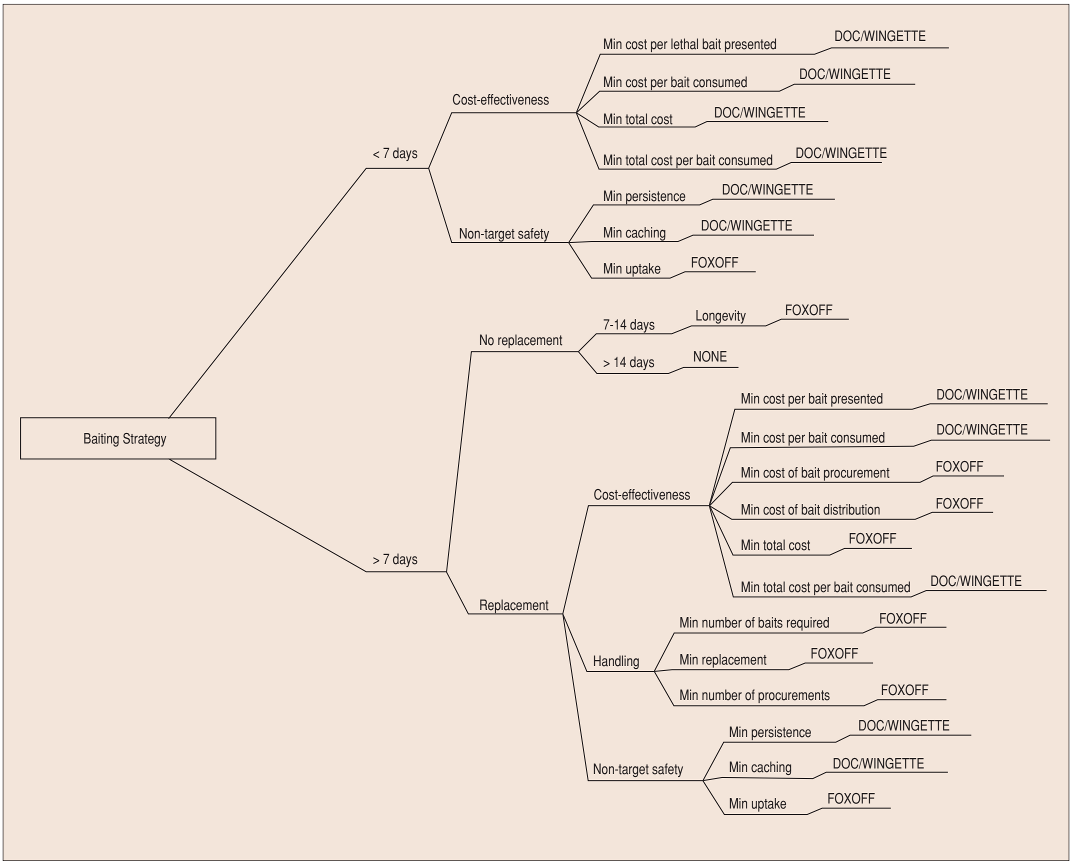


Figure 2.2 *Decision tree for illustrating the issues and sequence of decisions to be made in choosing the appropriate bait type for a fox-baiting campaign in the Central Tablelands of NSW (from Gentle 2005). Bait types: DOC = day-old chicks; WINGETTE = chicken wingette; and FOXOFF = Foxoff®.*

Flavour additives can enhance bait palatability and may also help mask the toxic substances added to the bait (Teranishi et al. 1981). Saunders and Harris (2000) found that captive foxes preferred sugar and synthetic beef flavour as additives. Baits covered in granulated sugar have been used to deliver chemosterilants to wild foxes (Oleyar and McGinnes 1974; Allen 1982). The increased acceptance of baits treated with sugar (sucrose) has been observed in a number of coyote studies (Fagre et al. 1981; Teranishi et al. 1981; Fagre and Ebbert 1988). Hunt (2005) found that both foxes and wild dogs accepted marshmallows in a pre-baiting trial in southern New South Wales and proposed the development of a sweet-tasting scent coating for existing commercial baits. Steelman et al. (1998) found that grey foxes (*Urocyon cinereoargenteus*) showed a high acceptance rate of sweet baits throughout the whole year. Meat attractant did not enhance acceptance by foxes of two types of synthetic baits tested in Canada (Bachmann et al. 1990).

A factor that may need to be considered when selecting a bait type for lethal baiting is potential regurgitation of the bait material once the animal experiences toxic effects. This phenomenon is particularly common with 1080 and can result in risk to non-target animals; however, the incidence (and risk) has been evaluated only in baiting feral pigs (see O'Brien and Kleba 1986).

Another factor to consider when selecting a bait type is the degradation rates of the baits. This is discussed in detail in Section 3.1. Gentle (2005) developed a decision tree (Figure 2.2) for choosing an appropriate bait type for a fox-baiting campaign in the Central Tablelands of New South Wales. The longevity of the various baits was one of the factors considered in the decision process, along with the length of the baiting campaign; bait palatability; costs of bait purchase, distribution, handling and replacement; cost-effectiveness (measured by minimum cost per bait presented or consumed); and non-target safety issues. In this decision model the author considered only those factors that were relevant to his study area. In other areas of Australia alternative or additional considerations may become important and may thus affect the final outcomes.

2.3 Timing of baiting

Temporal distribution strategies play an important role in maximising baiting effectiveness (Linhart et al. 1997a). Seasonal differences in bait uptake are known to occur (Linhart 1964). The following discussion refers to choosing the best time of the year to implement strategic control programmes (e.g. once or twice a year) for protection of agricultural production. Instances where multiple baiting is initiated to protect native fauna are discussed in Section 2.5.

The optimum timing of a baiting programme (in terms of bait uptake) can be determined by a number of factors that can come into play at different times of the year. These include:

- behavioural (and reproductive) changes in fox populations;
- seasonal dietary preferences and energy demands of foxes;
- availability of alternative food sources for foxes;
- the prey animals being protected from foxes and the objectives of control;
- cost-effectiveness and availability of resources to implement fox control;
- coordination with 1080-based rabbit control programmes; and
- non-target activity and bait uptake.

The effectiveness of a baiting operation may be improved by taking advantage of the peak demands for food by foxes (Saunders et al. 1995), although this has not been tested experimentally. The most significant change in body energy reserves of the red fox is associated with its reproductive cycle (Winstanley et al. 1999). On the basis of a seasonal study of fat deposition and body composition of foxes in central New South Wales, these authors concluded that the greatest decline in condition for both sexes occurred between August and November, which coincided with the peak birth and cub-raising period. Males also underwent a decline in July, reflecting the high energy demands of establishing and defending a breeding territory. The peak period of energy gain for both sexes was from November to January, and females also rapidly gained condition from April to July (before gestation).

It is difficult to interpret these outcomes. A decline in body condition might imply that the fox is relying more on its energy reserves and less on food. Males in early winter, for example, are so intent on territory defence and seeking mating opportunities that foraging becomes a secondary priority. Baiting at this time may result in a lowered effectiveness, at least for males. The greatest decline in body fat for females was in September, which is also the mean month of birth (McIlroy et al. 2001). This could suggest that dietary intake did not match energy demands and that any food offered at this time (as bait) would be readily accepted.

'Generally speaking, the best time to bait foxes is in November, at the crossover point between energy depletion and gain.'

All factors considered, the Winstanley et al. (1999) study suggests that, on the basis of energy reserves and demand, the optimal month to bait foxes is at the crossover point from energy depletion to gain (November), when appetite would be at its most voracious.

Yearly changes in behaviour may influence bait uptake. Some of these changes are directly related to energy demands, as discussed above.

Others relate to territorial behaviour. Robertson et al. (2000) studied the ranging behaviour of juvenile foxes and found that movements were very focused leading up to the dispersal period. These movements were limited to areas around secure den and rendezvous sites. From a management perspective, they concluded that baiting campaigns implemented before the dispersal period would risk missing cubs, unless these secure sites could be targeted. From this movement behaviour, they suggested that juveniles should be as susceptible as adults to baiting after dispersal begins.

Adult home range size and distance travelled within a home range can change throughout the year (Saunders et al. 2002). Females, for example, are less likely to travel large distances from the den when cubs are suckling. Baiting at this time may reduce the probability of females finding bait. Conversely, females (and males) provisioning for cubs have been observed to increase the distances they travel to forage for food (Saunders et al. 2002) and may therefore be more likely to come into contact with baits or carry baits back to the den (see Thomson and Kok 2002).

Seasonality in reproduction and yearly mortality rates means that the highest population densities of adult and sub-adult foxes occur during late summer, before dispersal. Baiting at this time may destabilise a population, but with dispersal soon to occur, the net outcome into the following breeding season (i.e. one adult pair per territory) will probably be much the same. The higher density of foxes per unit area may also increase the cost of control. Implementing a control programme just before females become pregnant and when the fox population is most stable may be the more cost-effective option. This, of course, will not be a consideration if year-round protection of native fauna is the control objective.

The lack of information on seasonal dietary preferences of foxes needs to be addressed before any temporal baiting strategies can be fully assessed. However, given the opportunistic feeding behaviour of foxes and the fact that baits are based on high-protein meat products, it is unlikely that baits will be less preferred to naturally occurring food items. An issue of greater importance is the competition of baits with much more readily available food sources. All animals are faced with a variety of potential food items in their environment. Foraging behaviour is based on the maximisation of energy intake in relation to the cost of detection, pursuit and handling time. Other influencing factors include nutrient requirements, prior learning, food palatability and food moisture content. Palatability can be relative — what is palatable at one time of the year, may not be so during other times due to different nutritional demands and food availability.

The presence of a seasonally abundant source of easily acquired food can detract from the desirability of baits. Detailed and geographically widespread Australian studies of fox diet have shown that up to 70% consists of sheep and rabbit (McIntosh 1963; Coman 1973; Croft and Hone 1978; Molsher et al. 2000; Saunders et al. 2004), although foxes can also survive on other primary sources of food in more restricted areas such as national parks (e.g. Meek and Triggs 1998; Green 2003) or when local alternative sources are available (e.g. dumps of kangaroo harvesting off-cuts, Read and Wilson 2004; or field dumps of meat-meal-based stockfood piles, Berghout 2000).

If sheep and rabbit are such important foods to foxes, how much is available as an ongoing resource? An attempt was made to measure this on a typical property near Orange, New South Wales, in 1996 and 1997 (Saunders and Kay unpublished data). Stock losses were monitored via direct counts (dead sheep or cattle) and changes in flock numbers over time (adult breeding ewes and wethers). The majority of stock losses occurred during lambing (spring or autumn). From typical carcass weights for each animal by age and species, the estimated available biomass of dead animals in autumn 1996 was equivalent to 786 grams per day per square kilometre. Estimated resident adult fox density on the same property just before the production of cubs was one fox per square kilometre, or 2.3 foxes per square kilometre if the previous year's cubs remained on site. Carrion could therefore represent a maximum of between 342 grams and 786 grams available food per day per fox in autumn.

Saunders et al. (1993), using a generalised energetics model, suggested that a female fox in autumn would require 526 grams of carrion per day to sustain herself. Carrion alone could therefore represent 65–100% of daily food intake. Except in years of intense drought, when hand feeding cannot be sustained and destocking occurs, the availability of carrion would be fairly consistent between years. In 1997, for example, the total biomass of carrion varied by only 14% of the 1996 estimate. If the availability of sheep carrion and rabbits is combined with the many other high protein natural prey items, it would appear that foxes were not food-limited in this study.

Similar findings were observed by Berghout (2000) in a study on sheep properties in the Young area of New South Wales. During the lambing period in winter, lamb carrion was abundantly available, and the author calculated that in one lambing paddock alone there was sufficient carrion to meet the energy needs of up to 440 foxes.

Baker et al. (2000), in a study of urban foxes, found that food supply was unrelated to range size in a population that was recovering from a major outbreak of sarcoptic mange. However, the pre-mange group size and territory arrangement were consistent with the Resource Dispersion Hypothesis (Macdonald 1981), which simply states that the density of fox populations is determined by some critical resource, usually food. The implication here is that food may not limit fox populations unless they are at equilibrium. Simplistically, this suggests that baiting of fox populations undergoing a positive rate of increase would be affected more by the presence of alternative food supplies.

The complete picture is obviously complicated, but such analyses demonstrate the potential for competition between fox baits normally foreign to the environment and naturally occurring and seasonally abundant food items. The urban observations of Baker et al. (2000) also indicate that the degree of competition may vary between populations, depending on how close they are to maximum carrying capacity.

'Twice-yearly baiting has been shown in some studies to keep fox population densities low all year round.'

The recommended timing of fox baiting on agricultural lands is not based on scientific evidence alone, but has been a compromise between the varying objectives and preconceptions within the agricultural industry. Baiting is most often done in the month leading up to lambing or kidding to reduce local fox populations and associated predation rates. This can be from autumn through to late spring, depending on the region. These times may also coincide with the availability of resources to undertake baiting campaigns (e.g. farmers may be more occupied with maintaining flock health and nutrition at other times of the year).

Under south-eastern Australian conditions, Thompson and Fleming (1994) recommend baiting at the end of winter when fox populations are lowest and nutritional stresses are claimed to be greatest; this is also supported by Fleming (1997). In Western Australia, baiting is similarly recommended during late winter and spring (Anon 2001). Thomson et al. (2000) suggest that the best time to bait in buffer zones to protect intensively controlled areas is in autumn, when naïve juveniles are dispersing. The 'Outfox the Fox' control programme initiated in New South Wales (Balogh et al. 2001) recommends baiting twice a year: once in autumn when dispersal is greatest and once in early spring when females are breeding and under the greatest food stress (also coinciding with the autumn and spring lambing).

McLeod et al. (2004) developed a model to simulate the dynamics of structured (by age

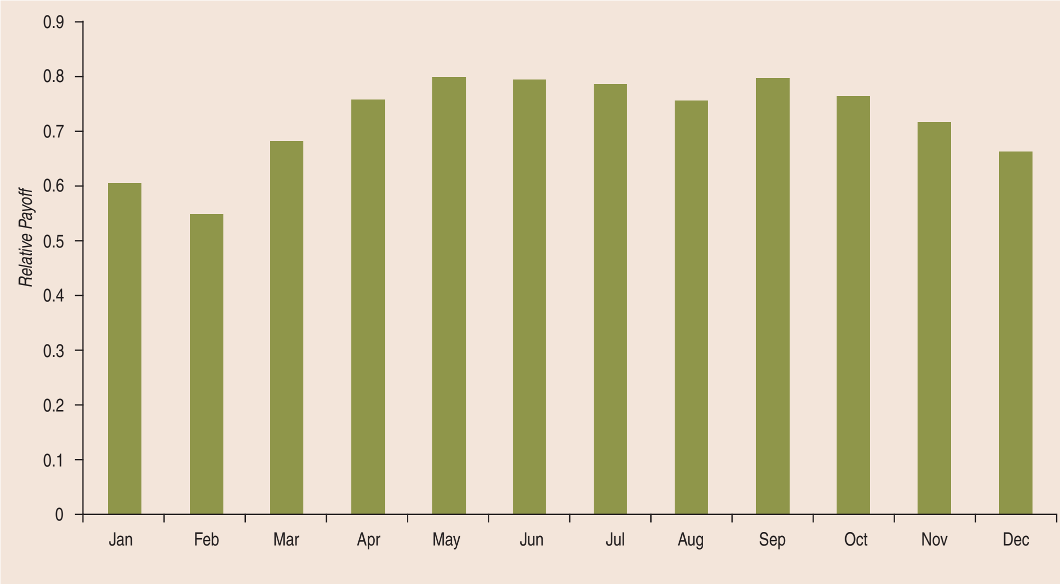


Figure 2.3 *Relative 'payoffs' of reducing the population density of foxes in an annual baiting campaign. Payoffs are shown for each month of the year when the campaign was undertaken (from McLeod et al. 2004).*

and sex) fox populations. The dynamics of this model are linked to climate and fox density. The authors calculated a 'payoff' from the degree of suppression of the fox population from 1080 poison baiting and found that, for baiting strategies that include a once-a-year baiting campaign, the efficacy was highest in the late autumn to early spring (May–September). From an agricultural perspective the payoff ranges from a minimum in February to a maximum in May (Figure 2.3).

Although McLeod et al. (2004) used their model to look mainly at fertility control, it can be used to examine scenarios with 1080 poison baiting only. Figure 2.4 shows the results of a 1080 baiting campaign conducted at different times of the year (April, July and November only). For full details of the variables used in the models see McLeod et al. (2004). The main assumptions were:

- all births take place in September;
- immigration occurs from February to July (with maximum dispersal in April);
- sex ratio is 1:1;
- all reproductively active females give birth;
- the carrying capacity is five foxes per square kilometre; and
- the proportion of foxes eating baits is 60%.

If no control is imposed on the modelled fox population the density follows the same pattern from year to year, and in any one year there is a spike in the breeding season followed by a slow decline until the next breeding season (Figure 2.4). The timing of an annual baiting campaign has major effects on the fox density. In an autumn-controlled area (month of April) fox numbers are boosted by late immigrants and a reasonably successful breeding season can still occur, even after the initial reduction in population numbers earlier in the season. After a winter control (month of July), what breeding occurs is left to the few surviving individuals, as immigration at this time is low. However, this poor breeding season can be compensated for by increased immigration during the next autumn. With late spring control (month of November), foxes are allowed to breed and so reach relatively high densities (compared with the other control strategies) before being knocked down. As is the case for the winter control, numbers increase over the following year due to immigration and increased

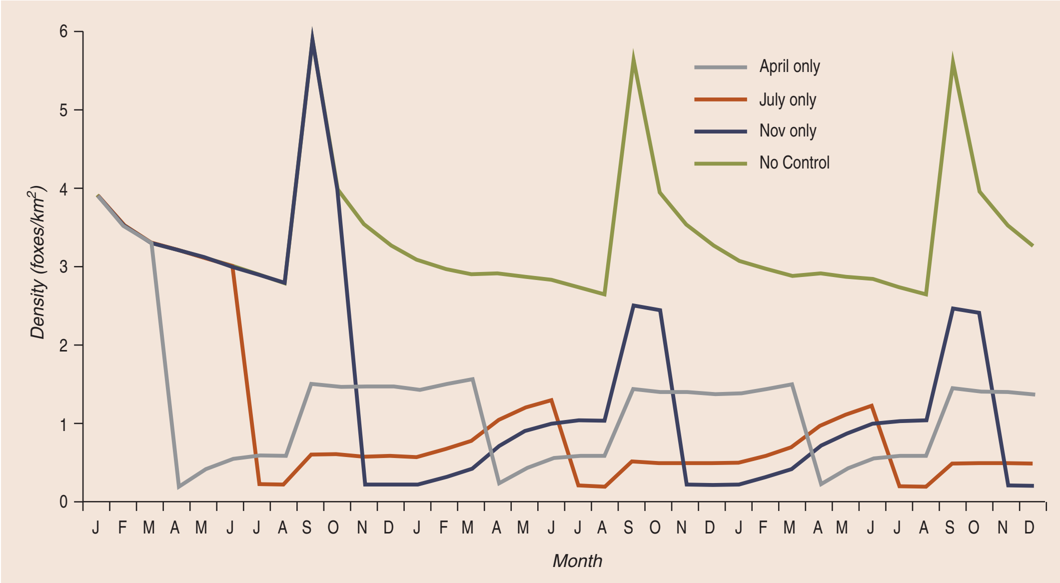


Figure 2.4 *Projection of a fox population subject to once-a-year 1080 baiting control campaigns conducted at varying times through the year (bait density set at ten baits per square kilometre).*

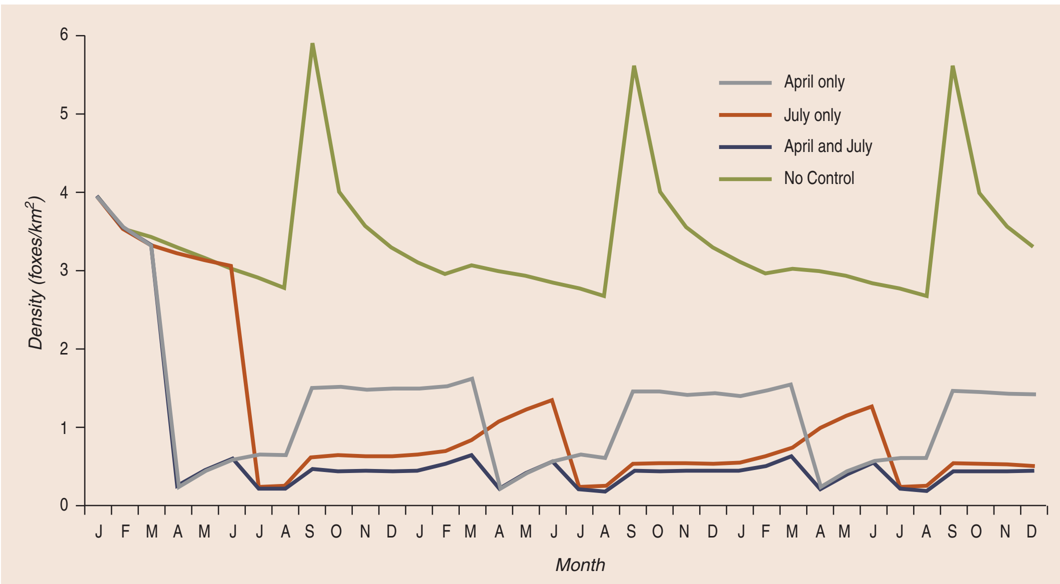


Figure 2.5 *Projection of a fox population subject to varying 1080 baiting control campaigns (bait density set at ten baits per square kilometre).*

survivorship of the remaining population. These results show that once-a-year baiting campaigns provide only short-term decline in fox densities, but that by combining, for example, an autumn and a winter campaign fox densities can be kept low all year round by curtailing immigration into areas that have had reduced breeding due to winter baiting (see April and July, Figure 2.5).

Considering all of the above influencing factors, when is the optimum time or times of the year to bait foxes? The decision needs to be arrived at through a combination of processes and will ultimately be a trade-off between maximising the

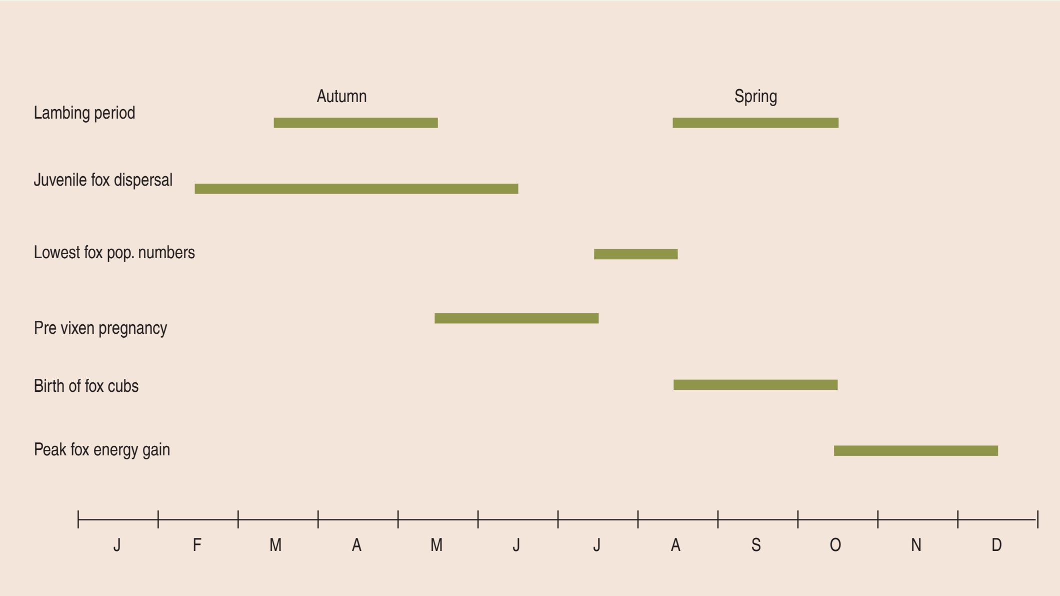


Figure 2.6 *Factors that affect optimum timing of a baiting program (in terms of bait uptake).*

effect and the logistics of undertaking a control programme. Figure 2.6 illustrates factors (energy demands, behavioural and reproductive, prey biology) that have been discussed in this Section that affect the optimum time for baiting. Other considerations would be diet and alternate food availability, which would vary geographically and seasonally.

2.4 Bait coverage

Foxes live mainly in family territories (Corbet and Harris 1991). Although territorial boundaries are not necessarily symmetrical and can overlap, the uniform application of baits is thought to give more individuals access to baits than would be the case if clusters of baits were placed at certain points (Hässig 1984, as cited in Linhart et al. 1997a). Aerial baiting is ideally suited to achieve the uniform coverage required to ensure that all foxes have access to bait. A prerequisite of most ground baiting programmes is vehicular access. Baits are generally laid within short distances from tracks or fire trails. On agricultural lands, those areas of a property exposed to fox predation are more likely to be treated (e.g. near lambing paddocks). Similarly, not all properties participate in group control programmes. Under these circumstances, large areas (and hence fox territories) within a control programme are going to be missed.

'About 30% of all foxes disperse in any one year. Mean dispersal distances vary from 2.8–43.5 kilometres for males and 1.8–38.6 kilometres for females.'

Fox movement patterns vary throughout the year depending on the breeding cycle. On a continual basis, itinerant foxes are always seeking opportunities to establish permanent territories. Resource-hungry foxes will also take over part or all of recently vacated adjacent territories. Dispersal, in particular, results in the regular mixing of fox populations. Most dispersing foxes are sub-adults, and dispersal starts in late summer and continues through to the onset of breeding in winter. Harris and Trewhella (1988) found that approximately 30% of all foxes dispersed in any one year. Mean dispersal distances vary from 2.8–43.5 kilometres for males and 1.8–38.6 kilometres for females (Trewhella and Harris 1988).

In a recent Australian study (Saunders et al. 2002), some extreme dispersal distances were observed. The longest of these was a straight-line distance of 300 kilometres. One individual was shot 260 kilometres from the site of capture only one month after being released. When foxes were first introduced to the Australian mainland in the 1870s, they spread across the continent at an annual rate of up to 160 kilometres (Jarman 1986).

With such inherent abilities to rapidly establish new territories over both short and long distances, the fox is perfectly adapted to compensate for any form of population reduction. It is therefore critical to assess the desired outcomes of a baiting programme so that the coverage of bait achieves the necessary level of control.

2.5 Baiting density

Effective baiting density is thought to depend on many factors, such as the population density and home range of foxes, the type of habitat, the seasonal conditions, and the method of laying the baits. In Europe, baits are laid at a rate of 15–30 per square kilometre for rabies vaccination; in some areas these rates were believed to be insufficient (Müller and Wiebe 1998). Although even higher fox-baiting densities have been employed elsewhere in the world (Trewhella et al. 1991), 30 baits per square kilometre appears to be a reasonable upper limit for either lethal control or vaccination campaigns.

Algar and Kinnear (1992) suggested that a baiting density of 5–6 per square kilometre was the most efficient for aerial baiting in Western Australia. Thomson and Algar (2000) found baiting at 5 baits per square kilometre was as effective as 10 baits per square kilometre where fox densities ranged between 0.5–1.0 adults per square kilometre. In other areas of Australia, where ground baiting is the predominate method of bait delivery and foxes occur at densities higher than those in Western Australia, effective baiting densities have not been fully assessed. The recommended procedure for placing baits on trails is to use one every 400–500 metres, which is roughly equivalent to a density of 9–12.5 baits per square kilometre (Saunders et al. 1997), but these distances have never been experimentally verified.

In forested habitats in Victoria, where fox densities are low, studies using unpoisoned baits impregnated with coloured beads and glitter have suggested that baits need be applied at only 1 per kilometre of trail for effective control (Murray 1998a; Murray et al. 2005). Fleming (1997) used a density of 4.4 baits per square kilometre but found that this would have been inadequate for effective control. The results of a simulation of various control regimes on a modelled fox population at densities of about 5 adults per square kilometre indicate that increasing bait density above 10 provides little benefit and there are minimal gains at bait densities between 5–10 baits per square kilometre (McLeod et al. 2004).

'The optimum baiting density under most Australian conditions is about 5–10 baits per square kilometre.'

Thompson and Fleming (1994) suggested that bait density per fox must be known for comparisons between studies. For example, Trewhella et al. (1991) laid 1.6–3.0 baits per fox, Thompson and Fleming (1994) 1.8–2.7, Fleming (1997) 2.5–4.0 and Thomson and Algar (2000) 0.1–0.2, all with varying outcomes. Perhaps of more importance, and a further complication in these comparisons, is the bait density over the duration of bait exposure — i.e. the number of nights bait is available (Fleming 1997). The optimum bait density for foxes will be a compromise between factors such as fox density, caching rate, encounter rate, and non-target risk, but it seems to be in the order of 5–10 per square kilometre under most Australian conditions. Although baits may be preferentially placed along fencelines and tracks to target likely lines of fox movement and for access considerations, it is important that there are no significant gaps in bait coverage across a landscape and between properties.

2.6 Bait delivery

In Australia, lethal fox baits are distributed either from the air or by ground delivery, dependent on local arrangements and/or legislation. In

Western Australia, aerial baiting using strategies originally developed for dingoes (Thomson 1986) is the method commonly used to distribute fox baits over large areas. Dried-meat baits (approximately 120 grams kangaroo meat, dried until 40% of original weight), which can be mass produced, have been the preferred bait for aerial application, although the newly developed Pro-bait® is increasingly being used. The plane travels at a set speed and height (e.g. 90 knots and 500 feet for a Cessna 182), following pre-determined transects. The baits are dropped at a linear rate to achieve the desired baiting density of 5 per square kilometre (Thomson and Algar 2000).

In New South Wales, aerial baiting for foxes is not permitted unless a special permit is obtained, usually for Crown land applications where endangered species are being protected. These are exceptions, and the majority of fox baiting in this region is conducted from the ground, although aerial baiting for wild dogs is common practice. Aerial baiting is permitted for fox control in Queensland although baits are usually deployed for wild dogs, with foxes an acceptable 'bycatch' (M. Gentle, Qld Department of Natural Resources and Water, pers. comm. 2006). Areas to be baited from the air must meet distance restrictions and other conditions under the relevant legislation (see Section 11.4), and with the discretion of the authorised officer.

'Burial of fox baits is mandatory in most of eastern Australia, but its full consequences have not been scientifically assessed.'

Burying of lethal baits for fox control is thought to reduce the removal of baits by non-target species (Brunner 1987; Allen et al. 1989; Staples and McPhee 1995; Glen and Dickman 2003a; Hegglin et al. 2004; Mooney et al. 2005). This practice is also thought to extend bait freshness (Saunders et al. 1995). However, the effect of burying fox baits, which is now mandatory in most of eastern Australia, on bait take and its implications for the cost of control have not been fully assessed. Korn and Lugton (1995) for example provided no experimental evidence for their claim that foxes prefer to eat buried baits. In Western Australia, Thomson and Kok (2002) found that unburied dried meat baits (both tethered and untethered) were significantly more likely to be taken (70% and 90% respectively) than buried baits (42%), although baits were offered only for one night. The effect of burying on bait attractiveness and palatability has been tested on wild dogs (Allen et al. 1989): buried baits were found to be as attractive and palatable as baits laid on the surface. In a study investigating the effect of bait-station design on canid (dog and fox) baiting in the Central Tablelands of New South Wales, Glen and Dickman (2003a) could reach no conclusions on bait uptake by foxes and wild dogs because of the small sample size.

With no strict guidelines in place there are many interpretations of the term 'buried', ranging from the bait being covered with a thin layer or clod, to shallow depressions, to burial ten to 15 centimetres deep. The term 'bait station' has become generally accepted as referring to a site repeatedly used to place bait. Sandpads or sandplots are commonly placed around bait stations to monitor visitation by foxes and non-target animals. In areas where non-target species, particularly quolls, are likely to be problematic, non-toxic baits are initially used until the visiting animal's tracks can be identified. Only when a non-target visitation is discounted will the lethal bait be employed (e.g. NSW National Parks and Wildlife Service 2001; Department of Environment and Heritage 2004; Murray et al. 2005). Sand pads or plots are commonly used for monitoring alone (see Section 12.3).

There are numerous designs for bait stations, but they generally fall into five main types:

I. Single bait buried below ground level at depths varying from 5–15 centimetres.

II. Single bait buried below ground level at depths varying from 5–15 centimetres, with the surrounding surface covered with a flat (one to two centimetres thick) area of sand or sifted soil (a 'sandpad' or 'sandplot').

III. Single bait buried below ground level at depths varying from 5–15 centimetres, with the surrounding surface covered with a raised mound (about 10–15 centimetres deep, one metre in diameter) of sand or sifted soil.

IV. Single bait laid on the existing ground surface and then covered with a raised mound of sand or sifted soil (depth 7–20 centimetres, about 1.0 metre in diameter).

V. Multiple baits inserted in a raised mound of sand or sifted soil (depth 20–40 centimetres, 1.0–1.5 metres in diameter). The baits are buried into the mound but above the existing ground surface.

Because of the many variations that have been developed there is often confusion about the terms used in the literature. For example, 'mound baiting' can refer to either types III, IV or V listed above. 'Mound baiting' (of type V listed above) was first described for a dog baiting campaign in Victoria by Brunner (1987) who used loose soil shaped into a mound about 20 centimetres high and 1 metre in diameter. Two pieces of deep-fried liver bait were then buried in the centre of each mound at a depth of 10 centimetres in each of two separate holes, 20 centimetres apart. The use of this mound was assumed to enhance the rate of location, because of the visual and olfactory cues of the mound, and to make excavation of the bait easier. This method was adopted for dog baiting in the southern regions of New South Wales, with usually three baits being buried in a large mound (height up to 40 centimetres), but the practice is rarely used today (A. Miner, South Coast RLPB, pers. comm. 2005).

Variations of the mound baiting corresponding to types III and IV above were developed and used independently in many areas. These methods were developed as a result of one or more of the following issues: the conditions made burial difficult; the soil was considered too wet for burial and there were concerns that the bait would degrade; there were concerns about non-target animals (particularly quolls); and/or, it was perceived that the mound would enhance baiting effectiveness, although this has not been demonstrated (NSW National Parks and Wildlife Service 2001).

Since publication of the results from Glen and Dickman (2003a), who found that spotted-tailed quolls were significantly less likely to remove baits that were buried under the surface than in raised mounds of sand, many agencies have shifted towards the type III mound baiting, particularly when quolls are present (e.g. Murray et al. 2005; NSW National Parks and Wildlife Service 2001; A. Miner, South Coast RLPB, pers. comm. 2005). Although not documented, the use of prominent mounds in the southern coastal regions of New South Wales was found to visually attract non-targets, such as birds, particularly crows, and goannas to a bait station site, so their use has been scaled down (J. Druhan, National Parks and Wildlife Service, pers. comm. 2005).

An alternative to bait burial is the tethering of baits by a length of tie-wire or strong nylon cord to a wire peg or fence post. This practice, using the dried meat baits in Western Australia, has been shown to reduce both the removal of baits by non-targets (particularly birds) and bait caching (because the bait has to be eaten at the bait site), however tethering appeared to assist consumption of the baits by birds at the bait site (Thomson and Kok 2000). The practicality of tethering on the softer bait materials has not been tested. Before burial of baits became mandatory in New South Wales, the tethering of baits was recommended practice (e.g. Department of Agriculture, NSW 1988). This practice is still recommended in Western Australia, particularly near closely settled areas (Anon 2003a).

2.7 Bait caching

Baiting effectiveness can also depend on the extent to which baits are found and removed by either non-target species or target animals that do not immediately consume the bait once it is removed ('bait caching'). The use of meat-based baits and the burying of lethal baits for dog and fox control are thought to reduce the likelihood of removal of baits by non-target species (Brunner

1987; Allen et al. 1989; Saunders et al. 1995; Staples and McPhee 1995; Glen and Dickman 2003a), although some non-target animals have been observed excavating buried baits (e.g. Fleming 1996b; Belcher 1998; Dexter and Meek 1998). Apart from the non-target implications, caching also needs to be considered in studies that involve the measurement of bait uptake as an index of population density and predicted reductions in population size (Saunders et al. 1993; Thompson and Fleming 1994).

Surplus killing and subsequent caching of prey by predators is an important adaptive strategy and can occur at times of temporary food surplus or changes in the vulnerability of a prey species (Tinbergen 1972; Kruuk 1972; Vander Wall 1990). It is also a means of securing food from the attention of competitors, in anticipation of the birth of young or to train offspring (Macdonald 1977, 1987; Macdonald et al. 1994). Foxes are known as scatter rather than central-place hoarders (Kruuk 1964) and depend on olfactory and visual cues to locate their caches (Tinbergen 1972; Henry 1977; Macdonald 1977). They tend to bury their caches about 10 centimetres below the surface, a compromise between being able to locate it later but having it hidden sufficiently to protect it from other scavenging animals (Henry 1977). Burying baits in shallow depressions, as is the recommended procedure in most States, could be considered to mimic caching behaviour in foxes.

'Bait aversion may occur when a fox consumes a sub-lethal dose of toxin, making the animal ill.'

In overseas studies foxes have been found to retrieve the majority of their caches within a relatively short period, particularly when preferred prey is cached (Scott 1943; Macdonald 1976; Henry 1977; Macdonald et al. 1994). However, in some cases, caches may not be revisited for a number of months (Kruuk 1964; Tinbergen 1972; Frank 1979). There is also evidence of foxes raiding other foxes' caches if they locate them (Macdonald 1976; Henry 1977).

Caching of baits by foxes is thought to have important implications for fox-baiting programmes (Saunders et al. 1999; van Polanen Petel 2001). Fewer baits may be available in a control programme if a small number of foxes monopolise the supply, and potential risks exist for non-target species and the development of bait aversion in foxes if the 1080 in cached baits degrades over time (Saunders et al. 1999). Bait aversion occurs when a sub-lethal dose of toxin is consumed, making the animal ill (Gustavson 1977). When the fox recovers, it may remember the association between the bait and the illness.

There have been four Australian studies published to date on bait caching by foxes, using a variety of bait types, timings, and baiting practices (see Table 2.1). The rate of caching varied between study sites, season, bait type and whether the bait was toxic or not. Retrieval of the non-toxic bait caches after six days was similar between studies, ranging from 56%–75% (Saunders et al. 1999; Thomson and Kok 2002; Gentle 2005). The rate of retrieval of caches when toxic baits were employed was lower, with between 8%–43% of caches being retrieved within six days (Saunders et al. 1999; Gentle 2005). All studies reported that the majority of caches were buried or highly concealed in vegetation.

Food preference plays a role in the caching behaviour of foxes (Macdonald 1977). For example, chicken heads were used preferentially over eggs in the early years of the rabies vaccination campaign in Europe because of a high preference for caching eggs (McKenzie 1983). From both pen and field trials, van Polanen Petel (2001) concluded that there was a strong negative relationship between food preference and caching behaviour. Gentle (2005) found a significant relationship between bait type and caching intensity, with the manufactured bait Foxoff® cached more often than other bait types tested (day-old chicks and chicken wingettes). Gentle (2005) also reported a significant difference in caching intensity between toxic and non-toxic baits in all three bait types tested.

Table 2.1 *Results from the four published caching studies conducted in Australia.*

Reference	Experimental protocol	Bait type	Baits cached / bait taken (%)	% retrieved within 6 days	Distance to cache (m) Mean	Median	Range
Saunders et al. 1999	• free-fed (same as toxic bait type) • baits replaced • bait stations 500 m apart	Foxoff® (non-toxic) Foxoff® (toxic)	37 29	75 43	156	50	10–800
Van Polanen Petel et al. 2001	• free-fed (different bait type) • baits not replaced • bait stations 50 m apart	Deep-fried liver (non-toxic) Foxoff® non-toxic	10 29		126 112	70 67	11–398 5–485
Thomson and Kok 2002	• not free-fed • baits available for one night • bait stations 200 m apart	Dried kangaroo meat (non-toxic)	25	70	87	50	3–380*
Gentle 2005	• free-fed (same as bait types) • baits replaced • bait stations 200 m apart	Day-old chicks (non-toxic) Chicken wingettes (non-toxic) Foxoff® (non-toxic)	4.5 5.7 66.9	68 57 56	136	90	3–880
		Day-old chicks (toxic) Chicken wingettes (toxic) Foxoff® (toxic)	26.2 43.1 74.3	27 14 8	90	57	0.5–398

* Excluding baits taken to active dens and cubs, the distance was up to 1250 m

All studies reported a large range in the distances of caches, but they all followed a similar pattern, with the majority of caches being found close to the original bait station (see Table 2.1). The larger distances were generally recorded in spring and were associated with active den sites (Saunders et al. 1999; Thomson and Kok 2002; Gentle 2005). Thomson and Kok (2002) also reported that some baits were often moved from the bait station area and just dropped, largely intact, on the ground surface; the majority were within 5 metres but one was found 200 metres away. These results indicate that baits can be moved between paddocks and onto neighbouring properties. Current distance restrictions for the laying of 1080 fox baits in New South Wales, for example, are 5 metres from property boundaries and 500 metres from the nearest habitation. These results suggest that some non-target risk is likely with these relocation distances, mainly to domestic dogs, although in most cases fox-baiting programmes are cooperative efforts with large numbers of neighbouring properties involved.

Caching intensity is thought to be related to the availability of prey and nutritional status of the predators (Scott 1943; Macdonald 1976); therefore it is expected to vary on a seasonal basis. Even though there have been numerous fox dietary studies and fox physiological studies in Australia, there is a lack of information on how fox dietary preferences and nutritional demands are related to bait preference and caching, particularly with respect to the effect of seasonal changes in their diet. Gentle (2005) investigated seasonal influences on bait uptake and caching behaviour in foxes but was unable to fully assess bait uptake because fox behavioural changes confounded the effects of the free-feeding technique. He did find that, overall, the intensity of caching did not change significantly between seasons, but for some bait types there were differences between some seasons at some of his experimental sites. Further information on seasonal influences is essential if the full effects of caching on baiting effectiveness are to be assessed.

2.8 Cost of bait application

Aerial baiting is accurate and cost-efficient for large areas (Thompson et al. 1990; Thompson and Fleming 1991). After aerial application the uptake of baits may be slower than after placement of ground baits (Thomson et al. 2000); ground baits tend to be targeted at areas of fox activity or tracks and trails. Foxes will take longer to encounter baits applied randomly from the air, although this does not seem to affect the overall baiting effectiveness. Aerial application also is thought to reduce the extent of multiple bait take (Thomson et al. 2000), although this has not been tested.

The cost of aerial baiting depends on many factors, including area to be treated, bait density, aircraft and precision. As a guide, details were provided for the 'Western Shield' programme in Western Australia (J. Asher, Western Australian Department of Environment and Conservation, pers. comm. 2002). To treat approximately 35,000 square kilometres a year (some of this from the ground) with 800,000 baits costs $1.3 million, which is equivalent to $0.37 per hectare per year. Included in this total cost are operating expenses ($200,000), which cover advertising, training, general materials and education. Baits cost $0.91 each and are applied at 5 per square kilometre four times a year. The cost of aerial application is $3.37 per square kilometre, which covers the provision of fuel and a bombardier. Using a pro-rata estimate for operating costs, the approximate cost for aerial application is $0.09 per hectare per treatment.

In Europe and North America, baiting of foxes for vaccination against rabies is common practice. In Europe between 1978 and 1996, 74 million baits were distributed over nearly 5 million square kilometres, with a bait cost alone of US$83 million (Stohr and Meslin 1996). A large proportion of this activity involves aerial distribution, from either helicopters or fixed-wing aircraft. In Canada, similar campaigns are conducted using precision baiting systems that allow areas of 15,000 square kilometres to be treated with nearly 300,000 baits by two aircraft in seven days (Voigt and Johnston 1992).

Ground baiting is the principal method of fox control in the eastern and southern states of Australia. To reduce the risk of baits being moved or consumed by non-targets, some States require baits to be buried (Brunner 1987; Allen et al. 1989). There is some controversy as to whether or not burial does prevent quolls from finding fox baits (Belcher 1998; Murray 1998b). For ease of retrieval of uneaten baits, stations are often marked. A variety of bait types is used, placed 400–500 metres apart along tracks and trails or areas frequented by foxes. Baits are checked every three to five days, and those taken are replaced. At the conclusion of a baiting programme the remaining baits are picked up and destroyed, although this is not always done. Although the majority of ground baiting programmes follow the procedures outlined in Korn and Lugton (1995), there are variations.

'Aerial baiting is about one-third the cost of ground baiting, provided that a big enough area is treated.'

If there are non-target concerns baiting procedures have to be modified, and this increases the cost of the programme. These modifications include the use of sand pads, which are placed around bait stations to monitor visitation by foxes and non-target animals. This requires bait stations to be checked daily, which again increases the cost of a programme. Tethering of baits, which is very labour intensive, can be used where there is concern that removal or caching of baits may result in unacceptable non-target risks (Thomson and Kok 2002). Mound baiting is another technique that has been employed; it involves placing the bait on or just below the ground surface and piling soil over the top of the bait. All these techniques are discussed in Section 2.6.

In central New South Wales, the cost per hectare of ground baiting for foxes was calculated for an 'average' 2000 hectares property as part of a larger study on fox control (after Saunders et al. 1997; Greentree 2000) (Table 2.2). Baiting was done by one person (casual farm labour rates of $11.45 per hour plus 15% on-costs), costed using a 4WD diesel utility and based on NRMA costs per kilometre. The use of a motorcycle, the number of kilometres travelled, or the effects of fuel rebates (up to 31 cents per litre) would significantly change the cost of treatment. The number of baits taken can also affect the costs of control. The average number of baits taken per property in this study was 81. This figure was used in the cost of control calculations, although the number of baits used ranged from 60–146 in the study. Costs of bait can vary: in this study Foxoff® Econobaits ($1.00 each) were purchased in bulk, as is the case for most group control programmes in New South Wales. Other miscellaneous costs for items such as initial travel to pick up baits and telephone calls to notify neighbours have not been included.

If we use figures from the above programme, what is the total cost of ground baiting operations using New South Wales as an example? At last count in New South Wales, the number of fox baits used per year was approaching two million; using a placement of 81 baits per programme, this represents approximately 25,000 individual (property-based) fox control programmes. If these involve checking and replacement only once, the landholder cost of control programmes in New South Wales would be in the order of $7.3 million per year. Bomford and Hart (2002) estimated that, nationally, governments spend around $2 million annually on fox control and landholders around $5 million. The value of such estimates will vary considerably, depending on the value placed on labour, particularly if it is that of the landholder. Nonetheless, it would seem the estimates of Bomford and Hart undervalue the present situation.

As part of his detailed cost-effectiveness analysis, Gentle (2005) considered: the cost of purchasing the baits including the cost of collecting bait from distributor; labour and vehicle costs associated with distributing the baits (as from the above figures); and, the characteristics of the bait type chosen (such as longevity and uptake, both of which affect replacement costs). Gentle calculated the total cost of a standard baiting campaign in his study area (average size of property 730 hectares; 43 baits initially placed; baiting duration of four weeks with check/replacement every four days) using manufactured Foxoff® baits to range from $813–$904 (depending on bait uptake ranging from 10%–50%). The bait costs were greater for the fresh chicken baits tested (range $1100–$1132). These amounts are much greater than the figures above (see Table 2.2) but are probably more realistic in terms of the actual costs

Table 2.2 *Costs of ground baiting.*

Item	No. of units	Unit price	Cost	Total cost	Cost per ha
Initially lay 60 baits	8 h labour	@ $13.17/h	$105.36		
Initial vehicle use	33 km	@ $0.36/km	$11.88		
				$117.24	
Baits	81 baits	@ $1.00/bait	$81.00		
Warning signs	10 signs	@ $2.00/sign	$20.00		
				$101.00	
Check and replace baits	5 h labour	@ $13.17/h	$65.85		
Vehicle use per day	33 km	@ $0.36/km	$11.88		
				$77.73	
Check and replace once				$295.97	$0.15
Check and replace twice				$373.70	$0.19
Check and replace 3x				$451.43	$0.23
Check and replace 4x				$529.16	$0.27
Check and replace 5x				$606.89	$0.30

incurred, and they highlight the underestimation of the costs of fox control in New South Wales.

Owing to the difficult nature of quantifying the benefits of fox control, cost effectiveness analysis has been used as a measure of efficiency of fox control (e.g. Hone 2004; McLeod et al. 2004; Moberly et al. 2004b; Gentle 2005). Gentle (2005) used cost-effectiveness analysis to compare different baiting strategies on the basis of longevity, palatability, and the handling/ replacement costs associated with three different bait types (day-old chicks, chicken wingettes and Foxoff®). Although the manufactured Foxoff® was the least expensive bait type (as per above calculations), when the minimum cost per bait presented or consumed was calculated the fresh chicken baits were the most cost-effective for campaigns up to four weeks in duration, at all bait uptake levels tested. Factors such as quality control, the consistency of dosage, and uptake by non-targets were not considered in these calculations.

Drawing cost-effectiveness comparisons between aerial and ground baiting is difficult. The above programme examples for 'Western Shield' and central New South Wales have different intents. The former is to allow the recovery of native species, many endangered, from the long-term effects of fox predation. This may require baiting up to six times a year to obtain the desired effect (de Tores et al. 1998). Similarly, rabies vaccination programmes in Europe require bait applications two or three times a year to prevent the disease cycling in fox populations (Müller and Wiebe 1998). Johnston et al. (1988) estimated that the ground baiting of foxes for rabies control, with its high labour component, is about ten times more expensive than aerial baiting. Fairbridge and Fisher (2001), in a simulated fox control programme in eastern Victoria, found that aerial baiting would be approximately seven times more economical than an equivalent ground baiting programme.

The New South Wales ground baiting study mimics the practice of once a year baiting just before lambing, a practice that offers only short-term protection from predation. However, using theWestern Australian value for once-off costs per hectare, aerial baiting is about one-third of the cost of ground baiting (assuming that ground-placed baits are checked five times, which is probably optimistic in most situations). Without the coordination of effort and scale of operation required in Western Australia, cost comparisons between aerial and ground baiting to protect localised agricultural enterprises or small conservation projects would probably decrease slightly. It does seem that, in certain circumstances in south-eastern Australia, aerial baiting of foxes would be a much more cost-effective alternative, provided that regulatory and non-target issues were addressed. The use of dog- and fox-specific toxins (see Chapter 3) may provide future opportunities. Given the logistics of organising an aerial campaign, as a guide, the Western Australian Department of Environment and Conservation recommend that only areas in excess of 20,000 hectares be treated in this way (Anon 1996).

2.9 Population reductions from lethal baiting

Many studies of fox control programmes have been conducted in Australia. Some of these concentrate on outcomes (e.g. survival of prey species), so that interpreting absolute reductions in fox numbers is difficult (e.g. Priddel and Wheeler 1997). Other studies remain unpublished, and this is a concern because they often indicate a failure to achieve desired reductions in fox numbers. A number of evaluations have been conducted and published on the effectiveness of instantaneous fox-baiting programmes in Australia. These are summarised in Table 2.3.

The obvious features of Table 2.3 are that successful (>70% reduction in fox population) aerial campaigns require a baiting rate five times that of the fox population density and that the ground baiting programmes were successful in conjunction with long free-feeding periods (although no evaluations without free-feeding were available for comparison). Such long free-

Table 2.3 *Effectiveness of fox baiting programmes.*

Bait density (per km²)	Initial fox population density (per km²)	Baiting Protocol	Population reduction (%)	Location	Reference
6	?	aerial: 1 day	86	WA wheat belt	Algar and Kinnear 1992
12	7.2	ground: 10 days free-fed then 10 days toxic	70	NSW tablelands – farmland	Thompson and Fleming 1994
1.7 -3.1*	0.05–0.2*	ground: 9-13 days free-fed then 10-14 days toxic	91	NSW tablelands – forest	Fleming 1996a * pers. comm.
4.4	1.3–1.9	ground: 16 days free-fed then 2 days toxic	50	NSW tablelands – farmland	Fleming 1997
0.14	?	ground: 13 days free-fed then 10 days toxic	97	NSW coast	Dexter and Meek 1998
5	0.5–1.0	aerial: 1 day	79	WA wheat belt and rangelands	Thomson and Algar 2000
10	0.5 -1.0	aerial: 1 day	82	WA wheat belt and rangelands	Thomson and Algar 2000
5	0.5	aerial: 1 day	95	WA rangelands	Thomson et al. 2000

feeding periods are not the norm in conventional control programmes. Similarly, there are other examples of fox baiting programmes that have been conducted intensively over long periods of time and that have significantly reduced fox populations (e.g. Banks et al. 1998 and Risbey et al. 2000).

An experimental evaluation of conventional (agricultural) ground baiting programmes was conducted over three years at Boorowa in central New South Wales (Greentree et al. 2000) (see Section 13.3). This study involved a large-scale, population-management, factorial experiment using properties and adjacent bushland refuges as experimental units. Sites were selected for homogeneity of habitat, stocking rate, management practice and prey species. Fox densities were maintained using one of three strategies, with two replicates of each. These were: no control; reduction of fox population density at lambing time using local Rural Lands Protection Board-recommended 1080 baiting strategies; and, intensive control (three times a year). Control programmes were conducted over the experimental units and adjacent buffer zones of approximately two fox territories in width (3 kilometres). Intensive baiting was carried out at critical times in the foxes' biological year. The mean differences in fox numbers over treatments, measured as spotlight indices (see Section 12.3) before and after each baiting programme, were variable. Some, but not all, counts showed a decrease in fox numbers after baiting. Regression analysis showed no significant change in fox numbers over the time of the study on either the no-treatment sites or the once-a-year sites. However, there was a significant decline in fox numbers on the intensive treatment sites over the two years when control was implemented, although densities at the end of each baiting period under maximum control still varied from 0.45 to as high as 3.74 foxes per square kilometre (Greentree et al. 2000).

Some of the above results raise serious concern over the efficacy of conventional once-a-year ground baiting programmes, especially when few programmes are monitored or evaluated. The level of resources and care that goes into research studies, compared with that which goes into baiting programmes conducted under normal circumstances, further confounds the experimental results presented in Table 2.3 and may further exaggerate the difference in control effectiveness between the two. Fox control is also about reducing impact, not just fox numbers.

After a wildlife population has been culled, the remaining animals' survival and breeding may be enhanced, immigration rates may increase, and dispersal rates may decline (Caughley 1977). These compensatory changes can hasten the recovery of the population (Sinclair and Pech 1996). Marlow et al. (1998) looked for compensatory responses in foxes subjected to 1080 baiting. A fox population reduced by 26% in density (compared with an undisturbed population) responded in the subsequent breeding season with significant increases in ovulation rate and embryo implantation rate. They also observed a (non-statistically significant) higher proportion of yearling recruits in the baited population than in the unbaited one. The cause of these compensatory effects was assumed to be the increase in per-capita resources for remaining foxes in the baited area.

2.10 Buffer zones

The use of spatial buffer zones for predator control involves removal of the predator (mostly by baiting) from an area surrounding the protected animal's refuge or the stocked land (Thomson 1984, 1993). This concept is based on the knowledge that most canid predators, including foxes, occupy discrete territories and will not allow dispersing non-family individuals to settle within these territories. It is thought that, once a resident fox is removed, its territory is quickly occupied by another individual (Burchfield 1979; Mulder 1985; Kinnear et al. 1988; Thomson et al. 2000). If foxes are removed from a large enough surrounding area, any new foxes entering this buffer zone will more likely settle there than keep moving towards the area to be protected.

The spatial buffer zone concept has become increasingly incorporated in fox control programmes. Such programmes advocate group participation so that fox control can extend over a wider area with more chance of long-term respite from damage (Saunders et al. 1995). Despite a detailed knowledge of the home ranges and dispersal movements of foxes under a variety of conditions in Australia, the spatial buffer zone concept has only recently been experimentally tested for foxes (Thomson et al. 2000). Their study found that a buffer zone 15 kilometres wide was insufficient to protect a core area from reinfestation without repeated baiting. However, baiting in the buffer zone once or twice during the autumn, when the greatest influx of immigrants was expected, effectively reduced any invasion into the core area (Thomson et al. 2000). These authors went on to recommend that, for a buffer zone to be effective, fox densities in the buffer must be kept as low as possible to maintain an effective 'dispersal sink', particularly during the dispersal phase of foxes.

'Spatial buffer zones are often used as part of fox control programmes.'

The size of the buffer zone required for the protection of a specific area is difficult to determine. In a study of dingoes in north-western Australia, Thomson (1984) reported that a buffer zone 15–20 kilometres wide (the width of between one and two home ranges) was sufficient to prevent dingoes moving into sheep country from unstocked land. Thomson et al. (2000) suggested that a buffer zone 10–15 kilometres wide in the semi-arid area of Western Australia would probably suffice. Greentree et al. (2000) used a buffer zone of 3 kilometres in a temperate area of central New South Wales but considered that immigration may have still affected the outcome of fox control efforts. Gentle (2005) modelled the potential for fox immigration after typical group baiting campaigns in central New South Wales and found that the spatial coverage and frequency of baiting were inadequate to prevent fox re-invasion. To estimate the appropriate size of a fox-controlled buffer zone, the resource productivity of an area, which is thought to affect the home range size of the fox (Ables 1969; Macdonald 1981), and the density of the fox population would need to be taken into account (Saunders et al. 1995).

Thomson et al. (2000) argue that a buffer zone strategy for foxes might not always be appropriate. In their study, a 15 kilometre-wide buffer zone of 2180 square kilometres was maintained to protect a core area of 1000 square kilometres (one side was bounded by the ocean). However, the ratio of buffer to core area would increase disproportionately as the core area decreased. Therefore, it may be more feasible, both economically and logistically, to bait a small core area more often than the larger buffer area. The use of buffer zones is more applicable when larger areas are to be protected.

The temporal buffer zone has historically played an important role in fox control programmes in Australia. The increase in fox control activities before and during times of high susceptibility to predation, such as at lambing, or before re-establishment of endangered animals, has been (and still is) a common practice. A temporal buffer zone gives short-term respite from predation, and it is usually employed on a reactionary basis, with little consideration for sustained reduction (Saunders et al. 1995).

2.11 Large-scale fox baiting programmes

As described in the previous Section (2.10) large-scale fox control programmes have been advocated to give more chance of long-term respite from predation damage while maximizing the efficiency and cost-effectiveness of the control programme (Saunders et al. 1995). During the 1990s, large-scale fox-baiting programmes, involving liaisons and cooperation between private and government agencies, were promoted and embraced in all areas of Australia, for both conservation and agricultural purposes.

'Western Shield', conducted in Western Australia, is a large-scale wildlife recovery programme based on fox baiting. It was initiated in 1996 and has expanded to cover nearly 3.5 million hectares, primarily conservation estate situated in the south-west of the State and including forests, coastal areas, the margins of farmed areas, and inland arid regions (Bailey 1996, Armstrong 1998 and 2004). 'Western Shield' has three elements: fox baiting on a large scale, research into feral cat control and the reintroduction of native animals to former habitats. The programme is coordinated by the Western Australian Department of Environment and Conservation (DEC), and public sector participation is encouraged.

'During the 1990s, large-scale fox-baiting programmes, involving cooperation between private and government agencies, were promoted in all areas of Australia.'

Fox control is achieved by regular baiting with 1080 dried-meat baits. These baits are laid by aerial or ground operations at least four times a year at an intensity of 5 baits per square kilometre (Bailey 1996; Armstrong 1998; Orell 2004). The impact of baiting is monitored by regular trapping, field counts and radio-tracking studies of foxes and native animals. Results from this baiting programme, along with those of previous experiments conducted by DEC over the past two decades, indicate increases in many native wildlife populations (e.g. Kinnear et al. 1988; Burbidge and Friend 1990; Friend 1990; Kinnear 1990; Kinnear 1992; Morris 1992; Armstrong 1998; Orell 2004), and the successful reintroduction of some species (e.g. Bailey 1996; Vertebrate Biocontrol CRC 1999; Orell 2004). Since the commencement of the programme, three species, the woylie (brush-tailed bettong, *Bettongia penicillata*), the quenda (southern brown bandicoot, *Isoodon obesulus*) and the tammar wallaby (*Macropus eugenii*) have been removed from the Schedule 1 endangered species listing under the *Endangered Species Protection Act* 1992 (Orell 2004).

A large-scale fox control programme was conducted on an army reserve in central Victoria in 1994 (Coman et al. 1995). The area covered was 44,000 hectares, over which 4,636 Foxoff® baits were laid by hand at 10.5 baits per square kilometre. Spotlight counts conducted pre-baiting and at three and six weeks post-baiting indicated a 90% reduction in the number of foxes seen. The cost of the control effort (excluding monitoring) was $1.02 per hectare.

Aerial baiting operations may involve GPS-guided bait delivery systems (photos [a] and [b]). There are benefits in having a range of bait types available to account for local conditions including climate and non-target risks – the salami-styled 'Pro-bait®' (left) and dried meat bait are shown at photo [c].

Source: [a], [b] and [c] Nicky Marlow, Western Australian Department of Environment and Conservation.

'Project Deliverance', a large-scale fox-baiting research project in the forests of south-eastern Victoria, commenced in 1998 (Murray and Poore 2001). The project was divided into three separate study areas, with a total baited area of 33,000 hectares. Manufactured Foxoff® bait was buried at permanent baiting stations spaced at approximately 1 kilometre intervals along tracks and roads throughout the study sites. Baiting was continuous, with baits checked and replaced every four weeks (Murray et al. 2005). The results from two of the study sites in the five-year project indicate that the fox control effort was having positive effects on the abundance of two species of small mammals, the long-nosed potoroo (*Potorous tridactylus*) and the southern brown bandicoot (*Isoodon obesulus*), which were considered to be at great conservation risk (Murray et al. 2005). The 'Southern Ark' programme has continued this large-scale fox-baiting programme in partnership with many government agencies and the local community (Victorian Department of Sustainability and Environment 2003).

In South Australia's Flinders Ranges, 'Operation Bounceback' is a major ecological restoration programme that includes predator-control activities (De Preu 2000). Since 1994, baiting programmes have been conducted four times a year. Two of these programmes (April and October) are carried out over 300 kilometres of walking and vehicle tracks throughout the park and a buffer area on neighbouring properties. Programmes in January and July concentrate on only the more accessible tracks. Baiting intensity is 4–5 baits per square kilometre. Spotlight surveys began in 1995 and are conducted every two months. Reductions in fox densities appear to be close to 100-fold, down to less than 0.1 fox sightings per 100 transect kilometres. Control sites where no fox baiting is conducted confirm the overall effect of this programme. Reporting on associated prey recovery is patchy, but data collection is still in progress.

In New South Wales, large coordinated group fox control programmes have become popular in both agricultural and conservation areas.

These group programmes are structured to the strategic goals of:

- minimising agricultural production losses caused by invasive agricultural pests;
- promoting responsible and timely chemical usage;
- developing working liaisons with Rural Lands Protection Boards (RLPBs), other agencies and landholders;
- forming regional pest management groups; and
- promoting agricultural sustainability and protecting the natural environment.

One such programme, 'Outfox the Fox', began in 1999, incorporating over one-fifth of the State's pastoral region (Balogh et al. 2001). It involves some 1400 landholders and several State government agencies and crown land managers. The main aim of the programme is to get as many landholders strategically fox baiting over as large an area as possible, to protect young stock by reducing the rate of fox immigration. The programme aims to improve the efficiency and cost-effectiveness of landholder 1080 fox-baiting practices by promoting best practice techniques. These techniques are specifically to:

- synchronise baiting within a control group;
- bait at least twice a year;
- bait during periods when the fox is most susceptible;
- regularly check and replace baits that are taken; and
- continue the baiting programme until bait take declines.

'Outfox the Fox' targets two set times of the year when foxes are thought to be susceptible to bait placement: March–April, when juvenile foxes disperse from their natal dens to seek their own territories; and August–September, when vixens require additional food (pre- and post-whelping). The latter also coincides with spring lambing, a period critical to lamb producers. The average outlay for a twice-yearly fox-baiting campaign is approximately $120 per landholder. A recent evaluation of the programme (Jones et al. 2006) indicates that the economic benefits outweighed the combined private and public investment. The evaluation also suggested social benefits of programmes that bring communities together to solve common problems, although these weren't quantified.

The Southern New England Landcare coord-inated fox control programme began in 1994 with a few Landcare groups and is now a joint venture between several local and government agencies (NSW National Parks, Southern New England Landcare and Armidale RLPB), involving around 800 landholders baiting during the winter months, with a smaller number baiting over autumn as well (Pollard 2000; M. Somerville, Southern New England Landcare Coordinating Committee, pers. comm. 2005). Another large group fox-baiting programme is conducted annually in the Riverina area of New South Wales. This programme began in 2002 and involves approximately 2000 landholders, along with Forests NSW and the Riverina RLPB (M. Mullins Riverina RLPB, pers. comm. 2005).

'There are problems with extending the 'Western Shield' approach to south-eastern Australia.'

Some fox control projects aimed specifically at conservation outcomes and involving medium-sized to large areas of land have been reported in the scientific literature (Priddel and Wheeler 1997; Risbey et al. 2000). Others are under way or have only been briefly reported in conference proceedings, e.g. Rummery et al. 2001 (NSW Hunter Valley), Sharp et al. 2001a (Western NSW), Dexter et al. 2001 (NSW South Coast), Norton et al. 2001 (Kangaroo Valley NSW), Kirkwood et al. 2005 (Phillip Island), and de Jongh et al. 2005 and Hazell 2005 (central NSW).

The apparent success of some of the above programmes has led to suggestions of similar 'Western Shield' activities in other regions of Australia. One such proposal is for an 'Eastern Shield' encompassing the Macquarie Catchment Basin in New South Wales (McIlroy and Saunders 1998; Taylor 1998). The aim of the 'Eastern Shield' approach would be to identify management objectives and determine baiting strategies relative to those objectives, with emphasis on buffer zones to limit fox reinvasion. The scale of operation proposed has inbuilt cost efficiencies and is capable of raising public awareness of (and support for) the need to control foxes. There are problems, however, in extending this approach to south-eastern Australia (McIlroy and Saunders 1998; Murray 1998a), where farmlands and National Park areas are more fragmented. The greater density and number of private landholders would make the gaining of approvals and adhering to 1080 distance restrictions a logistical nightmare. Because aerial baiting is not legal on private land in New South Wales, and all baits must be buried, such a widespread baiting programme would be very labour-intensive and costly unless current practices could be changed (see cost comparisons in Section 2.8). Non-target problems also need to be considered, given the lower tolerance of native species to 1080 in eastern Australia (Twigg and King 1991). Although tolerance of native species to 1080 can be, and is, used as part of public relations exercises to gain acceptance of broadscale applications of toxic baits in the west, the same may not apply in the east.

'A concern with these large projects is the ability to indefinitely sustain control effort, with its associated costs.'

A major concern with these projects is the ability to indefinitely sustain control effort, with its associated costs. 'Operation Bounceback', for example is heavily supported through the Natural Heritage Trust. 'Western Shield' receives substantial funds from corporate and private sector sponsorship (Orell 2004). Other programmes are funded through State government assistance. Changing priorities could see a withdrawal of support and (perhaps in some cases) a rapid return to pre-control fox densities, with its associated impact. Embarking on future control programmes will require careful consideration of sustainability, a fact that is mentioned in Threat Abatement Plans.

It is debatable what role the government, representing the public, should take in subsidising the costs of pest control on private land: i.e. private good (production) versus public good (conservation). It is important that governments, through subsidising landholders' management practices, do not encourage inappropriate actions like those resulting from bounty systems, but instead encourage good management practices. This could be preferably achieved by the ongoing funding of research to develop and improve control techniques and strategies and by the funding of regional pest coordinators to oversee control programmes and provide education and training (Braysher 1993; Hassall and Associates 1998; Olsen 1998).

It is unfortunate that the reporting of outcomes for many of the predator control programmes described above remains circumstantial and out of the scientific press (or in many cases not reported at all). That is not to say that the perceived outcomes are not real. Walker (1998) highlights the fact that much of wildlife management remains more of an art than a science. The result is that mistakes can be continually repeated and that rates of improvement in management practices are often slow to develop. Given that the interest and support of predator control programmes remains high at all levels from government to public, it should be a priority to collate information on the methods used and outcomes of all programmes conducted throughout Australia.

2.12 An optimum baiting strategy

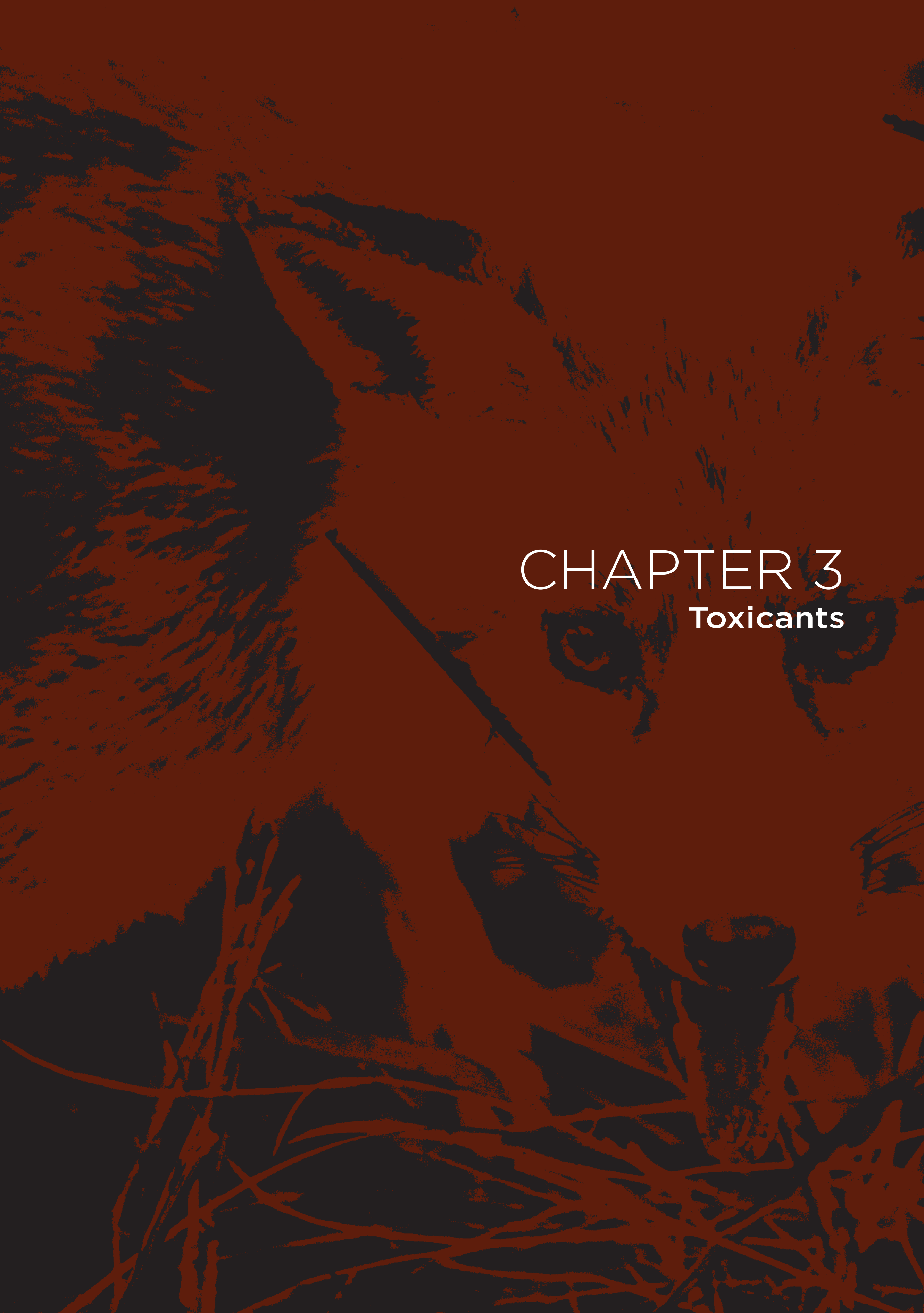
The selection and presentation of various bait types and the inclusion of attractants and additives with the aim of optimising consumption can be a complicated process. Ultimately, foxes will find most baits (provided they are presented in an appropriate way), and only one bait needs to be consumed to have the desired lethal effect (perhaps more if fertility control is the aim). Many factors need to be considered in selecting a bait medium, particularly cost. For example, poultry by-products may be cheaper to purchase than commercial baits, but other factors such as costs of preparation, dosage consistency, safety, packaging, ease of distribution and longevity may far outweigh the initial purchase costs (Gentle 2005). Similarly, a bait that is more readily found and taken by foxes in the field may not necessarily be the most cost-effective when it comes to tallying the number of foxes that are controlled.

Where non-commercial products are used, factors to be considered include: ease of injection; retention and degradation of 1080; and, differing preferences for bait types by non-targets such as farm dogs and native fauna. The issue of caching is of concern if least-preferred baits are cached rather than consumed. However, multiple caching does not necessarily infer a significantly reduced cost-effectiveness. Caching rates of 10% in commercial baits are probably acceptable in terms of efficacy but remain an issue for non-target impacts.

The best time of the year to bait for foxes can be interpreted a number of ways. No optimum recommendation can be made on the basis of current information. Further complicating the process are decisions on bait application, coverage and density. Socioeconomic factors also need to be taken into account, particularly on private lands. Examination of previous studies on fox control suggests that standard baiting programmes may be falling short of achieving significant fox population reductions. This ignores the interpretation of outcomes on the basis of impact alone, which will be dealt with later in this review (see Section 13).

Aerial baiting has been highly successful in Western Australia. Differences in landscape, land ownership, density of human habitation and tolerance of native species to 1080 suggest that implementation of this strategy in south-eastern Australia may be problematic but warrants further consideration.

The above information suggests that unless baiting is both intensive and done over large areas, as occurs in 'Western Shield', conventional, one-off baiting programmes such as those mostly employed on agricultural lands in south-eastern Australia need to be re-evaluated. Greater research emphasis needs to be placed on how baits are deployed, rather than trying to develop the perfect bait.



CHAPTER 3
Toxicants

3. Toxicants

Key issues

- *In Australia, 1080 remains the most appropriate toxicant for lethal baiting of foxes. Continual efforts should be made to improve its application (including the potential for resistance) and to promote its advantages to ensure its longer-term registration and acceptance by the community at large.*
- *One of the key determinants of sensitivity to 1080 in Australia is the level of tolerance developed in native species through ingestion of fluoroacetate, which naturally occurs in a variety of native plants.*
- *Consumption of sub-lethal doses of 1080 because of the combined consequences of bait caching and the decay of 1080 has potentially important implications for the development of bait aversion. Government agencies should continue to encourage and emphasise the importance of picking up of baits that have not been taken. Research should be done to determine whether this is a real cause for concern.*
- *The use of strychnine against foxes should be phased out in all States on animal welfare grounds and alternatives investigated.*
- *The use of cyanide for fox control should be investigated. Registration would require overcoming various non-target and OH&S concerns.*
- *The necessary R&D required to register an alternative toxin to 1080 for foxes is probably not commercially justified. Public funding will therefore be important if such alternatives are to be developed.*
- *Para-aminopropiophenone (PAPP) appears to be the mostly highly promising alternative toxin to 1080 which is currently being researched.*
- *Alternative toxins for use against foxes in rabies outbreaks are being investigated in the UK. Developments in this area should be tracked.*
- *Alternative delivery mechanisms for toxins require further investigation.*

Many toxicants have been historically used to control pest animals, including the fox, in Australia. According to Rolls (1969) the early settlers were enthusiastic poisoners; anything that seemed likely to be troublesome was likely to be poisoned. Among the toxicants used in this period were arsenic, cyanide, strychnine and phosphorus. Fortunately, these chemicals may no longer be used indiscriminately; their use is carefully monitored by various authorities, and attention is paid to humaneness, non-target risk, safety of preparation, and persistence in the environment.

The only commonly used fox poison is 1080, which is reviewed here in detail. Other toxins such as strychnine are being phased out, and cyanide is perhaps the only potential back-up to 1080 in the short term (although it would only be useful under restricted circumstances). Another chemical, para-aminopropiophenone (PAPP), is being assessed as a longer-term alternative to 1080 for the control of foxes, cats and wild dogs (Marks et al. 2004b; Dall et al. 2005; Salleh 2005).

3.1 Sodium monofluoroacetate

Fluoroacetates were developed as rodenticides in Germany in the 1930s. In 1944 the compound sodium monofluoroacetate was tagged 1080 (the invoice number at the Patuxent Wildlife Research Centre, US) and was researched as a mammalian predacide (Howard and Schmidt 1984). Canids are among the most sensitive species to sodium monofluoroacetate, hereafter referred to as 1080.

Mode of action

Once ingested, 1080 is converted within the animal to fluorocitrate, which (among other things) competitively inhibits critical enzymes in the tricarboxylic acid (Krebs) cycle. This results in an accumulation of citrate in the tissues and blood, energy deprivation, and gross organ dysfunction, which can ultimately lead to death (Atzert 1971; Buffa et al. 1973; Kun 1982). Small amounts of 1080 can be rapidly detoxified by most animals, and sub-lethal doses are completely excreted within seven days. In some instances, where animals are exposed to 1080 on a daily basis, they can accumulate sublethal amounts until they finally ingest a lethal dose (McIlroy 1981). The lethal effects of 1080 are not experienced immediately, as time is required for the 1080 to be absorbed, for the synthesis of fluorocitrate, and for the disruption of cellular processes to occur. In mammals this can take 0.5 to 3 hours. In general, carnivores such as the fox experience central nervous system disturbances and convulsions, then die of respiratory failure. There is no effective antidote for 1080 poisoning, although because of its slow action there has been some success in symptomatic treatment in domestic dogs (Howard and Schmidt 1984).

Natural occurrence

Some 40 plant species that contain fluoroacetate have been identified in Australia, mostly in the genera *Gastrolobium* (Aplin 1971; Seawright 1989; Twigg and King 1991). Of these, 36 species are confined to the south-west corner of Western Australia. Others are found across northern (*Gastrolobium grandiflorum*) and central (*Gastrolobium brevipes, Acacia georginae*) Australia. No fluoroacetate plants are known to occur in South Australia, New South Wales, Victoria or Tasmania.

Sensitivity, susceptibility and non-target risks

It is useful to have a standardised measure of toxicity that allows comparisons between species. Sensitivity to an acute poison such as 1080 is usually expressed in terms of lethal doses and measured as milligrams per kilogram body weight. The median lethal dose (LD_{50}; the theoretical amount of toxin required to kill 50% of test subjects) is the most common measurement used to represent sensitivity, although this value is not always available for rare or endangered species (Thompson 1947; Twigg and King 1991; Calver et al. 1989). The scientific literature has extensive coverage of the sensitivity of birds, mammals and reptiles to 1080 (e.g. see McIlroy 1986, 1994; Twigg and King 1991). However, the potential risk to non-target species, as identified from laboratory-based studies, does not always equate to practical risk in the field (Martin et al. 2002).

In Australia, one of the key determinants of sensitivity to 1080 is the extent to which species have developed tolerance through ingestion of fluoroacetate that occurs naturally in a variety of native plants (Seawright 1989; Twigg and King 1991).

'In Australia, 1080 is currently the most appropriate toxicant for baiting foxes as many native species are naturally resistant to it.'

Tolerance to fluoroacetate has developed in native species in the order of herbivorous> omnivorous>carnivorous (Twigg and King 1991). Within animal groups (e.g. dasyurids, some birds), tolerance is most pronounced in those species indigenous to Western Australia (King et al. 1978; Oliver et al. 1979; Mead et al. 1985). This tolerance allows a demonstrable reduction in the risk of 1080 baiting programmes to non-target species. Although 1080 baiting programmes are particularly target-specific in Western Australia, it is important to recognise that 1080 baits can be safely used elsewhere in Australia provided that they are deployed according to the label directions.

Other factors can influence sensitivity to 1080 within and between species. These include age, breeding condition, inherited tolerance, body weight, metabolic rate, phylogenetic group and ambient temperature at time of ingestion (McIlroy 1994). Determination of LD_{50} values requires studies on captive animals: free-range tests can be performed but are much more difficult and expensive. Because of differences in experimental procedures (e.g. route of administration and ease of handling of the study animals), LD_{50} estimates may not always reflect the absolute sensitivity to 1080 of the same animals living in the wild. Similarly, there can be variations within estimates derived by different research institutions for the same species. Consequently, LD_{50} data are a useful but not absolute guide to the possible hazards presented to native species by 1080.

Along with the behaviour (e.g. food preferences) of the species being considered, LD_{50} information provides an indication of which species should be monitored at the population level if there are concerns about the potential risk to non-target species (e.g. rare and threatened species, species known to consume baits). Because of the high sensitivity of domestic dogs, particular care needs to be taken to avoid their accidental poisoning, irrespective of where or how any baiting programme is carried out.

The LD_{50} for foxes is 0.13 milligrams per kilogram (McIlroy and King 1990), which translates to 0.12 milligrams per kilogram if corrected for 1080 purity (L. Twigg, Department of Agriculture and Food, WA, pers. comm. 2003). It was on this basis that the national standard for fox baits was set at 3.0 milligrams of 1080 per bait. Adult foxes weigh, on average, 5 kilograms, so baits containing around 0.6 milligrams of 1080 would still be potentially lethal to foxes. Domestic dogs are very sensitive to 1080, with an LD_{50} of 0.07 milligrams per kilogram (Tourtellotte and Coon 1951). Baits containing around 1.05 milligrams of 1080 would be potentially dangerous to an average-size kelpie dog weighing 15 kilograms (Fleming and Parker 1991).

It is difficult to determine the concentration of 1080 at which baits would become non-lethal to all foxes and dogs. McIlroy and King (1990) found that no foxes died (n = 5) after receiving doses of 0.10 milligrams per kilogram or less. Tourtellotte and Coon (1951) found that only one of six dogs treated at 0.05 milligrams per kilogram died. Using these levels of 1080 as approximations of non-lethal doses, baits would be relatively safe for adult foxes at 0.50 milligrams and kelpie dogs at 0.75 milligrams.

The estimated LD_{50} for tiger quolls is 1.85 milligrams per kilogram (McIlroy 1981) and for eastern quolls, 1.5 milligrams per kilogram (King et al. 1989). Insufficient data are available to estimate non-lethal doses. Belcher (1998) suggested that adult tiger quolls weigh up to 4.5 kilograms and eastern quolls up to 1.3 kilograms. Quolls are sexually dimorphic for weight and do not attain adult weight in the first year (Belcher 1998). These weights therefore represent those of larger and more free-ranging animals. An LD_{50} amount of 1080 per bait for such animals would be reached at 8.3 milligrams (adult tiger quoll) and 2.0 milligrams (adult eastern quoll) (this equates to three and one 3.0-milligram 1080 fox baits respectively).

Harden and Bayne (1998) used the relevant literature to compile a list (Table 3.1) of oral LD_{50}s and the amount of bait necessary for the ingestion of an LD_{50}. This list was derived only for species tested from areas without fluoroacetate-bearing plants. Bearing in mind the caution needed in equating potential risk with sensitivity, this Table provides the relative toxicity of 1080 to a variety of species through potential ingestion of baits.

McIlroy (1994) suggested that body weight was particularly important in assessing susceptibility to 1080 baiting programmes. Ranking different animals according to the amounts of 1080 they would need to ingest to receive a lethal dose is therefore more likely to provide a better basis for evaluating the potential risk faced by non-targets than simply ranking them on sensitivity alone. This is demonstrated in Table 3.2.

Persistence in the environment

Although concerns have been raised about the impact of 1080 on the environment it has been shown that 1080 is neither mobile nor persistent in the soil and has an extremely remote chance of contaminating water supplies when used during conventional baiting programmes (Peters

Table 3.1 *Approximate oral LD_{50} of 1080 for a range of species in areas where there are no fluoroacetate-bearing plants. The amounts of 1080 and of baits for an LD_{50} are for individuals of the weights shown in the 'Body weight' column; they will not be correct for individuals of other weights. LD_{50} values preceded by '~' are only approximate; all other values in the same row are also only approximate (after Harden and Bayne 1998, and as derived from other studies).*

Species	Body weight (kg)	LD_{50} (mg/kg)	Amount of 1080 for LD_{50} (mg)	Approximate number of fox baits for an LD_{50} @ 3mg/bait (no. of baits)
Native amphibia and reptiles				
Bearded dragon, *Pogona barbatus*	0.267	< 110.00	< 29.37	< 9.79
Blotched blue tongued lizard, *Tiliqua nigrolutea*	0.434	336.40	146.00	48.67
Sand goanna, *Varanus gouldii*	0.84	43.60	36.62	12.21
Lace monitor, *Varanus varius*	3.65	100.00	365.00	121.67
Native mammals				
Fat-tailed dunnart, *Sminthopsis crassicaudata*	0.013	2.06	0.03	0.01
Brown antechinus, *Antechinus stuartii*	0.035	1.85	0.06	0.02
Swamp rat, *Rattus lutreolus*	0.154	1.71	0.26	0.09
Bush rat, *Rattus fuscipes*	0.12	1.13	0.14	0.05
Water rat, *Hydromys chrysogaster*	1.00	~ 2.94	2.94	0.98
Northern quoll, *Dasyurus hallucatus*	0.75	5.66	4.25	1.42
Tiger quoll, *Dasyurus maculatus*	2.80	1.85	5.18	1.73
Brushtail possum, *Trichosurus vulpecula*	2.60	0.75	1.95	0.65
Brown bandicoot, *Isoodon obesulus*	1.23	~ 7.00	8.61	2.87
Long-nosed bandicoot, *Perameles nasuta*	1.20	7.70	9.24	3.08
Common wombat, *Vombatus ursinus*	24.00	0.22	5.28	1.76
Eastern grey kangaroo, *Macropus giganteus*	47.00	~ 0.22	10.34	3.45
Red kangaroo, *Macropus rufus*	30.00	~ 3.20	96.00	32.00
Dingo, *Canis familiaris dingo*	16.00	0.11	1.76	0.59
Native birds				
Australian magpie-lark, *Grallina cyanoleuca*	0.09	~ 6.75	0.61	0.20
Australian magpie, *Gymnorhina tibicen*	0.32	9.91	3.17	1.06
Pied currawong, *Strepera graculina*	0.30	13.10	3.93	1.31
Laughing kookaburra, *Dacelo novaeguineae*	0.30	~ > 6.00	1.80	0.60
Little raven, *Corvus mellori*	0.56	3.10	1.74	0.58
Australian raven, *Corvus coronoides*	0.585	~ 5.10	2.98	0.99
Little crow, *Corvus bennetti*	0.40	13.40	5.36	1.79
Black kite, *Milvus migrans*	0.56	18.50	10.36	3.45
Wedge-tailed eagle, *Aquila audax*	3.10	9.50	29.45	9.82
Emu, *Dromaius novaehollandiae*	40.00	~ 250.00	10000.00	3333.33
Introduced mammals				
Sheep, *Ovis aries*	38.00	0.52	19.76	6.59
Goat, *Capra hircus*	37.00	~ 0.50	18.50	6.17
Pig, *Sus scrofa*	55.00	1.04	57.20	19.07
European cattle, *Bos taurus*	520.00	0.39	202.80	67.60
Horse, *Equus caballus*	500.00	~ 0.41	205.00	68.33
Rabbit, *Oryctolagus cuniculus*	1.50	0.37	0.55	0.18
Cat, *Felis silvestris catus*	4.20	0.40	1.68	0.56
Fox, *Vulpes vulpes*	4.70	~ 0.12	0.56	0.19
Man, *Homo sapiens*	72.00	2.00	144.00	48.00

Table 3.2 *Ranking of species according to their sensitivity to 1080 compared with ranking by the amount of 1080 they would need to ingest to receive the equivalent of an LD_{50} (after McIlroy 1994).*

Species	Sensitivity as LD_{50} Ranking	Sensitivity as LD_{50} mg/kg^{-1}	Mean body weight (kg)	Amount of 1080 for LD_{50} Ranking	Amount of 1080 for LD_{50} mg
Bennett's wallaby	1	c. 0.21	14.7	8	c. 3.1
European rabbit	2	0.37	1.5	4	0.56
Brushtail possum	3	0.80	2.6	5	2.1
Crimson rosella	4	0.88	0.15	3	0.13
Feral pig	5	1.04	55	12	57.2
Sulphur-crested cockatoo	6	3.46	0.84	7	2.91
Goldfinch	7	3.50	0.014	1	0.05
Pigeon	8	3.98	0.53	6	2.11
Mallard	9	7.09	0.700	10	4.96
Silvereye	10	c. 9.25	0.014	2	0.13
Magpie	11	9.93	0.32	9	3.18
Black duck	12	17.57	0.89	11	15.6

1975; King 1984; Parfitt et al. 1994; Walker 1994; Twigg et al. 1996). The breakdown, or defluorination, of 1080 appears dependent on temperature, moisture levels, pH, and the species of microorganisms present (King et al. 1994; Saunders et al. 2000; Twigg and Socha 2001). The risk of 1080 poisoning to unadapted herbivores from translocated 1080 in plants is negligible (Eason et al. 1998). However, secondary poisoning of some predators and scavengers is possible, particularly canids (McIlroy 1981, 1986, 1992, 1994; Gooneratne et al. 1994; Meenken and Booth 1997; Twigg et al. 2003), and secondary deaths, usually of introduced species, have been observed in the field after 1080 poisoning programmes (e.g. Burchfield 1979; Heyward and Norbury 1998).The accessibility and location of any carcasses of animals that succumb to 1080 during baiting programmes will also influence the potential for secondary poisoning to occur (Twigg et al. 2003).

Degradation of baits

The decline of 1080 concentration in fox baits with time is an advantage in terms of non-target risk. However, one of the most common concerns of land managers after each bait application is the length of time needed to elapse before it is safe for potential non-targets (e.g. unmuzzled working dogs). Non-target poisoning in areas inhabited by native carnivores such as the tiger quoll (*Dasyurus maculatus*) and eastern quoll (*D. viverrinus*) is also a potential impact of fox-baiting programmes (Belcher 1998), although these concerns are not necessarily realised (Körtner et al. 2003). Other issues associated with bait degradation include the environmental persistence of 1080, reduction in bait toxicity, and the non-target risk posed by cached baits (King 1989; Wong et al. 1991; Saunders et al. 1999; Twigg et al. 2001).

The decline of 1080 concentration in baits is known to occur as a consequence of seepage of 1080 solution, defluorination by microorganisms, decomposition by invertebrates, and leaching by rainfall (Korn and Livanos 1986; Kramer et al. 1987; McIlroy et al. 1988; Fleming and Parker 1991; Wong et al. 1991; Staples and McPhee 1995). Thus rainfall, soil moisture and temperature play an important role in the longevity of 1080 in baits, both directly and indirectly affecting the activity levels of microorganisms and invertebrates. Bait type has also been found to be an important factor: 1080 persists longer in baits that offer some protection from water infiltration and microbe activity, such as the 'crust' on dried-meat baits, the shell of egg baits, and (to a lesser extent) the skin on chicken wingettes (McIlroy et al. 1988; Fleming and Parker 1991; Saunders et al. 2000; Twigg et al. 2000; Twigg et al. 2001; Gentle 2005; Mooney et al. 2005).

The degradation of 1080 in buried Foxoff® baits containing 3.0 milligrams of 1080 was investigated by Saunders et al. (2000) in central New South Wales. Baits were exposed to five different treatments: shelf storage (controls), prevailing weather, no rainfall, average weekly rainfall and twice average weekly rainfall. Baits began to physically degrade from week three onwards, mostly because of fungal activity. The concentration of 1080 in baits from the 'no rainfall' treatment was highly variable over the duration of the experiment but, importantly, even after 11 weeks in the soil some baits still contained enough 1080 to kill a fox or dog. Modelling of the 1080 decay rates in baits suggested that, under mean rainfall conditions for central New South Wales, baits would become non-lethal to working dogs at 2.2 weeks and to foxes at 2.8 weeks.

'Issues associated with bait degradation include the environmental persistence of 1080, reduction in bait toxicity, and the non-target risk posed by cached baits.'

Gentle (2005) also studied the persistence of 1080 in buried Foxoff® baits, as well as in buried chicken wingettes, under two different climatic and three rainfall regimes. He found that the rate of 1080 degradation did not change significantly between the two climatic sites (Central Tablelands and the warmer Western Slopes of New South Wales), but Foxoff® remained lethal for longer than the wingettes under all conditions. The Foxoff® baits remained lethal to a 5 kilogram fox for an average of 2.1 weeks, and some baits remained lethal for up to five weeks. On average, wingettes remained lethal for 1.1 weeks, the longest lasting 2 weeks. Under the no-rain treatment, the degradation of the Foxoff® baits was highly variable, a similar finding to that of Saunders et al. (2000).

Twigg et al. (2001) investigated the longevity of 1080 in buried egg-baits in Western Australia. Irrespective of season, 94% of the baits remained lethal to all foxes for at least six weeks, even after heavy rain. Decay rate modelling predicted that the baits could remain lethal to most foxes for up to 32 weeks. In contrast, in a trial in Tasmania Mooney et al. (2005) reported that after two weeks fewer than 20% of buried dried kangaroo meat baits contained an LD_{50} for foxes.

Studies on unburied dried-meat baits for foxes (Kirkpatrick 1999) and wild dogs (McIlroy et al. 1988; Fleming and Parker 1991) in temperate areas have shown that, depending on rainfall, these baits remain potentially lethal for up to one or two months. If moderate rainfall is received, and the baits are buried, this can decline to as little as one week (Kirkpatrick 1999). In arid parts of Australia, in the absence of rainfall, unburied dried-meat baits can remain lethal for at least eight months (Twigg et al. 2000). These results suggest that at any time of the year when drought conditions occur, or in arid to semi-arid regions where negligible rainfall can be common, baits should be treated with caution in respect of potential, long-term, non-target losses.

An implication of these studies, and lending support to the practice of picking up baits that have not been taken (where it is practicable), involves the potential for consumption of sub-lethal doses of 1080, which could allow bait aversion to develop (Gustavson 1977; Saunders et al. 1999). This could occur after three weeks (or possibly even quicker in higher rainfall areas) if resident foxes do not immediately locate baits or when baits are found by foxes re-invading the area after the death of the resident fox. Preventing the risk of re-invading foxes locating sub-lethal baits also affirms the need for group baiting programmes, which are advocated in New South Wales.

Bait degradation associated with fox control programmes needs to be considered as an important component of any associated non-target risk analysis. A 1080 bait degradation model for meat baits is being developed and refined by the Queensland Department of Primary Industries and Fisheries (M. Gentle, Queensland Department of Primary Industries and Fisheries, pers. comm. 2006). However, further studies of degradation rates for the different bait types used against foxes and under different environmental conditions are still required. Ideally, research should also be conducted on the probability of foxes (and non-targets) finding and consuming baits that have been buried for extended periods, including those baits cached by other foxes. If this probability is low, the risks posed by these baits to non-targets and by sub-lethal doses to foxes may be correspondingly low. Consideration of the fate of 1080 in baits that are aerially-applied (above ground rather than buried) also needs to be assessed.

Resistance

It is now accepted that some animals can develop a tolerance to 1080, irrespective of any natural exposure to fluoroacetate-bearing plants. For example, resistance to 1080 can be selected for in rats (Howard et al. 1973) in the laboratory, and some free-ranging rabbit populations are becoming more tolerant to 1080 (Twigg et al. 2002). The increased tolerance in these rabbits was directly related to the length and intensity of past exposure to 1080 baiting campaigns. It could therefore be extrapolated that development of resistance to 1080 in Australia may well be occurring in pest species other than rabbits, such as foxes. However, the development of resistance is likely to be more rapid in *r*-adapted species (e.g. rodents and rabbits), which can have a relatively rapid population turnover, than in species with *k*-adapted life histories, such as the canids and mustelids (fur-bearing animals such as badgers, minks, otters and weasels) (Twigg et al. 2002). Nevertheless, if the development of resistance to 1080 were to occur in canids it would probably have major implications for the management of foxes (and wild dogs) in Australia.

Continuing use of 1080

Compound 1080 is currently used in Australia, New Zealand, Mexico, Japan, the United States and Israel, and use in many of these countries is under tight restrictions. The use of 1080 as a predacide was banned in the United States in 1972 by a Presidential Executive Order. This ban was imposed 'not because of sound biological argument but because of political conspiracies, emotional rhetoric and distortion of the biological facts' (Howard and Schmidt 1984). There has since been ongoing uncertainty as to the registration of 1080 as a predacide by the United States Environmental Protection Agency (Palmateer 1990), with its present registration limited to livestock protection collars (see Section 4.5). The use of poisons to control foxes has been illegal for nearly 90 years in the United Kingdom under the *Protection of Animals Act 1911* (White et al. 2000); yet, paradoxically, efforts to ban fox hunts on animal welfare grounds had consistently failed until recently, when the *Hunting Act 2004* was introduced and took effect early in 2005.

Concerns about the use of 1080 have been expressed by animal welfare agencies and the public in Australia and New Zealand (ANZFAS 1996; Fitzgerald et al. 1996, Oogjes 1996; RSPCA 1999), although most recognise that there is no alternative at this stage. A short-lived ban was imposed on the use of 1080 in New South Wales National Parks in July 1976. This ban was brought about by government intervention after adverse publicity surrounding the testing of 1080 on stray domestic dogs by NPWS personnel. However, after public pressure and consultation the ban was lifted a year later (New South Wales Parliamentary Debates (Hansard) 13 September 1977, SRL: N328.94401/1). Tasmania has recently amended its legislation to make it unlawful for government agencies to use 1080 to poison native fauna in that State (*Agricultural and Veterinary Chemicals (Control of Use) Amendment (Ban 1080) Act 2004*).

Despite the restriction on 1080 use in the United States, the only known producer of 1080 is based in that country. Recent concerns about environmental and terrorism fears, as well as cases of illegal use, have led to heavy scrutiny of the factory and calls for its closure by environmental groups and government agencies (e.g. Milstein 2004). These examples demonstrate that nothing can be taken for granted and that the use of 1080 could be banned without warning or time to develop suitable alternatives. It also points to the need for a proactive strategy to educate the community at large as to the inherent advantages of using 1080 as the preferred lethal control agent for foxes.

3.2 Other toxicants

Potential alternative or additional poisons include anticoagulants such as brodifacoum, bromadiolone and warfarin (Saunders et al. 1995), although it is improbable (and undesirable) that these would ever be approved on welfare grounds. Bleeding, in itself, is not painful, but the accumulation of blood in enclosed spaces can be, as shown by studies in humans where haemorrhage is generally very painful and may result in other poor welfare (Mason and Littin 2003; Broom 1999). Cyanide is probably the most likely short-term adjunct to 1080, although strychnine has been used in the past. Before any chemical could be registered for use against foxes, extensive evaluations of toxicity, efficacy, humaneness, non-target effects and bait delivery systems would be required. Although the expense of such evaluations is probably not commercially justified, the continuing uncertainty surrounding the use of 1080 supports the need for public funding of such work as a matter of priority.

Strychnine

Strychnine is an indole alkaloid derived from the seeds of the plant *Strychnos nux vomica* and acts upon the central nervous system, essentially preventing normal functioning of muscle tissue (Seawright 1989). Canids are among the most sensitive species to strychnine (Seawright 1989), and this toxicant was commonly used for dog and fox control before 1080 became available in the late 1960s (Saunders et al. 1995). The preparation of strychnine baits was the responsibility of the landholder, with recommended baiting materials including offal, cubes of meat or fat, chicken heads, day-old chicks, butter or dripping (Saunders et al. 1995).

The use of strychnine as a toxicant is being phased out in most States, although it is still registered for use against foxes in Queensland and for wild dogs in some States (mainly to lace the bindings of leg-hold traps) (see Section 4.1). Strychnine baits are viewed as inhumane, because the affected animals remain conscious and appear to suffer pain and anxiety from the onset of clinical signs through to death from asphyxia and exhaustion (Fleming et al. 2001). In 1991, a Working Group of the National Consultative Committee on Animal Welfare recommended that the sale and use of strychnine be banned in Australia (Department of Primary Industries and Energy 1992).

Cyanide

Cyanide and cyanide compounds occur naturally in some plants and are synthesised from a wide range of industrial processes (Marks and Gigliotti 1996). Sodium, potassium and calcium cyanides have all been used for the control of vertebrate pests in different countries of the world. In North America, cyanide is currently used to control coyotes. Although cyanide is not a registered vertebrate pesticide in any Australian State, limited use permits may be obtained for research purposes.

'Cyanide should be investigated further for fox control.'

Cyanide reacts with moisture in the animal's mouth to produce hydrocanic acid which causes asphyxiation by inhibition of respiratory enzymes and rendering tissues unable to absorb oxygen from the blood (Hone and Mulligan 1982). Because of the rapid mode of action of cyanide it is possible to collect poisoned animals. This allows for quick verification of target or non-target impacts, monitoring of the rates of re-invasion, development of indices of abundance, and monitoring of age structure and other conditions of foxes (Algar and Kinnear 1992; Marks and Gigliotti 1996; Marlow et al. 2000). It is an extremely hazardous compound to use, and strict safety procedures must be followed (see Marks and Gigliotti 1996). Scientific appraisals from an animal welfare viewpoint show that cyanide is a preferred toxin (O'Connor et al. 2001), although the possibility of cyanide use for routine fox baiting has not been tested at a policy level.

Recent developments involving encapsulation of cyanide for possum control in New Zealand (Feratox®) may prove extremely useful for fox control. This should be a subject of research in the immediate future. Although cyanide offers potential advantages for fox control, it must be recognized that it is a highly toxic substance to all species and will not offer many of the non-target safety mechanisms provided by 1080. The use of cyanide for fox control has some potential under strictly controlled situations, but is unlikely to be a suitable toxin for broadscale use in Australia.

Para-aminopropiophenone (PAPP)

Since the 1940s, para-aminopropiophenone (PAPP) has been known as an effective treatment for cyanide intoxication because of its methaemoglobin-inducing actions (Vandenbelt et al. 1944). Methaemoglobin is a form of haemoglobin found in the red blood cells of mammals, but unlike normal haemoglobin it cannot bind oxygen. The toxic effects of PAPP are associated with the clinical condition methaemoglobinaemia, which arises from the excessive conversion of haemoglobin to methaemoglobin causing a lethal deficit of oxygen in cardiac muscles and the brain (Vandenbelt et al. 1944).

'PAPP could be a highly effective supplementary toxin for fox control although there is currently no registered product.'

PAPP was investigated as a toxin for the control of coyotes (*Canis latrans*) in the United States in the 1980s (Savarie et al. 1983). Both the Canidae and Felidae families were found to be highly susceptible compared with rodents, mustelids and birds. The oral LD_{50} for coyotes and the domestic cat (*Felis sylvestris domestica*) was 5.6 milligrams per kilogram, compared with that for the rat (*Rattus norvegicus*) at 177 milligrams per kilogram and the starling (*Sturnus vulgaris*) at >316 milligrams per kilogram. Vandenbelt et al. (1944) reported that domestic dogs (*Canis domesticus*) survived oral doses of ten milligrams per kilogram, and 60% survived 50 milligrams per kilogram. Despite the very low LD_{50} in coyotes, Savarie et al. (1983) concluded that there was no practical value of PAPP as a selective toxin for coyotes, as theoretically a dose of 56 milligrams, required to kill 50% of (10 kilogram average) coyotes would also kill the average-sized cat, bobcat (*Lynx rufus*) or kit fox (*Vulpes macrotis*). This study also reported that vomiting was a complicating factor in many of the animals when PAPP was delivered in a bait, as opposed to a stomach tube.

More recently, PAPP has been investigated in New Zealand as a toxin for stoats (*Mustela erminea*) (Fisher et al. 2005), and future studies are proposed for ferrets (*Mustela furo*), feral cats (*Felis catus*) and wild dogs (Murphy et al. 2005). In Australia, PAPP is currently under investigation for use against wild dogs, foxes and feral cats (Marks et al. 2004b; Dall et al. 2005; Salleh 2005). In pen trials, Marks et al. (2004b) used M-44 ejectors (see Section 4.6) to deliver a standard dose of 226 milligrams of PAPP in a formulation with dimethylsulfoxide and condensed milk. There was rapid onset of symptoms, with foxes becoming progressively lethargic until collapse after 14–25 minutes. Death was confirmed after a mean of 43 minutes, which is over seven times faster than that observed with 1080. The authors concluded that the PAPP formulation was fast-acting and appeared to be a humane lethal agent, with victims showing few signs of activity or the convulsions, spasms and leg 'paddling' commonly associated with 1080 poisoning. As yet, no sensitivity assessments have been published for Australian native mammals. Recent developments suggest that PAPP could be a highly effective supplementary toxin for fox control although there is currently no registered product.

T3327

In the UK, the Department for the Environment, Food and Rural Affairs (DEFRA, formerly MAFF) has long been involved in the development of short-lived and highly toxic compounds for controlling foxes in the event of rabies incursions (C. Cheeseman, DEFRA, pers. comm. 2002). One such toxin is the carbamate compound octane-1, 8-bis[(3-dimethyl carbamoyloxy-2-pyridyl) di methyl] diammonium bromide at 4% w/w, otherwise known as T3327 (Anon 2003c). It works by inhibiting the action of acetylcholinesterase, which influences the neuromuscular junction and the mechanics and control of respiration (DEFRA 2005).

Although T3327 is considered more humane than strychnine with death occurring in minutes at high doses, convulsions were observed in two out of three foxes while they were still conscious (DEFRA 2005). Non-target poisoning is an important issue with T3327, as it is highly toxic to all animals. A fox-baiting trial using T3327, conducted in Scotland in September 2002, reported the accidental deaths of 11 badgers (*Meles meles*) (DEFRA 2005). The potential for secondary poisoning is unknown. Details of the effectiveness of T3327 as a lethal agent for foxes from the Scottish research have not yet been published, but a 'watching brief' should be maintained on developments in this area should they become applicable to Australia.

3.3 Delivery techniques for toxicants

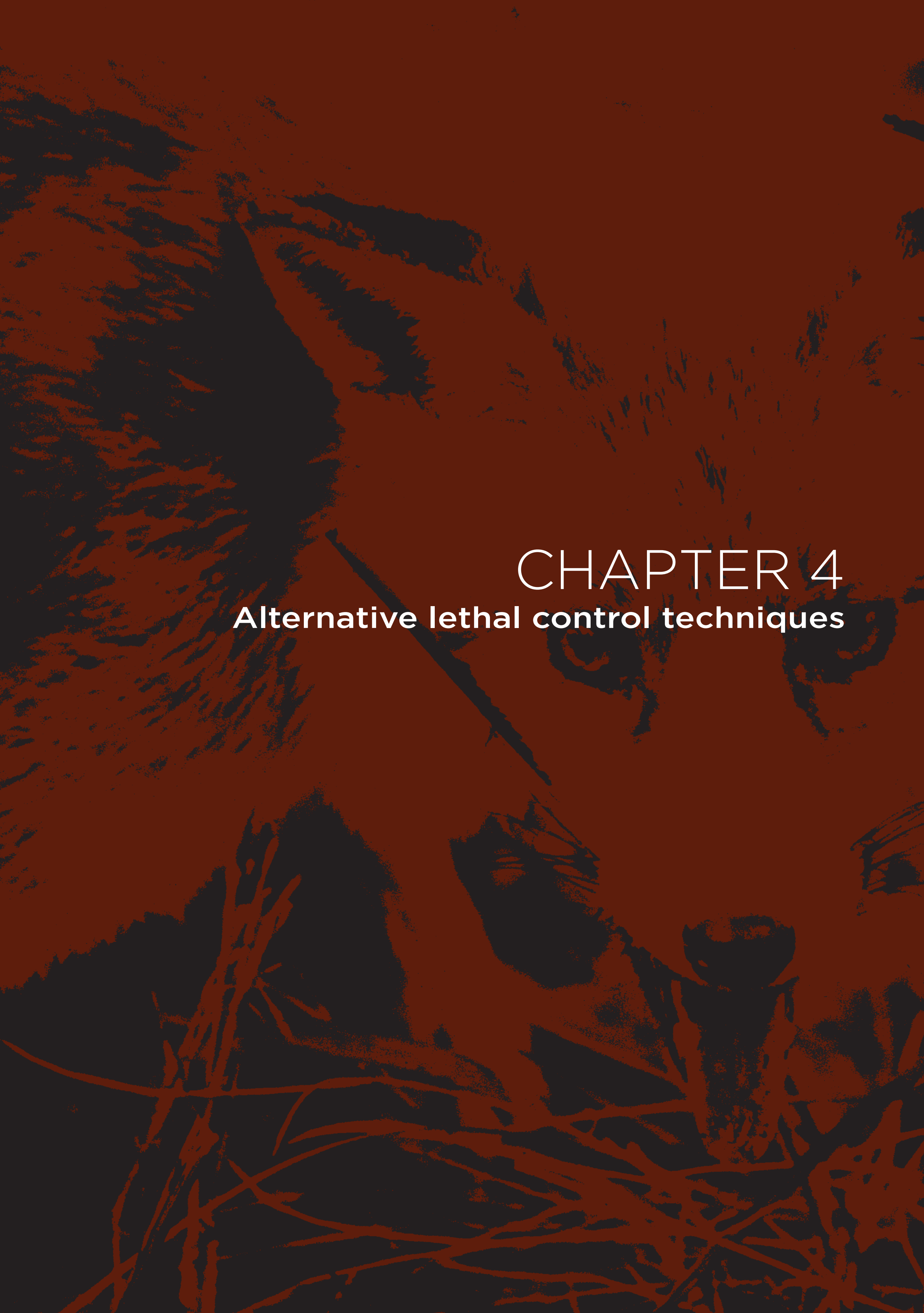
Bait delivery of toxicants is the principal technique used for fox control in Australia. These baits are delivered singly, either by hand or from the air. An alternative strategy for delivering fox baits has been developed by the NSW NPWS. This involves the use of a battery-operated carousel that can deliver baits to a feeding tray and replace each one as it is taken. The interval for replacement can be pre-set. The carousel is covered and locked, so that baits cannot be tampered, as the device (known as the FOXBAR) was intended for use primarily in remote areas, where regular visits for normal baiting are not practicable.

In an independent assessment of the FOXBAR (Jones 2002), a series of field trials were conducted. Fox visits and behavioural responses to the device were recorded using sand pads and automated video equipment. Over 277 days (machine set on a 24-hour rotation of baits) only 11 non-toxic baits were taken, and only three of these by foxes. In contrast, 105 baits were taken by foxes from free-feed stations (buried non-toxic baits) surrounding the device. These results were disappointing, but in further trials conducted by NPWS the results were much more encouraging (K. England, NSW NPWS, pers. comm. 2002). This suggests that further development may be warranted. The major limitations of the device are that it relies on rapid recruitment of foxes and/or overlap from neighbouring fox home ranges to achieve significant reductions at a population level; also, aversion is more likely to occur with such devices as compared to buried baits.

'The costs and benefits of using M-44 ejectors would need to be fully evaluated in both urban and rural landscapes.'

The only emerging alternative is the use of spring-loaded mechanical ejectors (known as M-44 ejectors), which are inserted partly into the ground (see Section 4.6). These are commonly used in the United States to deliver cyanide (Connolly 1988) and have been trialled in Australia using cyanide, 1080 and PAPP (Busana et al. 1998; Marks et al. 1999; Marks et al. 2003; Marks et al. 2004b; Van Polanen Petel et al. 2004). Marks et al. (2002b) suggest that the M-44 may have a role close to urban areas where non-target risks posed by baits are high. Convincing the public that domestic dogs and children would be any less at risk to M-44s may be problematic. The Queensland Department of Primary Industries and Fisheries is currently preparing a registration application for M-44 ejectors using cyanide for foxes and wild dogs. Van Polanen Petel et al. (2004) concluded that using M-44 ejectors with 1080 was the most time-effective technique used in a fox control programme on Phillip Island. The costs and benefits of using M-44 ejectors would need to be fully evaluated in both urban and rural landscapes.

Another alternative delivery method that has been suggested is the 'tarbaby' technique (Saunders et al. 1995), which introduces the toxicant by presenting it in a sticky grease on the floor of the den entrance and relies on the animal's grooming behaviour to remove the grease from its paws and fur. This technique could be applied to the entrances of breeding dens when cubs were still being fed by adults yet old enough to emerge from the den. Although this technique has been investigated in rabbits with some success (Hale and Myers 1970), its use in fox management has not been studied. This method was not adopted for routine rabbit control, as the high concentrations of 1080 present in the sticking agent posed too great a risk to non-target species. Since foxes are more sensitive to 1080 than rabbits, this risk could be reduced, as lower concentrations of the toxicant could be used. The doubtful practicalities of using the 'tarbaby' as a fox control method—the reason why it was never adopted for rabbits—remains to be seen. In particular, fox dens can be difficult and time-consuming to locate.



CHAPTER 4
Alternative lethal control techniques

4. Alternative lethal control techniques

Key issues

- *Trapping is an inefficient method for large-scale fox control in Australia.*
- *Shooting foxes on a contract basis is becoming increasingly popular. Large numbers of animals are being shot with no documentation of resultant changes in fox impact. The cost-effectiveness of this technique needs to be further researched if its use continues to expand.*
- *The principles behind bounty systems are ecologically and socially flawed, and this system should not be adopted as a fox management strategy.*
- *The use of dogs to control foxes can be considered only as a sport and should be discouraged on animal welfare grounds.*
- *Fumigation of fox dens offers only localised control and also has animal welfare concerns.*
- *Use of livestock protection collars for foxes is unlikely to be practical under Australian conditions.*
- *The use of M-44 ejectors may have some application in certain areas, although cost-effectiveness problems will limit its broad-scale application. The issue of registration of this technique remains to be addressed.*

The ongoing management of foxes will continue (at least in the short term) to be based on the deployment of toxic baits, for which the techniques have mostly been developed in Australia. Historically, the fox has been the subject of pursuit, mostly by more traditional hunting means, sometimes encouraged through the offer of bounties. Alternative techniques, such as the use of livestock protection collars and M-44 ejectors, have been developed elsewhere.

4.1 Hunting

The hunting of foxes using traps, firearms and/or dogs has a long history, perhaps peaking in medieval times. During this history, motivations for hunting have varied greatly between recreational pursuit, commercial industry and legitimate pest control. In time, the techniques used for hunting have varied also, as have the desired goals or outcomes (Macdonald et al. 2000). Perhaps more than for any other pest animal, this has confused the modern day assessment of the efficacy of many fox control techniques.

Trapping

The leg-hold, including foothold, trap has been historically an important wildlife management tool throughout the world, but there has long been opposition to traps and trapping on conservation and animal welfare grounds (Andelt et al. 1999b). In response to this opposition in England, strict trap regulations have been enforced since 1958 (Bateman 1976; Lloyd 1980; Baker and Harris 1997), and many other countries also have regulations and restrictions that govern the use of traps (Gentile 1987; Warburton 1995; Coolahan 1996; Coolahan and Snider 1998; Andelt et al. 1999b; International Association of Fish and Wildlife Agencies 2003).

Draft International Trap Standards have been developed for animal traps, with the participation of 14 European countries, the Americas, and New Zealand and Australia (Warburton 1995). Worldwide efforts have been made to modify or find efficient alternatives to standard leg-hold (steel jaw) traps so as to cause less injury to restrained animals and reduce the number of non-target captures (e.g. Saunders and Rowsell 1984; McKenzie 1989). Various models of padded (soft jaw) traps with offset jaws, and snares, have been developed and tested, along with modifications to standard traps.

Padded leg-hold traps have been reported to significantly reduce the incidence and severity of foot injuries sustained by canids compared with standard steel jaw traps (Meek et al. 1995; Phillips et al. 1996; Hubert et al. 1997; Fleming et al. 1998). Early studies produced conflicting reports on the trapping efficiency of the padded models (Linhart et al. 1986; Olsen et al. 1986; Linscombe and Wright 1988; Olsen et al. 1988). Inconsistencies were blamed on poor experimental design, varied trapper experience and trapping techniques, varied environmental factors, poor definition of terminology, possible differences in targeted species, and variations in the padded traps themselves, as designs were continually being developed and modified (Skinner and Todd 1990; Linhart and Dasch 1992).

Recent studies have reported that the refined padded trap designs are as efficient and selective as those of standard steel-jaw traps (Phillips and Mullis 1996; Fleming et al. 1998), with the addition of a pan tension modification reducing non-target captures as well (Turkowski et al. 1984; Phillips and Gruver 1996). Modified unpadded steel jaw traps, although showing a trend towards reducing injuries, are not thought to be as good as the padded models (Phillips et al. 1996; Hubert et al. 1997).

Further protection from injury in leg-hold traps can be derived through the use of trap devices that incorporate tranquilisers such as propiopromazine hydrochloride (Sahr and Knowlton 2000) or diazepam (Marks et al. 2004a). Trap-jaws can also be bound with strychnine-laced cloths to hasten death and prevent prolonged suffering. However, strychnine itself is not particularly humane, and for this reason research is currently under way to identify alternative compounds to be incorporated into a 'lethal trap device' pouch attached to wild dog trap jaws; if such a compound is identified, it could also be used for the rare circumstances where steel jaw trapping of foxes is justified.

Foot snares and treadle snares have also been reported to reduce injuries in restrained animals (Stevens and Brown 1987; Onderka et al. 1990; Skinner and Todd 1990; Meek et al. 1995; Saunders et al. 1995; Bubela et al. 1998; Fleming et al. 1998). These types of traps are marginally more target-specific than leg-hold traps (Stevens and Brown 1987; Meek et al. 1995) but have been reported to have higher failure rates (Onderka et al. 1990; Skinner and Todd 1990; Meek et al. 1995; Fleming et al. 1998).

Traditional neck snares are considered inhumane, and their use is limited or prohibited in most countries (Baker and Harris 1997), although stopped snares (diameter of closure limited to the size of a fox) are considered to offer an alternative to prevent accidental capture of non-target species (Lloyd 1980). The Collarum™ is a device which uses a bait pull-tab that triggers a pair of spring-loaded arms to throw a cable loop around the neck of the animal. It has shown to be highly selective for canids, and have relative low injury rates compared to other trapping devices; however its inefficiency compared to other trapping devices limits its usefulness in many management situations (Shivik et al. 2000). Use of the Collarum™ is permitted in most States except New South Wales and Tasmania.

Cage traps, although causing few injuries, are an ineffective method of trapping wild foxes (Lewis et al. 1998). This type of trap has achieved most success in urban areas throughout England (Baker et al. 2001a), where foxes are less wary of human scent and of entering restricted spaces. The recent illegal releases of foxes in Tasmania (see Section 11.6) resulted in some suggestions of using 'lure' traps consisting of a fox contained within a compound. The fox would attract the small number of released individuals on the assumption that they would be searching intensively for mates. It is not known whether such a strategy has ever been used elsewhere, and it remains untested. However, the social structure and behaviour of most fox populations suggest that this approach would have limited usefulness in routine fox control programmes.

Trapping is an inefficient method for large-scale fox control in Australia (Saunders et al. 1995). It is perhaps useful only when other means of control are inappropriate, such as in urban areas, where non-target species can be harmed by baiting, or when live capture is required for research purposes (Saunders et al. 1995; Fleming et al. 1998). Even under these circumstances, with trapping efficiency ranging in the order of one fox every 40–150 trap nights (Meek et al. 1995; Kay et al. 2000), the labour resources required to reach a desired outcome should be carefully considered before implementing any trapping programme for foxes.

'Trapping is an inefficient method of large-scale fox control in Australia, and there are animal welfare concerns over its use.'

Each State and Territory in Australia has its own legislation covering the use of traps and trapping (see Chapter 11 for details).

Shooting

The shooting of foxes has been a popular control technique used by the agricultural community in Australia. It is a very selective method (Beasom 1974), but is time consuming and not suitable where dense cover is available for foxes or near human habitation (Saunders et al. 1995). Traditionally, most fox shooting was carried out by professional or experienced amateur shooters who were given the rights to take foxes from individual properties. With the reduction in the fox pelt trade and the absence of bounties, the prevalence of professionals has diminished, leaving landholders and enthusiastic amateurs to do the bulk of the shooting (Saunders et al. 1995).

Although a popular control method, shooting is ineffective in significantly reducing fox population numbers, particularly over the longer term (Coman 1988; Newsome et al. 1989; Fleming 1997). In a sample of 317 foxes shot in rural Victoria, at least 54% were juveniles and 74% were less than two years old (Coman 1988). This biasing towards younger, less wary individuals leads to an alteration in the age structure of the population but does not necessarily lead to a decline in the population or the impact these foxes cause. As previously discussed, a population subject to culling shows evidence of compensatory effects that allow the remaining animals' survival and breeding to be enhanced, immigration rates to increase, and dispersal rates to decrease (Caughley 1977). Newsome et al. (1989) report that the replacement rate of foxes was very high after an intensive shooting campaign conducted in western New South Wales.

'Shooting is not effective in significantly reducing fox populations over large areas.'

Shooting is usually done at night from a vehicle with the aid of a spotlight. This method relies on the ability of the shooter to approach the animal until it is in shooting range. Some shooters try to lure animals into range by using whistles. Coman (1988) reported that, as the season progressed, fewer foxes could be shot, either because naïve foxes had already been removed or because the remaining foxes had learned to avoid shooters. 'Battues' (fox drives) are also still common in some rural areas. These involve the use of unarmed beaters, often with dogs, to drive foxes into a waiting line of guns. Many foxes can be taken by this method, but as the time and resources required are prohibitive only small areas can be covered. Although battues do not offer a long-term control solution and are not as selective as field or spotlight shooting (Coman 1988), they may help to further reduce populations already subject to baiting and spotlight shooting and that contain wary adults (Saunders et al. 1995).

Shooting of foxes by hired contractors is being actively promoted by pest control companies and is becoming a popular method of control when used to protect newborn lambs. Impressive numbers of foxes are shot over large areas, although, as with baiting, there is little effort to correlate the costs of control with changes in production values or fox impact. In many instances, a similarly high number of foxes are shot in the same area each year, illustrating the problems of immigration and demographic compensation discussed earlier in Section 2.3.

Dogging

Hunting on horseback with the aid of hounds was the most widespread form of fox hunting employed in the UK (Macdonald et al. 2000) before the introduction of the *Hunting Act 2004*. Another technique of fox hunting used in some parts of Australia is dogging. This involves the use of small terrier dog breeds to flush foxes from dens. The dislodged animals are either killed with shotguns or coursed with large 'lurcher' dogs. Dogging, along with any kind of hunting of foxes with dogs, is considered a sport rather than a control tool in Australia (Saunders et al. 1995). Only temporary and localised reduction in fox numbers is achieved. There are also serious animal welfare concerns associated with this kind of activity.

4.2 Commercialisation

The commercial value of fox pelts was seen as an incentive to use shooting as a major form of fox control. Illegal poison baits, such as cyanide in condensed milk, were also used to retrieve carcasses (and skins). The size of the fox harvest in Australia, however, is constrained by overseas demand (reflected in the price paid) for fur rather than by any limitations on the supply of wild foxes (Ramsay 1994). Creating a source of income does not necessarily encourage the long-term control or permanent reduction in the pest species population. Commercialisation can also replace more cost-effective techniques such as lethal baiting.

In recent years the world demand for fur has declined, mainly because of the activities of animal rights groups (Ramsay 1994). This decline in demand is reflected in the fox fur exports figures, down from 510,000 in 1979–80 to 2100 in 1999–00 (Fig. 4.1). In the early 1990s, about 60% of furs were supplied from New South Wales, 30% from Victoria and 10% from South Australia, with fewer than 1% from Queensland and Western Australia (Ramsey 1994). In 1998-99 and 1999-00 the only shipment to leave Australia was from New South Wales. The last shipment from South Australia was in 1996–97. Since 2000–01, New South Wales and Victoria have been the only States to supply furs for export. (Source: Australian Bureau of Statistics). In 2002, 'natural fur', as harvested from wild foxes, began to make a comeback, with advertised prices offered for pelts in the order of \$10–\$15, and exports rising to over 7600 furs. How viable this re-emerging industry will become is still uncertain.

The reliance of fox harvesting on labour-intensive techniques such as shooting and trapping make it an inefficient form of broadscale fox population control relative to cooperative baiting programmes.

Source: Margaret Warriner, Numeralla, NSW

4.3 Bounty systems

Bounty systems offer financial incentives to hunt and destroy a pest animal and, by necessity, require the hunter to present part or all of the animal. These systems have been frequently used against foxes in Australia since the late 19th century (e.g. Gooding 1955; Smith 1990; Hrdina 1997) and included a scheme known as 'Fox Lotto' in Victoria in the early 1990s where presentation of a fox skin entered the presenter in a lottery (Oogjes 1995; Olsen 1998). Another Victorian scheme was implemented in 2002 with a government-sponsored 'fox bounty trial'. Most of these programmes were put in place because of political pressures or deals, with little evaluation of the perceived problem, alternative solutions or success criteria (Oogjes 1995; Hassall and Associates 1998), and in the absence of, or

Bounty systems may produce superficially impressive figures for the number of pest animals killed, but such kill rates are usually inadequate to achieve sustained population reductions. Bounty schemes are also subject to fraud – this photo of foxes with their tail skins removed was taken in New South Wales at the time of the 2002-03 Victorian bounty scheme.

Source: Kerry Wratten and Gordon Murray, NSW DPI

with disregard for, scientific advice. Reviews of past bounty schemes in Australia have shown this method to be an ineffective form of pest animal control (e.g. Gooding 1955; Smith 1990; Oogjes 1995; Hassall and Associates 1998; Victorian Institute of Animal Science Vertebrate Pest Research Department (VIASVPRD) 2003).

The principles behind bounty systems are ecologically and socially flawed. The *ad hoc* removal of individual pest animals does not necessarily lead to a reduction in pest impact or damage. To collect a bounty, hunters have to present a nominated body part (e.g. a scalp or tail). This practice is not only open to fraudulent practices (e.g. Hrdina 1997; VIASVPRD 2003) but also encourages the use of inefficient (and sometimes inhumane) methods and impedes the implementation of more effective and targeted methods of control (Smith 1990; Hassall and Associates 1998; VIASVPRD 2003).

A major problem with bounty payments is the creation of a source of income that does little to encourage long-term control of, or permanent reduction in, the pest species population. Anecdotal evidence received during the 2002-03 scheme in Victoria reported that shooters reduced their activity during fox breeding periods to ensure a continuous harvest (VIASVPRD 2003). Bounty hunters have been known to target areas where they can get maximum return for their effort, regardless of impact or damage in that area, and to be selective in the individuals that they do take. During the recent scheme in Victoria, fox collection rates were found to be no higher in sheep production areas than in other areas, despite the protection of sheep flocks being a major objective of the trial. There were also reports of large numbers of foxes being shot interstate and their tails being transported to Victoria to claim the bounty, as well as theft of

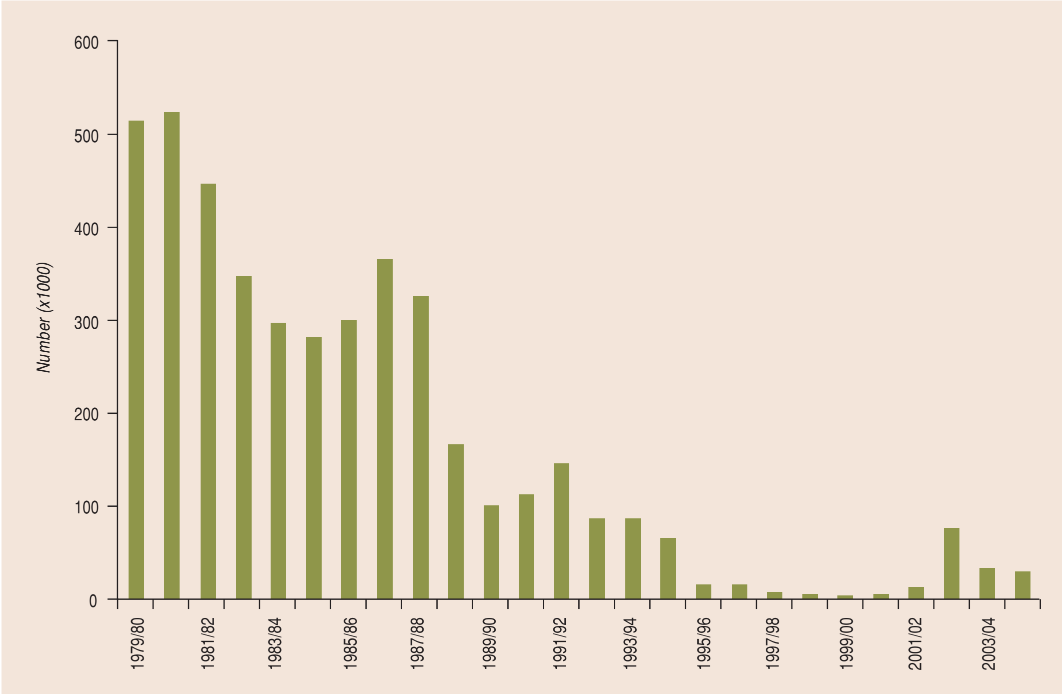


Figure 4.1 *Raw fox fur exports from Australia from 1979–80 to 2004–05. (Source: Australian Bureau of Statistics).*

fox tails already presented (VIASVPRD 2003).

Although capable of offering positive benefit–cost ratios, bounty schemes remain a clumsy pest animal management tool. Their focus on reducing pest population size rather than minimising damage is out of step with recent recommended control practices. They require considerable supervision, are subject to many fraudulent practices, and do not guarantee increased control activity or a significant reduction in pest animal damage (Smith 1990; Hassall and Associates 1998; VIASVPRD 2003).

'Bounty schemes are a clumsy pest animal management tool. The principles behind their use are ecologically and socially flawed.'

4.4 Fumigation

The introduction of a lethal gas into fox natal dens is sometimes employed to destroy young cubs. In Australia the only registered fumigant for foxes is carbon monoxide (CO), although, before its registration in 1996, unapproved use of chloropicrin and phosphine rabbit fumigants was not uncommon (Anon 1995; Saunders et al. 1995). Carbon monoxide is highly toxic to mammals, leading to oxygen depletion of the brain, unconsciousness and death (Savarie et al. 1980; Page 1994), and is considered more humane than either chloropicrin or phosphine (Savarie et al. 1980; Ross 1986). The ingredients

The Den-Co-Fume® cartridges distributed by Animal Control Technologies provide an option for localised fox control in situations where baiting is not feasible.

Source: Animal Control Technologies

in the CO cartridges (65% sodium nitrate and 35% charcoal) are inert until ignition, the gas is generated only in the den or warren and is relatively unaffected by weather conditions, and there appears to be no risk of secondary poisoning (Savarie et al. 1980; Page 1994).

Carbon monoxide-producing cartridges have been used in the United States for control of several different burrowing species, including coyotes (Savarie et al. 1980). 'Gassing' of foxes in dens is illegal in the UK, where it is considered by many to be inhumane (White et al. 2000). Field trials of these cartridges on foxes in Australia appeared to reduce cub activity by 80% at the treated dens (Anon 1995; Hart et al. 1996). Carbon monoxide fumigant cartridges (Den-Co-Fume®; Animal Control Technologies) are now available commercially in most States of Australia.

Unless used to treat localised fox problems such as active dens within lambing paddocks or near poultry, fumigation, like many other techniques, cannot be considered a cost-effective measure for broadscale application. It is suitable for use in urban areas.

4.5 Livestock Protection Collars

Livestock Protection Collars (LPCs) have been developed in the USA for control of coyote depredation. The advantage of LPCs is that they target the individual coyotes that are killing livestock (Connolly et al. 1978; Connolly and Burns 1990). The collars exploit the coyote's habit of killing sheep by biting at the neck and throat (Connolly et al. 1976). When coyotes attack collared sheep or goats there is a high probability they will puncture the collar and receive a lethal dose of toxicant (Connolly et al. 1978; Burns et al. 1988; Connolly and Burns 1990; Burns et al. 1996). Lethal collars containing various toxicants have been tried, with 1080 giving the best results (Connolly et al. 1978; Savarie and Sterner 1979; Burns et al. 1988; Connolly and Burns 1990; Walton 1990; Burns et al. 1996). Non-lethal compounds have also been tested in LPCs to deter coyote attacks, with little success (Burns et al. 1984; Burns and Mason 1996). Even though a small number of collars have accidentally punctured in the field and scavengers are known to feed on dead coyotes, no adverse impacts on humans, livestock or non-target wildlife have been demonstrated (Burns et al. 1988; Connolly and Burns 1990; Burns et al. 1991).

Although foxes show a high incidence of attacking lambs around the neck (Rowley 1970) the use of collars has never been tried in Australia. Foxes usually attack newborn or very young animals. Mustering a flock containing newborn lambs would mostly be unacceptable because of the losses that would be incurred through mismothering, so collaring in the majority of the Australian sheep industry would not be feasible. The technique would have even fewer conservation benefits. There are greater similarities between coyote and dingo/wild dog attacks (size and age of prey), and dingo/wild dog control may be the area where this technique has greater application in Australia.

4.6 M-44 ejectors

The M-44 is a tube-like spring-loaded device partly buried in the ground. The exposed portion is baited with an attractant, which, upon being pulled, ejects a lethal dose of toxicant into the target animal's mouth (Connolly and Simmons 1984; Phillips and Blom 1994). The M-44 ejector containing sodium cyanide (NaCN) is an important control tool used in the management of coyotes in the western United States (Connolly and Simmons 1984; Phillips and Blom 1994), where it is also registered for the control of the red fox, grey fox and wild dog (Connolly 1988).

Trials using a modified M-44, delivering both NaCN and 1080, have been conducted in Victoria (Busana et al. 1998; Marks et al. 1999; Marks et al. 2002b; Marks et al. 2003; Van Polanen Petel et al. 2004). Several modifications were made to the M-44 ejector, including:

- allowing it to be fully buried (even in sandy soil) in accordance with State baiting regulations (Busana et al. 1998; Van Polanen Petel et al. 2004); and

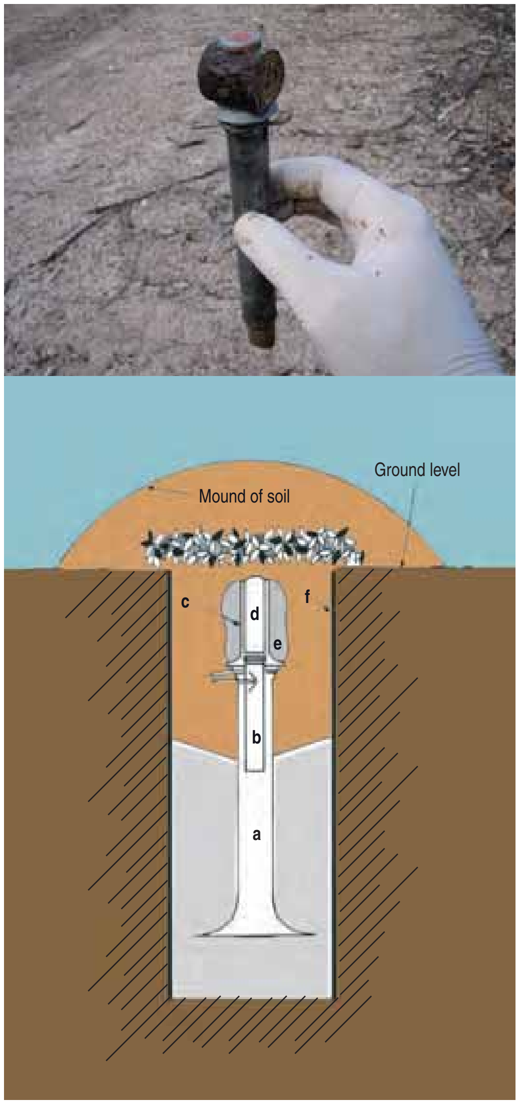
- ensuring that the fox grasped the bait with its head oriented vertically above the ejector, to increase the likelihood of receiving a full dose of the toxicant (Marks et al. 1999).

Although the attractiveness of the M-44 compared with other types of bait was not determined, once triggered by a fox the M-44 was found to deliver a reliable lethal dose of either cyanide or 1080 in the field (Busana et al. 1998; Marks et al. 1999). Because of this reliability and the absence of water leaching or microbial and insect degradation of the encapsulated 1080, the amount of 1080 that can be used in the capsules is less than the 3.0 milligrams currently used in fox baits (Marks et al. 1999). Pen trials indicated that the 1080 dose can be reduced to 2.7 milligrams.

'M-44 ejectors are spring-loaded toxin delivery devices that may be of use in some situations.'

The M-44 ejector is activated only by an upward pull or force on the bait (Matheny 1976; Connolly and Simmons 1984), an action that only larger animals are thought to be able to accomplish (Connolly 1988; Busana et al. 1998). The ejector is not triggered when only the edible bait material, used as the attractant, is disturbed or consumed (Marks et al. 1999; Van Polanen Petel et al. 2004). Marks and Wilson (2005) found a significant relationship between animal body mass and the pull force able to be exerted on the M-44 ejector. Also influencing this pull force was the animal's ability to grasp the bait substrate. They estimated that an ejector trigger force of 26.46 Newtons would allow an animal weighing greater than 3 kilograms to trigger the device, and their findings suggested that, although the majority of adult foxes would be capable of triggering the M-44 ejector, 26 of the 31 potential bait-consuming mammals in south-eastern Australia would not, thereby reducing the risk to non-target species, particularly smaller animals and birds.

Nicholson and Gigliotti (2005) reported a further modification which exploits the differences in head morphology between foxes and some native predators. A specially designed collar fitted to



M-44 ejector (photo Rob Hunt, NSW NPWS) and schematic diagram: (a) hollow metal stake; (b) M-44 ejector; (c) bait/capsule holder; (d) poison capsule; (e) bait; and (f) plastic cylinder (Reproduced with permission from Wildlife Research 31: 143-147 (van Polanen, AM; Kirkwood, R; Gigliotti, F and Marks, C). Copyright CSIRO 2004. Published by CSIRO PUBLISHING, Melbourne AUSTRALIA - http://www.publish.csiro.au/journals/wr)

the device can exclude larger native non-target species such as the spotted-tail quoll (*Dasyurus maculatus*) and the Tasmanian devil (*Sarcophilus harrisii*) while still allowing adult foxes to trigger the ejector. The use of specific colours or colourodour combination of the attractant might also possibly reduce triggering by non-target species (Mason et al. 1999).

In studies conducted in the western United States and Canada, non-target species comprised 0–12% of the total number of animals killed by M-44s (Beasom 1974; Matheny 1976; Dorrance 1980; Connolly 1988). However, in a recent study in eastern United States, where non-target densities are considered to be higher than in the west, non-target species triggered 80–83% of M-44s (Mason et al. 1999). Non-target species included other species of fox, large cat species, badgers, skunks, opossums, raccoons, porcupines, rabbits, beavers, wood rats, large bird species (such as vultures, crows, ravens, hawks and wild turkeys), pigs, bears and deer. A small number of sheep and young cattle are reported to have died (Matheny 1976; Dorrance 1980; Connolly 1988), but stock interference was less with M-44s than with traps (Connolly 1988).

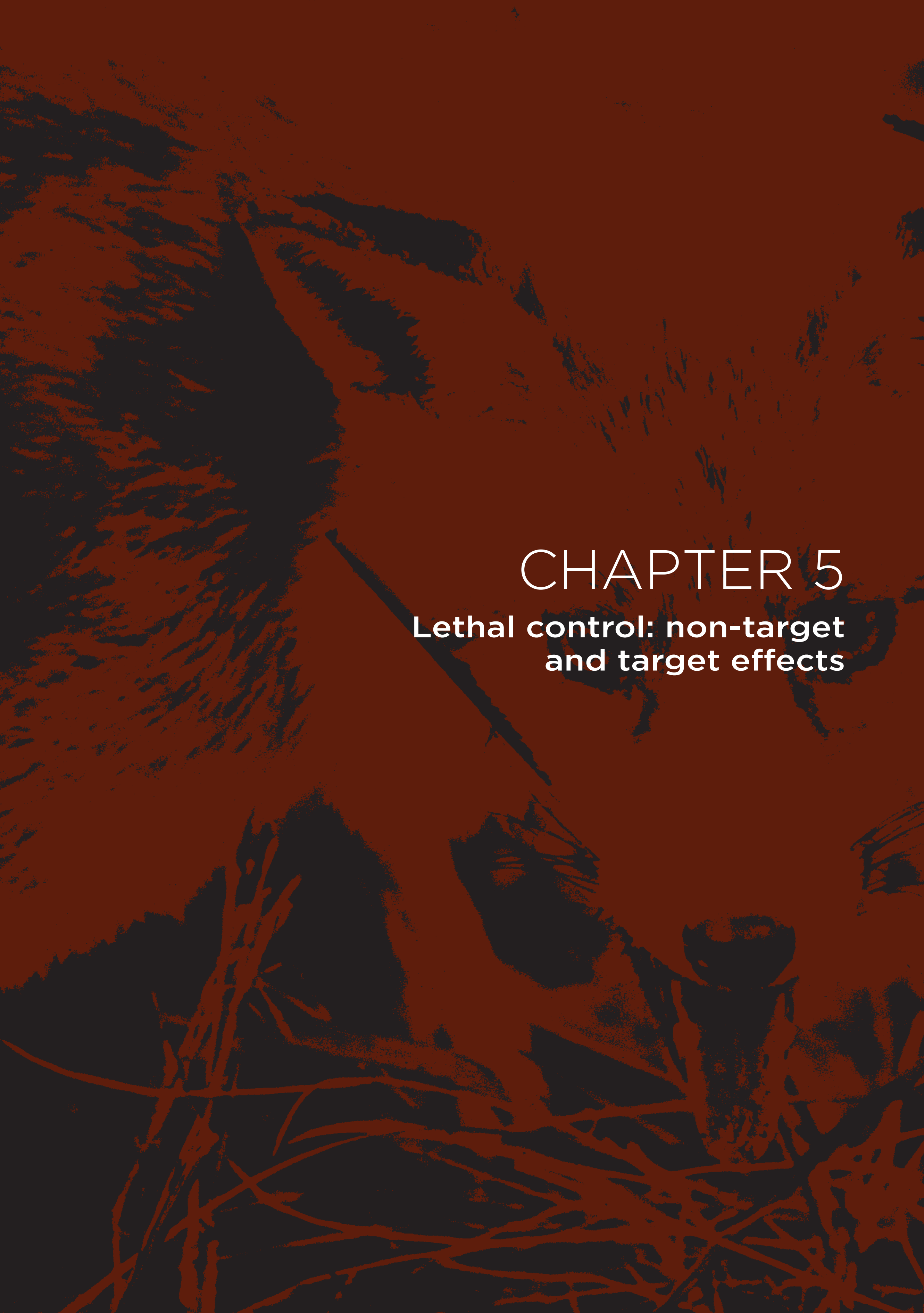
In Australia, Marks et al. (1999) reported a single non-target death (an Australian raven, *Corvus coronoides*) in 2000 bait-nights using 1080-loaded M-44 ejectors. No M-44 ejectors loaded with cyanide were triggered by non-target species in a study on Phillip Island in 2787 bait-nights, although 35 baits were eaten, mainly by rodents and birds (Van Polanen Petel et al. 2004). These results support the findings of Marks and Wilson (2005), but the risk posed to larger carnivorous species in Australia that may be able to trigger the device, such as quolls (*Dasyurus* spp.), is still unknown (Marks et al. 1999).

Van Polanen Petel et al. (2004) compared the catch per unit effort of various techniques (M-44 ejectors with cyanide, hunting with fox hounds, trapping using treadle snares and spotlight shooting) used in a fox control programme on Phillip Island. They concluded that M-44 ejectors with 1080 (estimated to use one-sixth the man-hours of M-44 ejectors with NaCN, because of the reduced handling time due to fewer safety precautions than required for handling NaCN) was the most time-effective technique of the four used in this area. Although the use of M-44s may have application in certain areas (e.g. research, conservation, urban control programmes), there is clearly an issue of cost-effectiveness that requires further investigation before they would be widely accepted in Australia. The means for full registration of this technique also need to be addressed.

The Queensland Department of Primary Industries and Fisheries is currently preparing a registration application for the use of M-44 ejectors, using cyanide as the toxin against foxes and wild dogs. Apart from the requirements for registration, issues that also need to be dealt with include the classification of the device as a weapon under some jurisdictions and the authorisation of users in respect of cyanide use (R. Parker, Queensland Department of Primary Industries and Fisheries, pers. comm. 2006). Relevant legislation in most jurisdictions allows limited access by authorised individuals to this technology (e.g. State government pest controllers), and some amendment of the legislation will be required to allow a wider range of M-44s.

4.7 Other strategies

The recent release of foxes in Tasmania (see Section 11.6) resulted in a number of new suggestions for fox control. These suggestions were specifically aimed at removing individual foxes rather than populations (see also Section 4.1). Professor Roger Short proposed the use of 'lure' vixens that would be given oestrogen implants to keep them in continuous oestrus. These animals would be surgically sterilised to prevent them from adding to the population, fitted with satellite tracking collars, and released (Hodge 2002). The principle applied would be similar to that of the 'Judas' goat technique (Henzell 1987), where tracked animals move into previously unknown locations of other animals. Goats, being herding animals, are strongly suited to this technique. Success in foxes would be less likely because they are more solitary and wary of humans and also highly cryptic. The technique would also be most likely biased towards attracting males.



CHAPTER 5

Lethal control: non-target and target effects

5. Lethal control: non-target and target effects

Key issues

- *The sensitivity or toxicity of 1080 and other poisons should not be used alone as a measure of non-target risk.*
- *Most studies support the conclusion that properly conducted 1080 baiting programmes have no significant effects on non-targets.*
- *There is a commonly held view in Australia that the control of wild dog populations can lead to an increase in fox numbers, even though there is only anecdotal supporting evidence. A better understanding of the relationship between resource availability and use is needed to clarify the relationship between foxes and wild dogs.*
- *There is a need to be concerned for 'at risk' or endangered native wildlife in circumstances where cats are present and foxes are controlled. This particularly applies where rabbits are also present and where resources are limited in time by drought. The relationship between cats and foxes (including availability of prey, e.g. rabbits) and the implications of mesopredator release requires further research.*
- *If conclusive evidence is available that cats will become a significant problem following the control of foxes, strategies that address the simultaneous control of both species should be developed.*
- *Control strategies may be biased towards certain age classes in the fox population, and control effects may be maximised by targeting certain age classes. How these biases or potential advantages can be addressed to maximise management outcomes remains unclear.*

Any method of fox control can potentially impose a risk to other, non-target species. This potential non-target impact can be broadly divided into two groups: primary impact resulting from direct effects of the control measure (e.g. consuming toxic bait, caught in trap); and, secondary impact resulting from indirect effects of the control measure (e.g. scavenging on a poisoned carcass or vomited food). As yet, no fox control method can be perfectly targeted, and the loss of some non-target individuals seems inevitable. It is important to find out whether the loss of these isolated individuals will affect the population dynamics and distribution of the species being affected. Species that are rare (low density) and/or have a poor capacity to compensate for such potential losses will be at most risk (Caughley and Sinclair 1994).

It is important to continually research, monitor and evaluate lethal control strategies to:

- modify methodologies and behaviour to keep any losses of non-target populations below the level at which they are severely affected;
- make sure the benefit of control outweighs potential risk factors;
- determine methods of reducing risks;
- continue education to increase the adoption of new technologies to improve selectivity, reduce risk, increase efficacy and maintain cost-effectiveness; and
- educate the public (Miller 1988).

5.1 Non-target species and 1080

Non-target animals (both native and introduced) can be exposed to 1080 either directly by eating baits intended for pest animals (primary poisoning) or through the scavenging of tissues from a poisoned animal (secondary poisoning). The sensitivity or toxicity of 1080 to native species is often equated to the degree of risk these species are exposed to in 1080 baiting programmes, even though it provides little information on the effect that exposure to a poisoning programme may have on the density of non-target species. Ultimately, the degree of risk can be determined only by measuring responses of non-target populations to 1080 baiting programmes — although, even then, important biological implications can still be overlooked (Choquenot and Ruscoe 1999).

'The theoretical sensitivity of native species to 1080 cannot be assumed to indicate the degree of risk faced by these species in operational baiting programs.'

It is misleading to use sensitivity alone, as other factors also come into play (McIlroy 1982, 1986 and 1992; Sinclair and Bird 1984; Calver et al. 1989; King 1989; Soderquist and Serena 1993). These include: the design of the management programme (e.g. time of year and baiting method — risk minimisation); the extent of interaction between pest and non-target (home range and distribution); bait type, palatability or scavenging preference (food habits); ability to consume sufficient bait or carcass to acquire a lethal dose (feeding rates); degree of exposure to bait or carcasses (encounter rates); toxic loadings of bait or carcasses (target species requirements); and, the longevity and degradation of 1080 in carcass tissues (secondary poisoning).

Several Australian studies have attempted to monitor and evaluate non-target species that are at risk of 1080 poisoning under field conditions — e.g. poisoning programmes for feral pigs (Hone 1983), wild dogs (McIlroy 1982; McIlroy et al. 1986; King 1989; Murray et al. 2001) and rabbits (Statham 1987). These studies mostly indicate no significant effect on non-target animals (i.e. the studied populations/species remained relatively stable before and after the baiting programme) and suggest that assessments based on sensitivity alone tend to exaggerate the risk faced in the wild.

There are some published field evaluations of the non-target impact of fox poisoning programmes (Morris et al. 1995; Dexter and Meek

Sand pads can be used at bait stations to determine which target and non-target species are present and may be taking bait.

Source: Paul Meek, Forests NSW

1998; Fairbridge et al. 2003; Glen and Dickman 2003a; Körtner et al. 2003), and the results of wild dog studies using meat baits would be relevant in many circumstances (e.g. Körtner and Watson 2005). However, evidence of the impact of fox poisoning programmes mostly relies on anecdotal reports and circumstantial evidence (e.g. Belcher 1994; McPhee et al. 1995; Murray and Belcher 1996). Other studies measure the likelihood of non-targets consuming fox baits without assessing the likely effect at a population level (e.g. Belcher 1998).

Dexter and Meek (1998) established 301 fox bait stations in a New South Wales coastal reserve. Each station consisted of a raked one square metre sandplot and was flagged with yellow tape. Non-toxic baits were offered for 13 days, followed by 10 days of toxic baiting. Birds (mostly pied currawongs, *Strepera graculina*) and rats (mostly black, *Rattus rattus*) were identified as taking baits, although the proportions taken by these non-targets did not decline during the period of toxic baiting, suggesting that they were not being killed or adversely affected by the baits. The authors also suggested that the level of bait take by birds in particular may have been enhanced by the attraction of the flagging tape used to mark bait station sites.

Körtner et al. (2003) examined the mortality of spotted-tailed quolls (*Dasyurus maculatus*) associated with fox-baiting programmes in the New England area of New South Wales. A total of 57 quolls were fitted with mortality collars during four experimental fox-baiting programmes. In all experiments, quolls visited bait stations regularly and removed 20 baits, all but one of which were found in close proximity to the station. Only one of the 57 quolls was thought to have died from 1080 poisoning, suggesting that they removed the baits without ingesting them. In a similar, but less substantive study, Morris et al. (1995) monitored 10 radio-collared western quolls (*D. geoffroii*) in association with a series of fox-baiting programmes and found no 1080-induced mortalities.

Recent trials in forested areas of southern Queensland have had similar outcomes. Over a four-year period, the fate of 72 quolls was monitored during a series of coordinated wild dog baiting campaigns. Quolls were exposed to fresh meat baits containing 6 milligrams of 1080 for 740 bait nights. A total of five buried fresh meat baits may have been removed by quolls across the campaign (less than 0.6% bait uptake), with only two quolls confirmed to have died from 1080 poisoning. Regardless, the mortality rate from poisoning was very low compared to other causes of mortality, and the quoll population remained stable (P. Cremasco, QLD Department of Primary Industries and Fisheries, pers. comm. 2006).

Burying of baits (see Section 2.6) reduced bait take by non-targets in a dingo/wild dog baiting trial (Allen et al. 1989), and this practice is claimed to reduce the risk to non-targets in fox-baiting programmes (Staples and McPhee 1995). The claim that foxes prefer to eat buried baits (e.g. Korn and Lugton 1995) is not supported by any experimental evidence, and Thomson and Kok (2000) found that buried dried meat baits were less likely to be eaten, and more likely to be cached by foxes than baits left on the surface. Belcher (1998) and Murray (1998b) have shown that quolls are capable of detecting and excavating buried baits to a depth of 5–8 centimetres but are not inclined to excavate baits buried deeper than 10 centimetres. Mooney et al. (2005) reported that dasyurids in Tasmania could not efficiently find baits buried at 15 centimetres until the baits began to rot, typically after two weeks.

'The mortality rate from poisoning was very low compared to other causes of mortality, and the quoll population remained stable.'

Priddel and Wheeler (1997) report that fox baits were dug up by little crows (*Corvus bennetti*), and McIlroy et al. (1986) observed some bird species uncovering baits. Fairbridge et al. (2003) found that four small mammal species, including the brush-tailed phascogale (*Phascogale tapoatafa*) had accessed and at least partly consumed non-toxic baits buried under ten centimetres of mounded sand during a simulated fox-baiting exercise in Victoria. Cattle are also capable of recovering buried baits. In Western Australia, target specificity is enhanced by drying meat baits to a biltong consistency, which prevents them from being consumed by smaller carnivorous marsupials and scavenging birds (Calver et al. 1989).

Glen and Dickman (2003a) monitored the removal of non-toxic Foxoff® baits during a simulated baiting programme for foxes and wild dogs. The trial was conducted in forested country and consisted of two methods of application: 29 stations with the bait buried 7 centimetres below the surface and 28 stations in which the bait was covered by a raised mound. All stations were monitored by remote photography and by identification of animal tracks on sand pads. Baits were removed on 91 out of 659 bait nights (13.8%), and of these only one bait was removed by a fox and a further five by wild dogs. Of the species identified, spotted-tailed quolls (*D. maculatus*) removed the most baits (7.0%), followed by brush turkeys (*Alectura lathami*) (1.8%). The generality of experiments such as this makes them difficult to interpret, given the habitat, lack of target predators, lack of replication and use of non-toxic baits. They also fail to determine whether non-targets consume baits that have been removed from stations and whether only individuals, rather than populations, are placed at risk (see Körtner et al. 2003). However, they all indicate that, under the right circumstances, non-targets are at risk from fox-baiting programmes, and that this needs always to be considered in the design and application of control programmes.

Free-feeding (see Section 2.1), used in conjunction with sandplots, has been proposed as a way of assessing any risk to local non-target animals before poison baits are offered (Saunders et al. 1995). Belcher (1998) warns that this method may not always be reliable, as various animals can investigate a site once a bait has been removed, obliterating the initial visitor's tracks. Pre-feeding can also potentially 'train' non-target animals to feed readily at bait stations; this is an undesirable outcome (see previous discussion of Dexter and Meek 1998).

Secondary poisoning is associated mainly with 1080 poison programmes aimed at potential prey species such as rabbits and pigs. Their likely predators and scavengers (e.g. foxes, corvids and raptors) are the animals at risk (Burchfield 1979; McIlroy 1981, 1986, 1992, 1994; Gooneratne et al. 1994; Meenken and Booth 1997). Secondary poisoning from fox control programmes, if it occurs at all, could occur from a non-target consuming vomited food, although scavenging from a fox carcass is also remotely possible.

5.2 Non-target species and other control methods

If done properly by suitably trained personnel, shooting is probably the most target-specific method of fox control. Worldwide efforts have been made to modify or find efficient alternatives to standard leg-hold traps so as to cause less injury to restrained animals and reduce non-target captures (see Section 4.1). The use of M-44 ejector devices in North America has resulted in numerous documented non-target kills (see Section 4.6). Trials using modified M-44 ejectors in Australia have reported minimal mortality of non-target species (Marks et al. 1999; Van Polanen Petel et al. 2004; Marks and Wilson 2005). Chemical fertility control can be non-specific and have similar effects on target and non-target species if used indiscriminately. Similarly, if immunocontraception (see Section 7.3) aimed at foxes is only canid-specific and not fox-specific, protected dingo populations or valuable working dogs could be placed at risk. Exclusion fencing can negatively affect non-targets by altering their dispersion and foraging patterns, or entangling or electrocuting them.

5.3 Fox and other predator relationships

The relationship between foxes and dingoes or wild dogs (*Canis familiaris dingo, C. f. familiaris* and hybrids) in Australia is poorly understood (Fleming et al. 2001; Glen and Dickman 2005). Observations of an inverse relationship between the abundances of foxes and wild dogs in Australia (Jarman 1986) have been popularly interpreted to mean that the latter may limit the distribution and abundance of foxes (e.g. Wilson et al. 1992; Corbett 1995; Saunders et al. 1995; Newsome 2001). Hence the lethal control of one species may, in turn, influence the distribution and abundance of the other. Dietary studies that have shown some overlap between the two species have also suggested potential competition, particularly when conditions are poor (Corbett 1995). It is, however, misleading to assume that just because these correlations exist they cause competition (Sinclair 1991). In many areas the marked difference in habitats and the management of agricultural land (higher fox numbers) versus non-agricultural land (higher dingo/wild dog numbers) could confound comparisons of the abundances of the two species and could provide alternative hypotheses to explain the observed differences (Fleming et al. 2001). Since observational studies cannot provide unequivocal interpretations of ecological relationships, controlled removal experiments (e.g. Underwood 1990; Eberhardt and Thomas 1991) need to be conducted to determine the underlying causes and consequences of these patterns in terms of the distribution and dietary overlap of foxes and wild dogs in Australia (Glen and Dickman 2005).

Several intensive radio-tracking studies have been conducted in North America to investigate the relationship between large canid species, such as wolves and coyotes, and foxes. Even though these larger canids and foxes appear to coexist on a regional scale, local spatial segregation was found, with foxes usually avoiding the larger canids' territories (Dekker 1983; Voigt and Earle 1983; Sargeant et al. 1987; Dekker 1989; Harrison et al. 1989). Cavallini (1996) suggests that foxes evolved under predation pressure from larger carnivores and therefore may have adapted to the spatial constraints imposed by the ranging behaviour of larger predators. He predicted that the re-introduction of a larger canid (or perhaps, in Australia co-existence with dingoes) would profoundly affect the ranging behaviour, territoriality, sociality and mating system of the fox.

Observations of the co-occurrence, or sympatry, of wild dogs and foxes have been documented in many areas of Australia (Newsome et al. 1983; Triggs et al. 1984; Robertshaw and Harden 1985; Marsack and Campbell 1990; Thomson 1992; Catling and Burt 1995; Corbett 1995; Fleming 1996a; Catling and Burt 1997; Fleming et al. 2001). Very few studies have attempted to investigate the consequences of this relationship. There have been no radio-tracking studies conducted in Australia, but two studies in eastern New South Wales used the presence of signs such as footprints and faeces to investigate wild dog and fox interactions (Catling and Burt 1995; P. Fleming and J. Thompson unpublished data). Catling and Burt (1995) found no evidence of exclusion of foxes by wild dogs. There was little evidence of spatial avoidance of wild dogs by foxes, although the possibility of temporal avoidance could not be ruled out. Fleming (1996a) also reported that wild dogs and foxes were not spatially separated in his study site, but the possibility of temporal separation was not investigated.

Fleming and Thompson (unpublished data) investigated wild dog and fox sympatry in eastern New South Wales by using sign presence along 100-metre sections of set transects. They found that the co-occurrence of signs at a site that was baited with 1080 meat baits declined significantly after baiting, whereas there was little change over the same period at an unbaited site. This decline in co-occurrence of the surviving population of dogs and foxes led Fleming and Thompson to speculate that sympatry was necessary only when the population density of either or both species was high relative to the available space or resources.

'There was little evidence of spatial avoidance of wild dogs by foxes, although the possibility of temporal avoidance could not be ruled out.'

A study investigating coyote–fox interactions found that coyotes will generally tolerate a fox's presence in their territory (Gese et al. 1996), depending on the circumstances. Tolerance was found to decrease in the presence of a carcass, especially if the coyote had not eaten, or if a number of coyotes were present. Wild dogs have been observed excluding foxes from carcasses in central Australia (Corbett 1995), but it is not known if this exclusion leads to increased mortality or lower fecundity in foxes. Detailed studies are needed on resource availability and use if the relationship between foxes and wild dogs is to be understood.

Wolves and coyotes are known to kill fox cubs and adults (Pils and Martin 1974; Macdonald et al. 1980; Lewis et al. 1998). Marsack and Campbell (1990) and Corbett (1995) report incidences of dingoes killing foxes, but these occurrences appeared to be opportunistic. Fleming (1996a) reports anecdotal evidence of predation of resident foxes by newly arrived wild dogs in his study site in northern New South Wales. The remains of foxes have been found in the faeces and stomach contents of dingoes and wild dogs (e.g. Thomson 1992; Corbett 1995), with the occurrence estimated at between 0.1% and 3.8% of the total diet.

'Foxes and feral cats have major negative impacts on small and medium-sized native vertebrates, whereas dingoes and wild dogs have impacts on larger species.'

There is a commonly held opinion in Australia that the control of wild dog populations can lead to an increase in fox numbers (e.g. Denny 1992; Smith et al. 1992), even though there is only anecdotal supporting evidence (e.g. Jarman 1986; Fleming et al. 2001). On the other hand, foxes are often considered a 'bycatch' in many wild dog control programmes (McIlroy et al. 1986; Fleming 1996a). As predation by foxes is considered a significant factor in the reduction in numbers of many native mammalian species, an increase in fox numbers as a result of the control of wild dogs in a particular area could lead to an unsatisfactory increase in the predatory burden on these native mammals (Smith et al. 1992). Dickman (1996b) concluded that foxes and feral cats have major negative impacts on small and medium-sized native vertebrates, whereas dingoes and wild dogs have major negative impacts on larger species. In this way, dingoes could enhance the survival of the smaller native species if the dingoes could suppress fox and cat populations. Issues such as this cannot be resolved either way until there is a better understanding of fox/wild dog interactions in Australia. The relationship of foxes to other predators, such as feral cats, may also have important implications, particularly in situations where fox control is undertaken.

5.4 Mesopredator release

Mesopredator release occurs when a higher-order predator (superpredator) is controlled or eliminated, thus allowing an increase in the predatory pressure applied by a lower-order predator. This process is illustrated by island situations where cats, rats and prey populations (e.g. seabirds) co-locate (see Courchamp et al. 1999 for review). Cats are known to be a major threat to many island bird species. Rats, too, can affect bird populations through predation of eggs and chicks. They can also have an indirect effect through competition for food and nest sites. Removing cats from such a system can result in a compensatory increase in rat numbers (mesopredator release), which in turn can theoretically result in greater overall predation pressure on the birds. An opposite deleterious effect could also occur in this situation if the rats were to be removed and the cats switched prey.

Apart from island examples of mesopredator release involving cats, the process has also been inferred from various population studies, e.g. the Iberian lynx with the mongoose and rabbit (Palomares et al. 1995); the coyote with the red fox and duck (Sovada et al. 1995); the coyote with the grey fox, cat, opossum and scrub-feeding birds (Crooks and Soule (1999); and the coyote with the badger, grey fox and bobcat, jackrabbit and rodent (Henke and Bryant 1999). Application of the mesopredator release concept as an explanation for changes in the composition of human-altered communities is gaining wide acceptance; although it has had limited critical evaluation (Litvaitis and Villafuerte 1996), but evidence appears to be mounting. The key assumption, which is difficult to demonstrate, is that the superpredator can in fact have an effect on mesopredator populations, either through direct predation or by exclusion via aggressive competition.

'Control of foxes could exacerbate predation of native species by feral cats.'

In Australia, the relationship between foxes and cats is of the most concern. For example, native prey re-introduced into fox-free areas have been killed by feral cats, which have increased in number in response to fox removal (Christensen and Burrows 1995). The relationship remains unclear: the effect of canids in decreasing, or occasionally increasing, feral cat populations is likely to be modified by the season and availability of food and habitat. The potential impact is usually greater in lean periods (Dickman (1996a). Dietary overlap between foxes and cats (as demonstrated by the following Australian studies) suggests that interspecific competition can occur between these two species. Of particular importance in this diet is the rabbit. Catling (1988) concluded that both predators successfully co-exist in semi-arid environments by primarily utilising different age groups of this dietary staple (foxes on adult rabbits and cats on rabbit young) and different supplementary prey. The presence of drought, resulting in a lack of rabbit breeding and hence poor availability of young, could swing this relationship in favour of foxes. Risbey et al. (1999) speculate that the control of foxes at their study site (Heirisson Prong, Western Australia) could relax any competitive and predatory pressures on cats and in turn could have a 'mesopredator-like' effect. This speculation was based on the assumption that foxes have a significant predatory effect on cats, and the assumption in turn was based on limited evidence of cat remains in fox dietary studies.

In a subsequent study, Risbey et al. (2000) compared spotlight counts of foxes and cats and small mammal surveys in areas where cat and fox populations were manipulated. Although the authors acknowledged that their study had a number of experimental design problems, they observed: increased spotlight counts of cats following fox control; increased small mammal abundance following control of both cats and foxes; and, decline in small mammal numbers where cats were the major predators. They concluded that their study supported concerns that unilateral fox control could exacerbate predation by cats.

Molsher (1999) studied the interactions of cats and foxes at Lake Burrendong in central New South Wales. Cats and foxes were found to have a large overlap in diet, home range and habitat use, indicating a high potential for competition should resources become limited. Interference competition was observed with foxes displaying aggressive behaviour towards cats, and cats tending to avoid conflict situations with foxes. After foxes were removed from the area, cats displayed a significant shift in resource use, but because cats did not increase in abundance within the period of the study, mesopredator release could only be inferred rather than statistically demonstrated.

Clearly there is a need for concern for at-risk or endangered native wildlife in circumstances where cats are present and foxes are controlled. This particularly applies where rabbits co-occur and where resources are limited in time by drought. Unequivocal demonstration of the concept of mesopredator release under these circumstances is going to require complex and costly experimental field studies in a range of environments. In the absence of these, inferential studies can continue to add to our understanding of the consequences of fox control programmes. The presence of native fauna and cats in Tasmania in the absence of foxes may also provide useful observations. Assuming that mesopredator release can occur, the development of techniques that simultaneously control foxes and cats would be the ideal solution.

Another example of mesopredator release has been reported between foxes and the native sand goanna (*Varanus gouldii*), in western New South Wales. Olsson et al. (2005) reported on the effects on the lizard community at Yathong Nature Reserve after five years of 1080 fox baiting. The population density of sand goannas in the baited areas was more than five times that at the unbaited control sites. The authors suggested that this could be due to the reduction of fox predation on goanna eggs and juveniles, or the release of the goannas from fox competitive pressures. Olsson et al. (2005) provided some evidence for their mesopredator release hypothesis, measuring a reduction in some of the goanna's prey species, most notably geckos, in the baited areas (high goanna density) compared with the unbaited areas and areas where both predators had been excluded for over 15 years. They also concluded that a better understanding of all species relationships is needed if the investments made in pest management are to be fully realised.

Conservation-based fox control programmes should consider concurrent feral cat control to avoid the possibility of 'mesopredator release'.

Source: Jeff Short, Wildlife Research and Management Pty Ltd

5.5 Targeted and biased lethal control measures

Fox control programmes do not intentionally target specific age classes, although this can inadvertently occur. Coman (1988) demonstrated this when comparing the age structures of groups of foxes collected by two different methods: spotlighting and battues. He concluded that this was not unexpected, as spotlighting is biased towards inexperienced, juvenile animals, which are more likely to be lured into the shooter's range. Battues, on the other hand, tend to drive all resident foxes, regardless of age, into the line of shooters. A greater propensity for naïve juvenile foxes to be collected in shot samples is also common in Europe (Englund 1980) and North America (Phillips et al. 1972). Other forms of human-related mortality can also be biased towards juveniles (e.g. road kills) (Phillips et al. 1972).

In central New South Wales, Kay et al. (2000) compared two large shot (n=353) and trapped (n=276) samples of foxes and found that proportionally more males were trapped (0.6) than shot (0.5), but they explained that this may have been a consequence of their experimental design rather than a true bias. They also recorded a higher proportion of juveniles/adults shot (0.53/0.47) compared with those trapped (0.26 juveniles/0.74 adults).

Marlow et al. (2000) compared three sampling techniques (cyanide baiting, trapping and shooting) in Western Australia and found no apparent age or sex bias with any of the techniques. Their study was specifically aimed at removing all foxes from within their study site, and an estimated 94% (n=204) of the population was sampled. This perhaps demonstrates that bias towards juveniles may occur early in the sampling period, but, as time passes, all of the population is eventually exposed to a control technique. In a review of population dynamics in furbearers (mostly North American) Clark and Fritzell (1992) also observed that, as harvest effort increases, age bias disappears.

The proportion of juveniles to adults within fox populations (providing they are adequately sampled) can be a reliable indicator of the intensity of control measures (Phillips 1970; Harris 1977) being close to unity where population control is light and as high as 5:1 where substantial control operations are undertaken. For example, the ratio of juveniles to adults in central New South Wales (1.27:1, n=520) suggested an ongoing 'average' level of control (by the definition of Harris 1977), as was expected from knowledge of the region where the samples were collected (Saunders et al. 2002).

In a study of fox populations using matrix analysis, McLeod and Saunders (2001) determined that the first and second age classes (i.e. foxes two years old and younger) made the greatest contribution to rate of increase. In the context of existing management strategies, these results indicate that the efficacy of lethal methods of control may be enhanced by targeting these age classes. This outcome can equally be applied to emerging non-lethal methods such as fertility control. Control of specific age classes would not necessarily reduce fox impact, and it would be difficult to achieve using conventional control programmes.

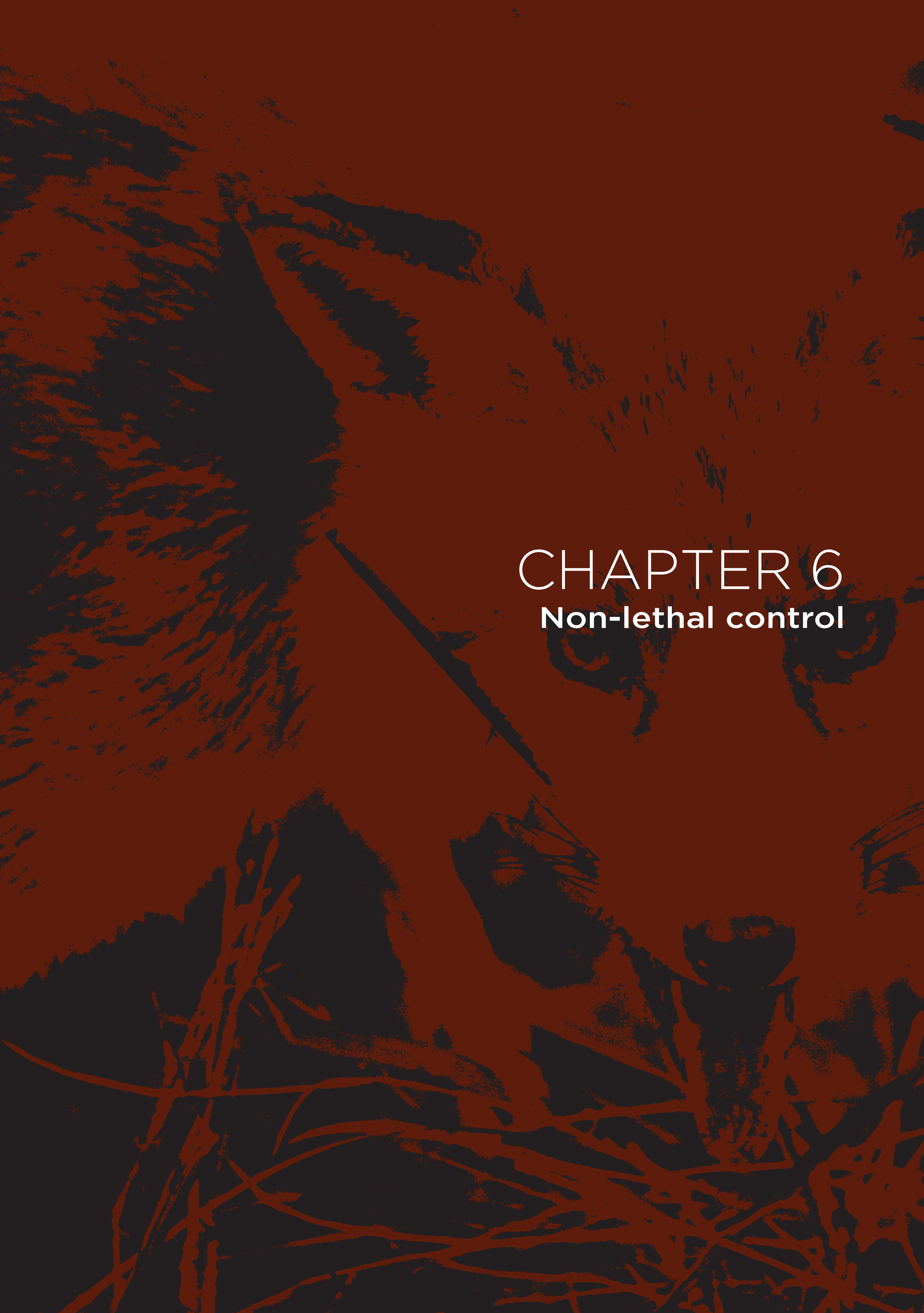
Although shooting may be biased towards juveniles (see Section 4.1), no current population control method specifically targets particular age classes. Only a few studies have examined age-specific bait consumption by foxes. Thomson et al. (2000) found that older foxes tend to be the last to eat baits during control programmes, perhaps because of their greater awareness (or suspicion) of novel foods. Allen (1982) concluded that, in a rural fox population in North Dakota, a higher proportion of young animals consumed baits than did older animals. Unfortunately it is not possible to distinguish between this conclusion and an alternative conclusion that the data simply reflect bait consumption by age groups in proportion to their abundance (McLeod and Saunders 2001).

In a study of urban foxes in England, Trewhella et al. (1991) found that adults tended to be more likely to consume baits than were juveniles, although baiting density was considered to be too low to draw any strong conclusions. It may be possible to enhance age-specific bait uptake by baiting at a time of year when selected age classes are most exposed; e.g. juveniles will be most active and abundant just before dispersal (see Section 2.3).

'Although shooting may be biased towards juveniles, no current population control method specifically targets particular age classes.'

Fertility control, by necessity, is a gender-specific fox management strategy. Recent work on immunocontraception, for example, targeted the female (see Chapter 7). Although the production of a gender-specific bait is unlikely to have any major impact on efficacy, production of a bait that is preferentially eaten by females may allow for decreased baiting density and hence improved cost-effectiveness. Production of a gender-specific and species-specific bait, perhaps based on a sex-related fox pheromone, would have even greater benefits but is probably beyond the realm of current technologies.

CHAPTER 6
Non-lethal control



6. Non-lethal control

Key issues

- *The fact that research into taste aversion with the aim of reducing predatory impact on livestock has been done for nearly 30 years with still no universally accepted technique or chemical demonstrates that there is a considerable gap between theoretical and field application.*
- *Taste aversion is more likely to have application in changing behaviour towards baits, sources of food, and possibly the eggs of endangered bird and reptile species. These aspects warrant further investigation.*
- *There has been no research on the efficacy of frightening devices or similar practices for reducing the impact of foxes. Given the likely outcomes and limited application of these devices, their development should be given low priority.*
- *Evidence of the effectiveness of guard animals for protecting livestock under Australian conditions remains equivocal. Overseas research suggests that they may have potential in certain circumstances (e.g. raising of intensive livestock and stud animals). The economics and logistics of using guard animals under Australian conditions need to be reviewed before their use or further research can be recommended.*
- *Manipulation of food supply to foxes has been suggested as a means of reducing fox impact. This includes the removal of additional sources of food (e.g. rabbits and carrion) or the provision of diversionary sources of food at times of peak predation. These practices remain untested and are most likely to be logistically impractical.*
- *More case studies of effective habitat manipulation to enhance the survival of threatened species and of habitat modifications that have the opposite effect are needed before making dramatic changes to existing land management practices. Concentration on directly reducing the predatory effect of foxes, as championed by Kinnear and others, remains the preferred option.*
- *Modified farm management practices aimed at reducing fox impact generally require additional resources and effort and frequently only delay the onset of predation or have undesirable side effects. Verification of the costs and benefits of suggested changes to management practices will facilitate greater adoption of this approach for reducing fox impact.*
- *Most, if not all, of the techniques in this Section have to be viewed at this stage as impractical for any regional application in the Australian environment. Their use would be limited to small-scale operations where the protection of highly valued wildlife or domestic flocks was the imperative. However, they should not be discounted and verification of the costs and benefits of suggested changes to management practices will facilitate greater adoption of this approach for reducing fox impact.*

6.1 Aversion conditioning

In pest control, the most important aspect of food selection is the ability of animals to learn to reject food that may be toxic; this ability is known as bait or poison shyness (Barnett 1988). Although this can be a serious problem encountered in many pest control programmes, it is a behaviour that can also be turned to advantage. Aversion conditioning is a process by which a negative stimulus encourages an animal to discontinue a particular behaviour. Animals can be trained to avoid eating specific foods by being offered the food as well as an emetic (a substance that induces vomiting). The animal associates the taste of the food with the induced illness and subsequently avoids eating the food.

Conditioned food (or taste) aversion (CTA) has been studied most extensively in rodents (Gustavson et al. 1974). It has been used successfully to train livestock to avoid toxic plants (Ralphs 1992) and to treat various illnesses in humans (Bernstein 1999). It has also been extensively promoted as a means of protecting livestock from predators, although exactly how food manipulation could be used to minimise fox predation remains unclear and untested.

Cowan et al. (2000) state that the CTA chemicals needed to modify predatory behaviour must have the following characteristics:

- the chemical must induce a long-lasting CTA after an oral dose;
- the effective dose should be well below the LD_{50} dose for target and potential non-target species;
- the taste of the effective dose must be undetectable when mixed with the bait; the taste can be masked by formulation (e.g. microencapsulation);
- the chemical must remain stable in baits; and
- the onset of illness should be slow enough to allow bait consumption, but not greater than about 12 hours.

Taste aversion to prevent coyote predation, primarily by using lithium chloride (LiCl) in baits, carcasses and livestock protection collars and on live sheep, has been the subject of much research and controversy in the United States (e.g. Gustavson et al. 1974; Conover et al. 1977; Griffiths et al. 1978; Olsen and Lehner 1978; Burns 1980; Burns and Connolly 1980; Bourne and Dorrance 1982; Gustavson et al. 1982; Burns 1983a, b; Burns et al. 1984; Conover and Kessler 1994; Burns and Mason 1996). Early studies, although reporting success with LiCl-conditioned prey-killing aversions, were plagued by poor experimental design (Griffiths et al. 1978; Burns 1983a). Later work found that LiCl bait aversion could be conditioned, but this fact did not measurably reduce coyote predation on live prey (Burns 1980; Burns and Connolly 1980; Bourne and Dorrance 1982; Burns 1983a, b). In a pilot study in Norway (Hansen et al. 1997), sheep baits treated with LiCl also failed to prevent dogs from attacking sheep.

Coyotes are primarily visual predators (Olsen and Lehner 1978; Wells and Lehner 1978); therefore, use of taste and odour cues on baits is thought not to influence prey killing (Burns 1980; Burns and Connolly 1980; Bourne and Dorrance 1982; Burns 1983 a and b; Conover and Kessler 1994). Thus, for coyotes to develop prey aversion, Burns (1983b) hypothesised that the negative stimulus would need to be delivered during the killing process. Hunting dogs are often trained with an electric collar to give them conditioned aversions to sheep (Hansen et al. 1997). Linhart et al. (1976) conditioned three of four captive coyotes to avoid a particular type of prey for up to nine months by using an electronic collar, which was made to deliver a brief severe shock when the animal initially attacked the prey. Andelt et al. (1999a) also tested electronic dog-training collars on captive coyotes and found that they were effective in altering coyote behaviour for periods averaging four months or longer, but the practical application of this method is limited in the field.

Gustavson et al. (1983) conducted experiments on captive dingoes to evaluate the effectiveness of an alternative aversion-producing agent, the anthelmintic thiabendazole. They reported that thiabendazole-treated meat produced a conditioned taste aversion in dingoes, but further field investigations were not conducted. Rathore (1984) evaluated LiCl taste aversion in penned domestic dogs as a preliminary step in evaluating taste aversion to reduce dingo predation, but he found that the induced aversion lasted less than 24 hours. Other chemicals used to induce taste aversion are carbachol and oral oestrogen (Baker and Macdonald 1999).

Even though taste aversion might not prevent predation, it is still useful in situations where feeding is undesired. Cornell and Cornely (1979) reported on a trial using LiCl baits to discourage coyotes from feeding on handouts and rubbish at campsites in the United States. Ternent and

Garshelis (1999) used thiabendazole to deter black bears from feeding on pre-packed food in a military camp. Similar methods are also suggested for discouraging dingoes from campsites on Fraser Island (Anon 1999b). Predation on eggs can have damaging effects on bird populations. Hoover and Conover (2000) preconditioned coyotes with eggs containing an irritating volatile chemical (pulegone). They then simulated a nesting colony and offered treated and untreated eggs; the coyotes preferred to eat the latter. These authors suggest that it may be possible to deflect predation away from nests by exposing predators to injected eggs before the nesting season and then spraying the areas around the nests for subsequent protection.

'Even though taste aversion might not prevent predation, it is still useful in situations where feeding is undesired.'

Baker and Macdonald (1999) suggest that finding a safe, undetectable and sufficiently fast-acting emetic for foxes is likely to be a problem, and that a better goal may be to explore the use of a bitter taste in place of an emetic. Primary aversion to compounds that taste bitter is thought to result from natural selection for avoidance of toxic alkaloids and glycosides (Garcia and Hankins 1977). Macdonald and Baker (2004) conditioned captive foxes to avoid drinking milk containing Bitrex® (a bitter compound detectable only by taste). Similarly, Massei et al. (2003) found that levamisole hydrochloride (a broad-spectrum anthelmintic used in veterinary medicine) induced strong, long-lasting conditioned taste aversion in captive foxes.

When Gentle et al. (2004) tested levamisole on free-ranging foxes they could not replicate this induction of CTA to meat baits; instead, they achieved a learned aversion to the levamisole hydrochloride itself. This work needs further evaluation to determine whether CTA can be induced in free-living fox populations and to determine whether aversions can be transferred from dead to live prey.

Reynolds (1999), in reviewing the applicability of exploiting taste aversion in wildlife management, concluded that development of the technique will require both an adequate margin between the aversive and acutely toxic doses of the selected chemical and consideration of human safety, environmental contamination, and side effects on target and non-target wildlife. The fact that research into taste aversion with the aim of reducing predatory impact has been done for nearly 30 years with still no universally accepted technique or chemical demonstrates that there is a considerable gap between theoretical and field application.

6.2 Frightening devices

Various frightening devices, primarily visual and acoustic, have been used to prevent or alleviate damage by mammalian predators. There have been few in-depth studies to evaluate the effectiveness of these devices, which are generally thought to provide only short-term protection (Bomford and O'Brien 1990; Koehler et al. 1990; Mason 1998). Pfeifer and Goos (1982) inferred that gas exploders prevented coyote predation on lambs for an average of 31 days. Data from Linhart (1984) and Linhart et al. (1984) indicate that a frightening device, which emitted sound and light, was able to reduce sheep losses to coyotes at particular sites.

Devices used against foxes and coyotes in the United States include gas exploders, rope firecrackers, floodlights, strobe lights, flares, recordings of human voices and dogs barking, and blaring music (Pfeifer and Goos 1982; Linhart 1984; Linhart et al. 1984; Koehler et al. 1990). Ultrasonic devices in collars placed on sheep have also been used to deter coyote predation, but their effectiveness is questionable (Koehler et al. 1990).

The use of frightening devices to deter foxes is not common practice in Australia. There are incidences where lights have been used in lambing paddocks and to protect domestic birds. Also, the practice of hanging dead foxes on fences to ward off other foxes was popular for a time. There has been no research on the

The use of guard animals to protect against sheep predation requires further evaluation in Australia.

Source: David Jenkins, Australian Hydatid Control and Epidemiology Program.

efficacy of these or any other frightening devices or practices for reducing the impact of foxes or their effect on non-target species.

6.3 Guard animals

Guard dogs have been used to protect domestic stock from wild predators in Europe since ancient Roman times, but evidence for their effectiveness has relied mainly on testimonials (Saunders et al. 1995). There are several breeds of guard dog, but they all possess the similar characteristics of a large size, suppressed predatory behaviour, an almost placid nature, and the ability to form strong social bonds with stock (Parker 1978; Miller 1991; Coppinger and Coppinger 1993).

Livestock producers in the United States began using guard dogs to protect sheep and goats from predators, mainly coyotes, in the mid 1970s. The extent of use has steadily grown in that time. In Colorado, for example, the proportion of sheep protected by dogs has increased from about 7% in 1986 to 68% in 1993 (Andelt and Hooper 2000). Their effectiveness has been evaluated under a variety of conditions and using a variety of methods (Green et al. 1994; Andelt 1999). These evaluations usually compared losses before and after producers obtained guard dogs, but some earlier field studies were attempted under controlled conditions (Linhart et al. 1979; McGrew and Blakesley 1982; Hulet et al. 1987), and Coppinger et al. (1988) conducted a long-term field assessment. All of these studies reported similar findings that guard dogs, if they had the basic breed characteristics and were trained properly, were able to reduce predation. Although guard dogs are considered to be economical, their use is viewed as a complement to, rather than a substitute for, other control methods (Pfeifer and Goos 1982; Coppinger et al. 1988; Green and Woodruff 1988, 1990; Andelt 1992; Green et al.1994).

Although dogs are the main species used to guard livestock, other species such as cattle (*Bos taurus*), donkeys (*Equus assinus*), llamas (*Lama glama*) and alpacas (*Lama pacos*) are also used to protect livestock from predation (Green 1989; Hulet 1989; Walton and Field 1989; Franklin 1993; Iowa State University 1994; Bergman et al. 1998; Meadows and Knowlton 2000; Jenkins 2003). The advantage of these types of animals over dogs is that, like sheep, they are herbivores, so they do not have to be fed separately, and they do not cross fence-lines and wander. There is a lack of scientific evaluation (particularly field studies) of the effectiveness of these alternative guard species. Iowa State University (1994) conducted an extensive survey of sheep ranchers using guard llamas across the USA and reported an average annual loss of 11% to predation before the introduction of guard llamas, compared with a 1% average annual loss afterwards.

With the reintroduction and restoration of predators in many areas of Europe, livestock-guarding animals have been a popular introduction to appease opposing local farmers and herders (Hansen and Bakken 1999; Hansen and Smith 1999; Weber 2000; Stahl and Vandel 2001; Cugno 2002; Hansen et al. 2002). Trials that have been published have had mixed success, with reasons for failure including too large a range area, scattered sheep grazing patterns, and poor guard dog qualities (Hansen et al. 2002).

'There is interest in the use of guard animals such as dogs or alpacas to prevent fox predation.'

In Australia, three breeds of guard dog (Maremma, Anatolian Shepherd and Great Pyrenees), alpacas, llamas and donkeys are used to protect sheep and goats from fox predation. Evidence of their effectiveness consists mainly of testimonial accounts (Saunders et al. 1995; Jenkins 2003), with little empirical data to verify these claims. Only one Australian study that experimentally tested the value of alpacas in preventing lamb predation has been reported in the literature. Despite limitations with their experimental design, Mahoney and Charry (2004) concluded that the presence of alpacas resulted in a significant increase in lamb survival. Jenkins (2003) conducted a small phone survey of 85 producers in the Australian Capital Territory and Yass RLPB in New South Wales and found 8% in the ACT and 3% in the Yass RLPB already used livestock-guarding animals. There was a high level of interest, and about 50% of producers were willing to consider using guarding animals if they could be shown to be effective.

Many issues need to be resolved before the use of guard animals can be considered a viable technique that can be recommended to the agricultural community, including: evidence of efficacy under Australian conditions; availability of guard animals and training; industry perceptions of the technique as anything other than a novel measure of use in limited situations; security against theft; and, the cost to the producer of using guard animals as opposed to the economic impact of predators.

6.4 Exclusion fencing

Barrier or exclusion fencing is a non-lethal method commonly used to control canid predation on domestic livestock and threatened wildlife species. Modern use of exclusion fencing began in Australia in the early 1900s with the construction of the 'dingo fence' in South Australia and New South Wales to protect the emerging sheep industry in the south and east from the increasing dingo threat from the north (McKnight 1969; Breckwoldt 1988). Exclusion fencing for foxes has been a more recent development, mainly in response to the need to protect threatened wildlife species and the availability and relatively low cost of electric fencing materials.

In Australia, fox exclusion fences have generally been developed by trial and error in the field, rather than from rigorously controlled experiments and research (Coman and McCutchan 1994). A range of fence designs have been developed to exclude foxes, but there is little published information on their effectiveness, only anecdotal and correlative evidence (Lund et al. 1987; Coman and McCutchan 1994; McGeoch 1995; Saunders et al. 1995; Long and Robley 2004). In Australia no fence designed for agricultural purposes has been tested, and the only fence designed for conservation purposes that is known to have been experimentally tested is the Arid Recovery Project fence in South Australia (Moseby and Read 2006). These authors found that a 180-centimetre high wire netting fence with foot apron and a 60-centimetre wide external netting overhang, curved in an arc and supported by lengths of heavy gauge wire was the most effective barrier against foxes. Posts, and particularly corners, were targeted by foxes so the fence efficacy was

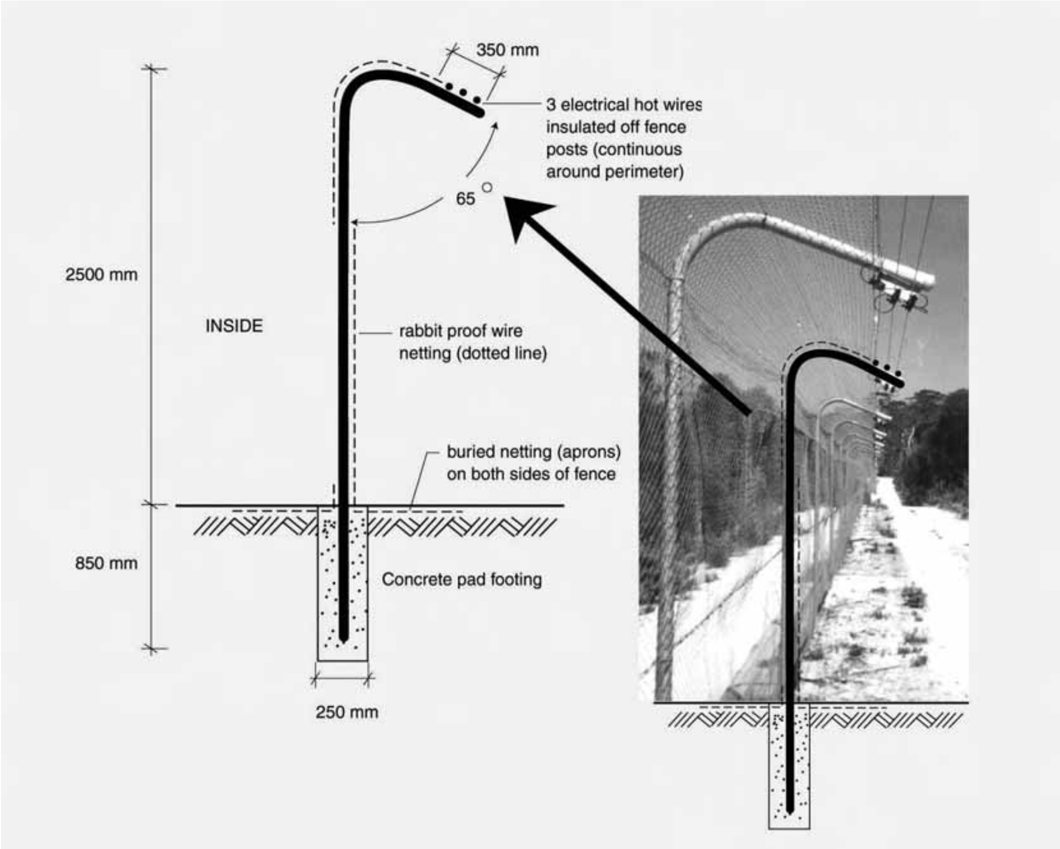


Figure 6.1 *Fox exclusion fence developed by the Western Australian Department of Environment and Conservation in the Narrogin District.*
Source: Brian MacMahon, WA DEC

improved with the use of steel posts rather than timber ones. Electric wires by themselves were ineffective, and needed an effective physical barrier present as well so that the animals could receive a severe enough shock to be repelled.

'Exclusion fences are important tools in the management and protection of threatened wildlife and other valuable animals.'

Most of the published literature on fox exclusion fences relates to the protection of nesting waterbirds in the Northern Hemisphere (e.g. Forster 1975; Patterson 1977 in Scotland; Lokemoen et al. 1982 in the United States; Poole and McKillop 2002 in Britain). Poole and McKillop (2002) tested two fence designs, one non-electrified and the other electrified. These designs consisted of:

a) a strained wire fence consisting of eight parallel strands of alternating electrified and earthed wires at heights of 5, 15, 25, 35, 45, 60, 80 and 105 centimetres above the ground; and

b) a netting fence 105 centimetres above the ground, with mesh size ranging from 8×6 centimetres at the bottom to 8×12 centimetres at the top.

The bottom strand contained three electrified wires. These were tested on a captive colony of eight foxes. Both designs were breached when not electrified, but no fox managed to cross either design when electrified. These trials had obvious limitations, such as the duration of exposure to the designs and the use of captive foxes.

In a review of the effectiveness of fox exclusion fences, Coman and McCutchan (1994) found that most fence designs provided a barrier to fox movement, but that this barrier was not absolute. Exclusion fencing needed to be combined with a monitoring system and a management plan within the enclosure to rapidly detect and control breaches. The control of foxes in a buffer zone outside the enclosure would also ensure maximum efficiency. One of the problems with exclusion fences, indicating the need for regular maintenance, is the potential for surplus killing by foxes if the fence is breached. Such events can be catastrophic where endangered species are being protected from fox predation (e.g. Short et al. 2002). Fence costs vary enormously, depending on the type and the ongoing maintenance programme. Coman and McCutchan (1994) concluded that exclusion fencing was an important tool in the management and protection of threatened wildlife species and other valuable animals.

Long and Robley (2004) comprehensively reviewed a range of exclusion fences that have been built in many different environments across Australia. Despite the limited experimental testing of exclusion fences in Australia they provide recommendations for the minimum design specifications required for foxes based on the measured effectiveness of those designs that have been tested, observational evidence from field personnel on fences in situ, and knowledge of relevant physical capabilities and behavioural responses of foxes. However they point out that it was not always possible to identify if a fence design is going to be adequate or over-engineered in any given environment. Features of the local environment such as topography, substrate, vegetation density, climatic conditions and geographical location may place constraints on the fence design, along with other considerations such as other species to be excluded, non-target animals present, as well as available funding and resources for ongoing monitoring and maintenance. They concluded that more research is required to fill the knowledge gaps to allow optimal, cost-effective fence designs to be determined.

An example of a fox exclusion fence is that developed by the Western Australian Department of Environment and Conservation (DEC) in the Narrogin District (see Figure 6.1), around their small mammal breeding enclosure. DEC has found this design to be effective, especially since the fence is self-straining at the corners, overcoming some of the problems with maintaining the strain on the wires (B. Macmahon, DEC-WA, pers. comm. 2002). The cost of the fence in 1998 was approximately $40,000 per kilometre. Moseby and Read (2006) estimated the material cost of their fence design to range between $8,814 and $12,432 per kilometre. With such high costs, the design of exclusion fencing used for conservation purposes is non-profitable for private landholders over large areas in the agriculture sector, and is mainly restricted to small paddocks and poultry enclosures.

6.5 Manipulating food supply

The influence of alternative food sources on fox-baiting programmes has been considered previously (see Section 2.3). Manipulation of foxes' food supply has been suggested as a way of managing the impact of foxes on prey species (Catling 1987). This idea may be based on observations of the reliance of foxes in Australia on rabbits as key prey items (Croft and Hone 1978). Fox predation has been shown to suppress rabbit populations, as demonstrated in predator removal experiments (Newsome et al. 1989; Banks et al. 1998). Conversely, when rabbit populations have crashed after myxomatosis outbreaks, fox populations have also declined after lag periods (Myers and Parker 1975; Newsome at al. 1989). It was also feared that, as a consequence of RHD on rabbit populations in Australia, foxes would prey more heavily on alternative and more valued prey species, although evidence of this prey switching has not yet been demonstrated (Newsome et al. 1997; Edwards et al. 2002; Saunders et al. 2004).

Catling (1987) proposed that removing rabbits as potential food items and, in parallel, removing sources of carrion (e.g. kangaroos) would cause a decline in fox populations and hence their impact. Wildlife regulatory authorities, with the support of some evidence from a South Australian study by Read and Wilson (2004), have claimed repeatedly that the practice of leaving remains (or, in the case of skin shooters, whole carcasses) in areas helps to maintain fox populations and results in greater predation pressure on native wildlife. This assumption (particularly in the absence of rabbit control) remains to be proven and is probably biologically naive.

In theory, giving foxes additional food sources at times of peak predation pressure (e.g. lambing) may also result in reduced impact. This would particularly apply if the peak in predation pressure coincided with the critical energetic demands of foxes, as can happen in spring, when fox cubbing overlaps with lamb production. Baker and Macdonald (1999) refer to this as 'diversionary feeding' and cite examples of where providing additional food can also lead to improved reproductive success and cub survival (and hence longer-term impacts). Newsome (1987) suggests that food manipulation should be used only as part of integrated fox management, and that it needs to be combined with other land management practices and effective fox control. Exactly how food manipulation could be implemented in this scenario to maximise the likely benefits remains unclear and untested.

6.6 Manipulating habitat

Caughley and Sinclair (1994) describe habitat manipulation as the most elegant of wildlife management techniques, because it does not work against negative feedback loops, e.g. density-dependent responses to population reductions. Habitat manipulation can be employed to reduce the habitat quality for a particular pest, and this can, in turn, reduce the population density of that pest or divert the pest away from the commodity being protected. This approach will work only for species whose limiting habitat resources have been identified and can be modified economically (van Vuren 1998).

Successful examples of manipulating habitats to reduce predator impact are rare, although Sinclair et al. (1998) state that the effects of predation can be counteracted by improving the survival of endangered prey through habitat manipulation. Conversely, in Australia, there is growing evidence of how minor habitat modifications or fragmentation can increase the impact of fox predation. Habitat modification alters habitats to attract or repel certain wildlife species or to separate prey from predator (Bergman et al. 1998). Kinnear et al. (1988) concluded that fauna subject to fox predation can survive only at sites that act as refuges from predators. Removal of predators allows the prey to utilise less protected sites. The results from some areas involved in the 'Western Shield' project in Western Australia support this conclusion (e.g. Haywood et al. 2005b), as does a study of brush-tail possums in south-eastern Australia woodlands (Pickett et al. 2005).

Disturbance to forests by logging and by clearing for agriculture has been found to influence fox movements within their range (Catling and Burt 1995). It has been suggested that foxes do not live entirely within closed canopy forests but can penetrate some distance into them in search of food through the use of roads and tracks (Jarman 1986; Mansergh and Marks 1993). May and Norton (1996) recommend that an important research need was to establish the relative impact that exotic predators may have under varying degrees of road construction in native forests. Meek and Saunders (2000) found that foxes consistently use roads and tracks for access but also found foxes living within dense forest and heath. Although foxes may use roads to optimise their foraging efficiency (e.g. by scavenging on road kills), these authors questioned the conclusion that foxes will use forested habitats only if assisted by man-made roads and tracks. Increasing the structural complexity of habitats that support predator-threatened fauna may provide protection for these species, but at the same time it may also enhance the survival of other pest species (Pech and Arthur 2001).

More case studies of effective habitat manipulations that enhance the survival of threatened species and of habitat modifications that have the opposite effect are needed before making dramatic changes to existing land management practices. Concentration on directly reducing the predatory effect of foxes, as championed by Kinnear et al. (2002), remains the preferred option.

6.7 Modified farm management practices

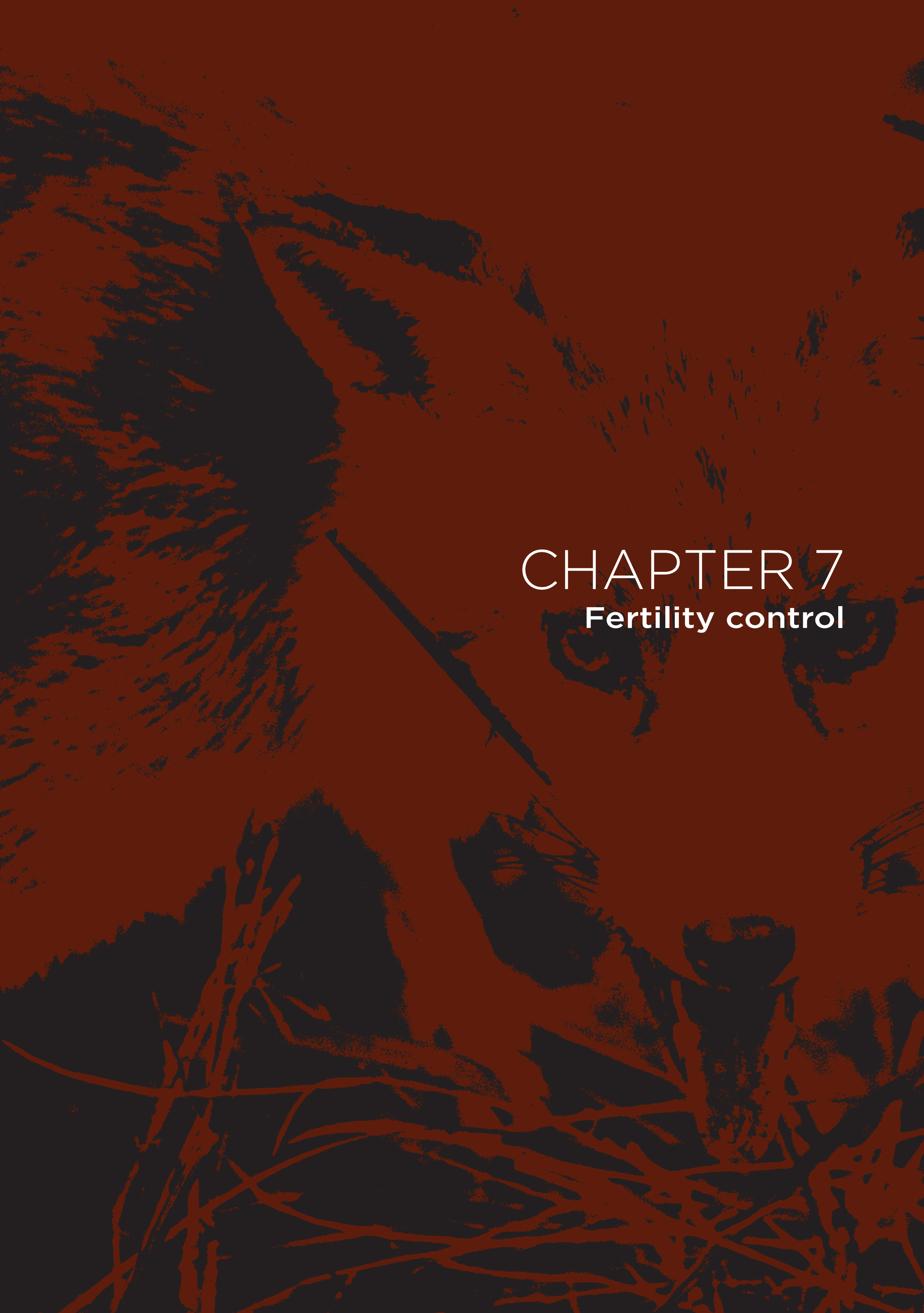
Alternative farm management practices may reduce fox predation (Newsome 1987; Hulet 1989; Bergman et al. 1998; Connolly and Wagner 1998; Moberly et al. 2004b). These practices include:

- modify the level of care or attention given to livestock (e.g. shed lambing);
- improve ewe/doe nutrition and select for more protective mothers;
- change the timing or duration of the lambing/kidding period;
- synchronise lambing;
- select paddocks to maximise protection from predators;
- use exclusion fencing;
- carrion removal to reduce learned behaviour of foxes;
- remove alternative foods (e.g. rabbits) to reduce long-term fox populations; and/or
- change habitats to deter foxes.

Saunders et al. (1995) suggested that if the duration of lambing/kidding can be restricted then the exposure of susceptible animals would be limited, and overall predation reduced. The maximum effect of this strategy could be achieved if lambing were synchronised with that on neighbouring properties. The timing of lambing/kidding may be critical to fox predation. Because foxes breed only once a year, population densities show a seasonal trend, with numbers lowest in late winter/early spring, after the completion of dispersal and before breeding (Newsome 1987; Saunders et al. 1995; Thomson et al. 2000). Newsome (1987) suggests that lambing/kidding at this time, when fox densities are lowest, could reduce the likelihood of fox predation. No relationship has been established between fox densities and levels of predation on livestock (see Section 13.1). Individual predatory behaviour can vary dramatically (Linnell et al. 1999), and so-called 'rogue' foxes can cause serious localised losses (Turner 1965; Moore et al. 1966; Rowley 1970; Glatz et al. 2005).

'Timing lambing to occur in winter or early spring, after foxes have finished dispersing but before they breed, could reduce the likelihood of fox predation.'

Modified farm management practices aimed at reducing fox impact generally require additional resources and effort and frequently only delay the onset of predation or have undesirable side effects (Knowlton et al. 1999). For example, changing the time of the year in which lambing takes place (a time probably used over many farming generations) to coincide with low fox numbers (perhaps as opposed to the highest market prices) may be unrealistic, given the absence of demonstrated improved profit levels. Further, if such a density/damage relationship existed, would it have a greater impact on livestock reproduction than other seasonal effects such as pasture, nutritional, market or climatic conditions? Despite all of these reservations, farmers do adopt land management practices to reduce predator impact. Connolly and Wagner (1998), in a survey of over 8000 sheep producers in the USA, found that 25% adopted such practices, although the types of predators and their known impacts differ greatly from those in Australia.



CHAPTER 7
Fertility control

7. Fertility control

Key issues

- *Results of population modelling show that fertility control in foxes has limited potential to lower population densities over the long term.*
- *Various recommendations have been made for the best use of fertility control. These include: strategic timing of fertility control after population density has been first reduced by lethal control; targeting of bait-shy and genetically resistant animals that survive poisoning campaigns; and control in urban areas where conventional methods cannot be used for social, ethical or legislative reasons.*
- *Fertility control should not change fox social behaviour or cause excessive compensatory changes in other population parameters such as mortality, immigration and dispersal. Research results to date suggest that such compensatory responses are minimal.*
- *Preliminary research on the use of cabergoline as a chemical fertility control agent is equivocal. If proven, the technique may be appropriate where active dens can be targeted (e.g. in urban environments), but the suitability of cabergoline in rural settings remains to be seen. Any economic assessment would need to take into account the likely maximum effect of this chemical in the early stages of gestation and the spread of births that can occur in fox populations from early August to late September in south-eastern Australia. The technique also raises some ethical concerns.*
- *Recent research into the use of immunocontraception for foxes involved a bait-delivered, immunocontraceptive vaccine containing ZP (zona pellucida) antigens. Recombinant canine herpesvirus have been identified as a likely vector for delivering this oral vaccine antigen.*
- *Acceptance of immunocontraception (and its associated use of genetically modified organisms) by the public at large, as well as by national and international regulators, cannot be a foregone conclusion.*
- *Given the large investment of research funds into the development of immunocontraceptive vaccines for foxes over the last decade, priority should be given to assessing the comparative benefits of an orally delivered immunocontraceptive for foxes versus orally delivered toxins.*
- *Proof of the concept of fox immunocontraception in the laboratory should not be seen as confirmation of efficacy in the field; there are many other issues surrounding the practicalities of implementation and the likely effects at a population level, and these issues need to be considered first.*

Fertility control is often advocated as a preferable form of pest animal management. Preventing births is perceived as a more humane and practical alternative than using lethal control measures to reduce pest population numbers (Balser 1964; Fitzgerald et al. 1996; Oogjes 1997). An ideal wildlife fertility control agent would generally need to be highly effective and environmentally safe (Tuyttens and Macdonald 1998). Other attributes that should also be considered include species specificity (or low risk to non-targets), low cost of production, ease of delivery (for wildlife this would involve acceptance in a bait without nausea or aversion), flexibility in the timing of administration, long duration of action, reversibility in the long-term, and low rate of impairment of sexual behaviour and social structure (Balser 1964; Allen 1982; Kirkpatrick and Turner 1985; Bomford 1990; Kirkpatrick and Turner 1991; Bradley 1994; Tyndale-Biscoe 1994; Robinson and Holland 1995; Bradley et al. 1998; Tuyttens and Macdonald 1998). Although no effective fertility control agents are currently available for broadscale use against foxes in Australia (or for any carnivore throughout the world), considerable research effort has recently been dedicated to their development.

7.1 Mechanisms of fertility control

Both natural and synthetic oestrogens have been used in attempts to control populations of many pest species (Bomford 1990). One major disadvantage with this group of chemicals is its low margin of safety: large doses of oestrogen are known to cause serious adverse effects (Balser 1964; Tuyttens and Macdonald 1998). Diethylstilbestrol (DES) is a synthetic oestrogen that has been found to disrupt pregnancy in a range of species (Balser 1964). It is inexpensive, fat soluble, stable under high temperatures, and orally active (Linhart and Enders 1964). Linhart and Enders (1964) found that DES inhibited reproduction in captive red foxes, but it had to be administered in about a three week period around mating (from nine days before mating to ten days after mating) to be effective. This substance has also been tested on field populations of red and grey foxes (Oleyar and McGinnes 1974; Allen 1982), with limited success. In the study of Oleyar and McGinnes (1974), no female red foxes and only a small number of grey foxes that had taken baits were recovered. Even though reproduction in grey foxes from the treated area appeared subnormal, critical evaluation of the data was not possible owing to the small sample size and imprecise age classifications. Allen (1982) found that field use of baits containing DES indicated limited changes in reproductive performance in a population of red foxes. Even though this study indicated good bait acceptance, it was possible that the DES-containing pellet used in the experiment may have been able to pass undigested through the digestive tract of the fox.

A synthetic oestrogen related to DES, mestranol (MES) has also been tested on foxes (described in Kirkpatrick and Turner 1991). Although MES was an effective reproductive inhibitor, bait acceptance was a problem after prolonged administration. This poor bait acceptance is not just limited to foxes and occurs in other species, decreasing the usefulness of MES as a fertility control substance (Marsh and Howard 1969; Bomford 1990).

Synthetic progestins are steroids that prevent ovulation in females and inhibit testicular activity in males (Bomford 1990), and have been used to prevent pregnancy in dogs (Tuyttens and Macdonald 1998). The synthetic progestin medroxyprogesterone acetate (MPA, Provera®) significantly reduced the number of litters produced by captive red foxes (Storm and Sanderson 1969), but the precise stage in the reproductive cycle that was affected was not determined. The synthetic progestin chlormadinone acetate (CPA), administered orally every 4, 7 or 10 days prevented oestrus in most vixens (described in Kirkpatrick and Turner 1991). To be effective, progestins require frequent oral dosing, making them impractical for wildlife control (Balser 1964, Bomford 1990).

'Both natural and synthetic oestrogens have been used in attempts to control populations of many pest species.'

Secretion of progesterone from the ovaries is crucial throughout gestation in dogs (Concannon et al. 1977). Progesterone antagonists interfere with progesterone function by binding to progesterone receptors (Tuyttens and Macdonald 1998). The progesterone antagonist mifepristone (RU486) is effective in producing abortion in dogs (Concannon et al. 1990; Linde-Forseberg et al. 1992) but has not been tested on foxes. Precise timing of delivery of RU486 is not critical, and it prevents implantation as well as early and late pregnancies. Tuyttens and Macdonald (1998) suggest that once-yearly administration of this substance during the gestation period could render seasonal breeders such as foxes infertile for a whole year, but no supporting studies have been done.

7.2 Ecological principles of fertility control

Although a range of techniques and substances are known to reduce the fertility of foxes, this reduction will not necessarily lead to a decline in population density or impact. To determine what effect fertility control will have on a population, first there must be an understanding of the dynamics of that population. Particularly important in this process are demographic parameters such as: population size; the rate of increase or decrease; the rate of production of young; the mortality rate; the rate of dispersal; and, the rate of immigration (Caughley 1977; Stenseth 1981). Conventional control methods artificially increase the rate of mortality, whereas fertility control aims to reduce the birth rate.

As with lethal or culling programmes, compensatory effects may occur after the use of fertility control. Suggested compensatory changes include: increased birth rates in remaining fertile individuals (suggested by preliminary analysis in Marlow et al. 1998); decreased juvenile mortality (or increased juvenile recruitment); decreased adult mortality; reduced dispersal rates; and/or, increased immigration rates (Stenseth 1981; Johnson and Tait 1983; Hone 1992; Newsome 1995; Saunders and Choquenot 1995; Barlow et al. 1997). All these factors would be viable compensatory options for the fox.

Models are useful tools in understanding population dynamics. There have been many attempts to theoretically test the effects of fertility control (e.g. Stenseth 1981; Bomford 1990; Caughley et al. 1992; Hone 1992; Saunders and Choquenot 1995; Barlow et al. 1997; Pech et al. 1997; Dolbeer 1998; Courchamp and Cornell 2000). Two major problems have been encountered: first, data on population parameter values are often inadequate, especially in the case of foxes in Australia (e.g. Saunders and Choquenot 1995; Pech et al. 1997); second, it has been difficult to account for all variables influencing a population (Dolbeer 1998), in particular the relationship between demographic parameters and available resources (Pech et al. 1997). Only a small number of models consider any compensatory effects (e.g. Caughley et al. 1992; Saunders and Choquenot 1995; Barlow et al. 1997).

'Population modelling studies show that fertility control has the potential to lower fox population densities over the long term.'

The results of population modelling indicate that fertility control in foxes has the potential to lower population densities over the long term. There are, however, many cautions. Fertility control should not change the social behaviour or cause excessive compensatory changes in other population parameters such as rates of mortality, immigration and dispersal (Stenseth 1981; Bomford 1990; Hone 1992). Sterility rates must be sufficiently high to reduce juvenile recruitment to the adult population (Bomford 1990; Pech et al. 1997). The initial fecundity rate is an important influence on the outcome of fertility control programmes (Stenseth 1981; Hone 1992).

Hone (1992) reported that the best strategic timing of fertility control was after the population density had been first reduced by lethal control. Thus fertility control could be used in conjunction with other control methods to prevent rapid recovery of the controlled populations (Bomford 1990). Fertility control has also been suggested to target bait-shy and genetically resistant animals that survive poisoning campaigns (Garrott 1995). Fertility control may also be useful for control in urban areas where conventional methods cannot be used for safety, social, ethical or legislative reasons (Warren 1995; Marks and Bloomfield 1999b).

Sensitivity analysis of life table vital rates is a useful method of identifying age classes that have the greatest influence on rate of increase (Caswell 1989). McLeod and Saunders (2001) used this approach to suggest ways of improving fox management strategies in Australia. Their results suggest that, under some circumstances, fertility control has the potential to have as great an effect on population growth rate as conventional methods of control that target survivorship, i.e. poisoning. However, subsequent and more detailed modelling of the age and sex structure of fox populations has suggested that immunocontraception delivered via bait is unlikely to provide a useful alternative to existing control programmes that rely on poison baits (McLeod et al. 2004).

The social structure and mating system of the population would influence the effects of fertility control (Bomford 1990; Caughley et al. 1992; Newsome 1995). The fox is known to have a highly variable and flexible social structure in other parts of the world (Harris 1977; Macdonald 1979; Schantz 1984; Voigt and Macdonald 1984; Mulder 1985; Lindström 1988). How foxes function socially in Australia's varied environments is relatively unknown (Newsome 1995). Most studies in Australia, covering a wide cross-section of habitat types, have reported (often circumstantially) that the monogamous pair with young of the year is the basic social group (Burchfield 1979; Coman et al. 1991; Phillips and Catling 1991; Marlow 1992; Marlow et al. 2000; McIlroy et al. 2001). Bubela (1995) reported foxes in subalpine and alpine regions occurring in social groups of one male, up to three adult females, and young of the year. Such social groups were found to occur only under relatively artificial conditions.

Would fertility control affect the social structure of foxes? There have been claims that the competitiveness of sterilised foxes would be altered and that subordinate individuals would begin breeding. Thus fertility control would simply cause different individuals in a population to breed rather than reduce the total number breeding (Bomford 1990; Caughley et al. 1992). A small experiment on the social control of breeding in captivity has been conducted (Newsome 1995). Although the researchers claim that no loss of dominance with sterilisation and no compensatory breeding in subordinates occurred, pen effects were obvious, and the relevance of these trials to the field is questionable.

Bubela (1995) tested the effects of surgical sterilisation on dominant females in a restricted field situation. In the first year the sterilised females maintained their home ranges and dominant status. However, in the second year there was evidence that one of the sterilised vixens lost her dominant position, allowing a previously subordinate female to breed.

Saunders et al. (2002) reported on the effects of surgical sterilisation on female foxes using large numbers of study animals and replicated sites. This approach has previously been suggested as a viable means of simulating fertility control of pest animals (Kennelly and Converse 1993). Population control through immunocontraception seeks to reduce the average rate of population increase (*r*) by suppressing the birth rate. To achieve this, levels of sterility of 65–80% may be needed (Pech et al. 1997; Hone 1999). This is a difficult target to simulate and maintain in free-living fox populations when using such a labour-intensive method as surgical sterilisation. In the study by Saunders et al. over four sites and two years, data from 155 foxes were used to determine ranging behaviour during the breeding season. There were no significant within-site differences between sterile and intact females, although sterilised females had slightly larger home ranges. There were no significant differences in survivorship between any of the site-by-sex combinations (sterilised and intact vixens, and males). Tests for significance between 'dispersers' and 'stayers' suggested that sterile females were more likely to stay within their original territories and not disperse, whereas intact females were the opposite. These findings in principle support the idea that immunocontraception would be ecologically feasible. The only contrary result was the increase in territory overlap between sterilized females, observed at only one of the sites, in one year. This 'stacking' may result in no net change in predation pressure, although this cannot be assumed to be a proven compensatory effect at this stage.

In similar experiments in coyotes, Bromley and Gese (2001) concluded that sterilised animals did not modify their territorial or affiliative behaviour and that sterilisation could be used as a management tool to exclude other potential sheep-killing coyotes in problem areas.

7.3 Means of fertility control

Cabergoline (CAB)

In some mammal species, prolactin is a crucial luteotrophic hormone during pregnancy. The prolactin inhibitor cabergoline (CAB) is a dopamine agonist that causes abortion in dogs (Jöchle et al.1989; Concannon and Meyers-Wallen 1991) and has been investigated as a potential fertility control agent for the red fox (Marks et al. 1996; Marks 2001; Marks et al. 2001; Marks et al. 2002a). The reported advantages of CAB are that it is simple to administer, has a high efficacy, a long duration of action, low toxicity, a wide margin of safety, and no severe side effects (Marks et al.1996; Tuyttens and Macdonald 1998). CAB is palatable to red foxes and can be included in oral baits (Marks et al. 1996).

The technical feasibility of a CAB baiting campaign to control red foxes in urban areas and island populations was demonstrated by Marks et al. (1996). Baits containing CAB were placed at active dens when vixens were assumed to be in mid-late pregnancy. Bait uptake and activity at the dens were assessed and the incidence of cubs was found to be significantly lower in the treatment dens than in the control dens, although it was not ascertained whether this reduced fertility was due to the induction of abortion or termination of lactation.

A later study in farmed silver foxes (a silver-coat phenotype of the red fox) was conducted to determine the dose of CAB required and the timing of CAB administration to induce sterilisation (Marks et al. 2001). A daily dose of 100 micrograms per kilogram from days 42 to 46 of pregnancy produced abortions and terminated lactation. A single dose of 100 micrograms per kilogram at day 25 of pregnancy and two doses of 50 micrograms per kilogram at days 25 and 27 of pregnancy also produced abortions. Single doses of 100 micrograms per kilogram and two doses of 50 micrograms per kilogram given two days apart later in pregnancy (day 35 or 48) did not produce reliable abortions. Doses of 25 micrograms per kilogram and 50 micrograms per kilogram given at any stage of pregnancy did not affect reproduction. Lactation was not terminated in any of the single-dose trials. This ability of a single dose of CAB to cause abortions during early to mid-, rather than late, pregnancy is contrary to observations in dogs and what was assumed to occur in foxes (see Marks et al. 1996).

'The mode of action of cabergoline raises animal welfare concerns.'

These results highlight the importance of delivering CAB at the right stage of pregnancy to gain maximum effect, and they show the potential disadvantage of using CAB for fertility control (Tuyttens and Macdonald 1998). Furthermore, owing to the prolactin-inhibiting action of CAB, lactation can stop. This raises a significant animal welfare problem, as the vixen would be unable to feed young that are born early (Marks et al. 1996; Tuyttens and Macdonald 1998) although lethal control of lactating vixens would have similar consequences. Caution may also be required with the use of CAB as a fertility control agent in wild fox populations because of the potential effect of this substance on non-target species (Marks et al. 1996; Tuyttens and Macdonald 1998) although lethal control of lactating vixens would have similar consequences. Delivery protocols would need to be devised to prevent bait uptake by non-targets or time it to cause minimal effect. Marks (2001) suggested that baiting foxes in August and September (at a time when most vixens are pregnant) would cause minimal impact to a range of Australian non-target species and that simple modifications to baiting strategies would even further minimise this risk.

Some doubt remains over the likely efficacy and cost effectiveness of CAB in broadscale field applications. Marks et al. (2002a) found that single doses of 100 micrograms per kilogram

Apart from doubts about the efficacy and cost-effectiveness of cabergoline, there are also animal welfare concerns given its effect on lactation and the ability of vixens to feed young.

Source: Paul Meek, Forests NSW

produced abortion in only 6 out of 24 test animals, although this result was significantly different from that in control groups. They also detected some emetic effects that may need to be overcome, particularly if higher doses rates are used. Because multiple bait take in the field is more likely, these authors concluded that the effects of single doses in this and previous trials may give a conservative indication of the potential for using CAB for fox management. Although the use of CAB may be appropriate where active dens can be targeted (e.g. in urban environments), as was the case in preliminary investigations (Marks et al. 1996), the suitability of CAB in rural settings remains to be seen. Any economic assessment would need to take into account the likely maximum effect of CAB in the early stages of gestation and the spread of births that can occur in fox populations from early August to late September in south-eastern Australia (McIlroy et al. 2001).

Immunocontraception

Immunological techniques of population control involve the development of a vaccine that immunises the target animal against one of it own reproductive hormones, gamete proteins or another protein essential to reproduction, thereby inducing sterility (see Figure 7.1). This approach is a natural process in that immune responses (antibody production and cell-mediated immunity) induced in the target animal inhibit reproduction and do not require constant or repetitive treatment, with initial treatments remaining effective for several years (Miller et al. 1995; Tuyttens and Macdonald 1998). The Cooperative Research Centre (CRC) for the Biological Control of Vertebrate Pest Populations, followed by the Pest Animal Control (PAC) CRC, investigated possible immunocontraception techniques for the fox (and other pest animal species) in Australia (Tyndale-Biscoe 1994;

Robinson and Holland 1995; Bradley et al. 1998). This research involved the identification of fox gamete antigens suitable for inducing an immunocontraceptive response and the identification and construction of delivery systems (Bradley 1994).

Initially, research on an immunocontraceptive vaccine was targeted at two groups of antigens: sperm antigens and zona pellucida (ZP) (the outer coat of the oocyte) antigens (Kirkpatrick and Turner 1991; Bradley et al. 1997). Although several fox sperm proteins were identified and their genes cloned, the most recent research concentrated on the egg ZP antigens, with ZP3 being identified as the primary protein to which sperm bind (Bradley et al. 1998).

An effective delivery system for the immunocontraceptive vaccine must be cost-effective to manufacture and administer and must be environmentally safe (Bradley et al. 1997). There are two main systems that have been investigated. The first is recombinant viruses such as vaccinia virus, which has been successfully used in rabies control in Europe (Pastoret et al. 1988; Brochier et al. 1990), or canine herpes virus (CHV), which has been recently identified as a canid-specific vaccine. The second delivery option is bacterial vectors such as *Salmonella typhimurium* (de Jersey et al. 1997; Bird et al. 1998; Bradley et al. 1998; Reubel et al. 2001).

'The costs and benefits of orally-delivered immunocontraceptives for foxes would need to be considered relative to the cost-effectiveness of orally-delivered toxins.'

On published results, the most likely outcome of this research would be a bait-delivered, immunocontraceptive vaccine containing ZP antigens. Recombinant canine herpesvirus was identified as a likely vector for delivering this oral vaccine antigen (Pest Animal Control CRC 2001). Limited information from pen trials indicates that CHV is not self-disseminating among foxes (G. Reubel, PAC CRC, pers. comm. 2002). CHV can also affect wild dogs, and in previous serological studies over 80% were tested as CHV seropositive (G. Reubel, PAC CRC, pers. comm. 2002). This would suggest that dogs will not be exposed to any greater risk of CHV than already occurs in the environment. Where even a minor risk could not be tolerated, such as the need to protect 'pure' colonies of dingoes, the management of foxes in the same area using this approach would simply not be an option. To overcome the problem of dogs being inadvertently sterilised via dissemination of the recombinant CHV, the CRC investigated a genetic 'switch' that would activate expression of the recombinant antigen only if the individual animal takes up, together with the recombinant virus, a trigger chemical (e.g. tetracycline) also contained in the bait. In this scenario, dogs may become infected with the recombinant virus and may also spread it to others, but only individuals that eat a bait containing both the virus and the switch would be immunised against the antigen, thus producing sterility (equivalent in a sense to non-targets in a poison baiting campaign) (G. Reubel, PAC CRC, pers. comm. 2002).

'Apart from the technical issues, there would be many hurdles to overcome before such a technique became available for broadscale use.'

Apart from the technical issues, there would be many hurdles to overcome before such a technique became available for broadscale use. These particularly include biosafety issues (Hinds 2001). Acceptance of immunocontraception (and its associated use of genetically modified organisms) by the public at large, as well as by national and international regulators, cannot be a foregone conclusion. Demonstration of low non-target risk to dogs would be critical to this process. Concern has also been expressed about the likelihood that this means of fertility control would constitute strong artificial selection, leading to the rapid evolution of resistance or failure to respond to the immunocontraceptive (Cooper and Herbert 2001). These authors also warn of the possible selection for an altered (most likely reduced) immune response, which could lead to an increased susceptibility to pathogens that affect the target species. Development of resistance can also occur to lethal control agents such as 1080 (Twigg et al. 2002) (see Section 3.1), suggesting that the ideal scenario is to have a range of management options available (lethal and fertility control).

At the time of writing this review, the Pest Animal Control CRC had ceased its activities and had been replaced by the new Invasive Animals CRC (IA CRC). All research on immunocontraception for foxes had ceased with the PAC CRC, and funding for any continuation of this work under the new IA CRC was not included in its first three year operational plan (T. Peacock, IA CRC, pers. comm. 2005).

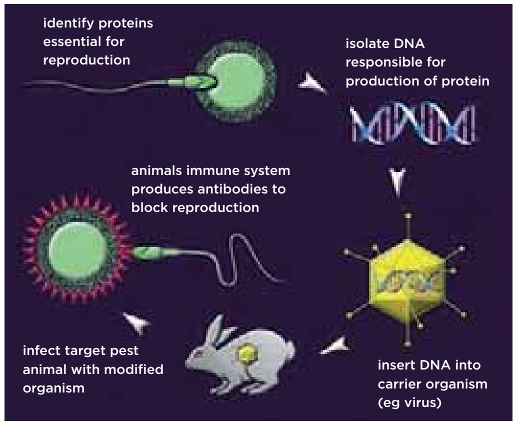


Figure 7.1 *Outline of the immunocontraception approach.*

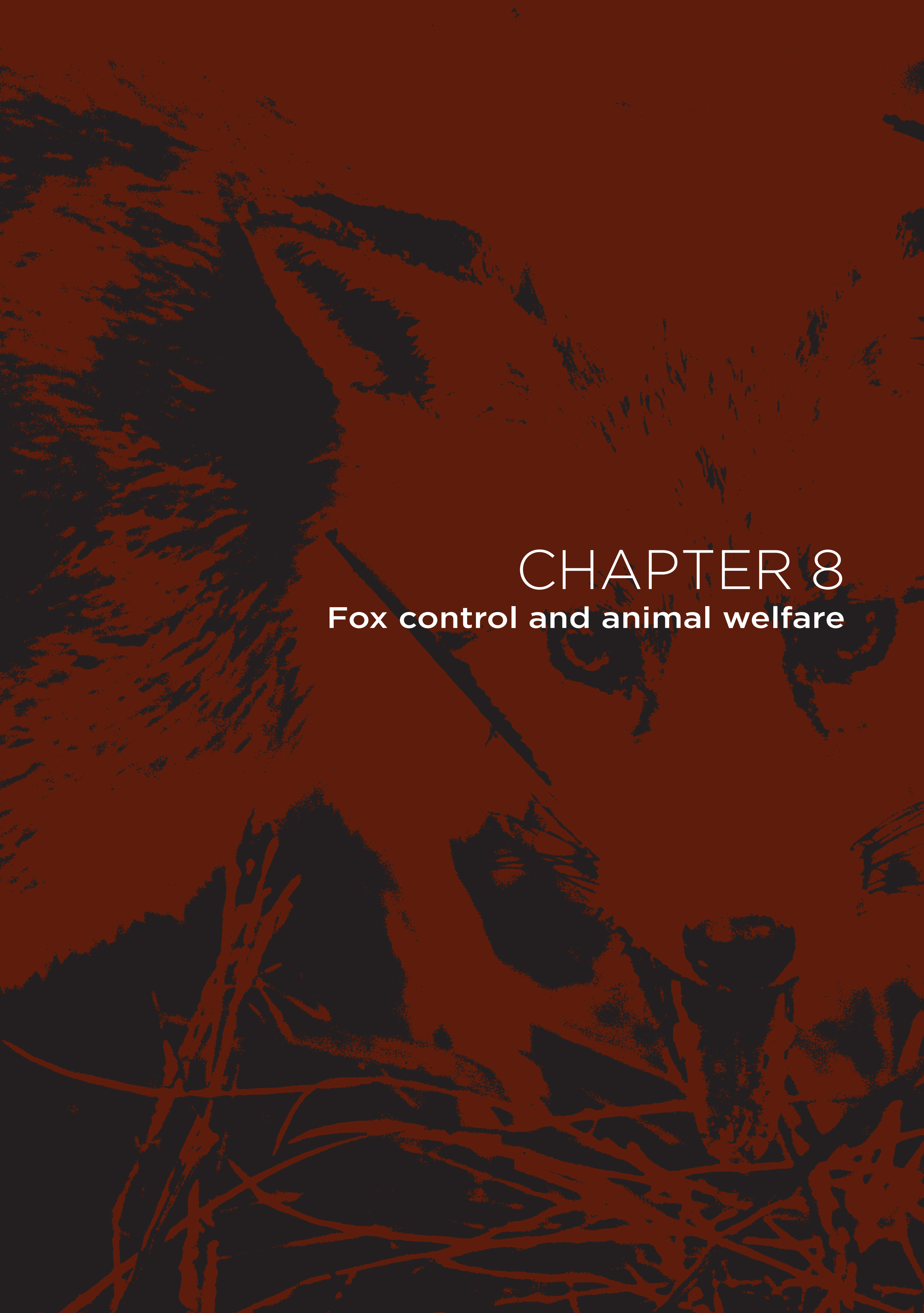
Source: Invasive Animals CRC

7.4 Will fertility control in foxes work?

Ecological and modelling studies of immunocontraception in foxes offer limited optimism in terms of the likely broadscale effectiveness of this technique in free-living populations (assuming no unknown, longer-term compensatory effects, nor the development of resistance). There are still many logistical considerations that may need to be overcome or at least accommodated (Saunders et al. 2002). These potentially include:

- integration with conventional (lethal) control operations;
- levels of bait uptake and rates of seroconversion;
- cost-effectiveness;
- scale of operation necessary to minimise the effect of recruitment;
- efficacy of bait versus virally-vectored delivery mechanisms; and
- legislative and/or regulatory control of the aerial application of fertility control baits.

Best practice principles require that a pest management technique be judged by its ability to reduce impact. How immunocontraception—or any other form of fertility control—can be integrated with conventional fox control practices in a way that significantly reduces impact on prey species will require careful consideration and development in the field. Because of the inherent appeal of fertility control as the preferred option for pest control on animal welfare grounds, there is some concern that proof of concept in the laboratory will automatically be seen as confirmation of its efficacy in the field. This view may be far removed from reality. Given all the other public and political issues that still need to be addressed, the likelihood of a field-tested and registered fox fertility control agent is not guaranteed and is going to be many years away. Further, its 'long-term potential' availability should not detract from the need to explore other control mechanisms or from protecting the ongoing use of 1080 baiting.



CHAPTER 8
Fox control and animal welfare

8. Fox control and animal welfare

Key issues

- *Concerns about the use of 1080 have been expressed by some animal welfare agencies in Australia. However, most recognise that there is no suitable alternative presently available and encourage research into more humane additional methods of controlling foxes.*
- *In carnivores, poisoning from 1080 is typified by severe central nervous system disturbance, convulsions, hyper-excitability, vocalising and ultimately respiratory failure. Although these signs of 1080 poisoning can be distressing to an observer, mental disorientation and unconsciousness do not necessarily mean that 1080 poisoning is inhumane. In the absence of studies that objectively assess pain perception in foxes poisoned by 1080, such extrapolations are inconclusive.*
- *The use of analgesic, sedative or anti-anxiety agents combined with 1080 has been proposed as a means to decrease or limit any suffering that may be associated with 1080 poisoning. This is an area that requires further research, particularly in assessing the field efficacy of incorporating analgesics with 1080 baits. Cost factors also need to be considered. If the use of analgesics becomes a reality (and/or a requirement) of fox baiting, non-commercial preparation of baits may become redundant because of restrictions on the handling and use of such chemicals. This will have cost–benefit implications but might also bring uniform standards into fox bait production.*
- *Fox control techniques such as dogging, fumigation and leg-hold traps are generally considered unacceptable on animal welfare grounds.*
- *There is a need for nationally accepted standard operating procedures for all techniques currently employed in pest animal management. These should be based on the documents produced by the NSW Department of Primary Industries (Sharp and Saunders 2005).*
- *Perceptions of humaneness of pest animal control techniques can hinder the research and development of more cost-efficient (and humane) means of controlling fox and other pest animal populations.*

There is a growing expectation that the animal suffering associated with pest management should be minimised (Braysher 1993). Although the ecological and economic rationales for the control of pests such as the fox are frequently documented, little attention has been paid to the development of an ethical justification as to how and when these pests are controlled (Marks 1999). In the animal welfare debate relative to pest animal management, there is a tendency to report on the suffering of individual animals rather than the population as a whole. This results in the use of zero suffering as a reference point from which to judge the acceptability of any population control method (Warburton and Choquenot 1999).

Regardless of any philosophical debate, pest animal control elicits a highly negative response from the animal welfare community that must be addressed by sincere attempts to incorporate this community's concerns into research and management practices (Schmidt 1989). The only way of ensuring that these approaches are uniformly applied as management practices is by producing agreed Codes of Practice and Standard Operating Procedures (SOPs) for pest animal control. These have been produced by the NSW Department of Primary Industries (Sharp and Saunders 2005) with supporting funds from the Natural Heritage Trust. The documents have already been adopted by the Commonwealth Government for lands under its control (particularly defence estates and national parks) and have been endorsed by NSW Pest Animal Council for use in New South Wales.

The purpose of these codes and SOPs will be to improve the humaneness of pest animal management programmes. The starting point for preparation of these documents was based on the New South Wales experience; similar principles nationally guided by appropriate State and Federal legislation were then applied.

Wildlife or pest animal research presently carried out in New South Wales must be done in accordance with the 'Australian Code of Practice for the Care and Use of Animals for Scientific Purposes' (sixth edition 1997) (the 'Code of Practice'), the *Animal Research Act 1985* and the Animal Research Regulation 1995. Part 2, Schedule 1, of the Animal Research Regulation 1995 deals specifically with free-living animals being used for scientific purposes, as does Section 5 of the sixth edition of the Code of Practice, 'Wildlife Studies'.

8.1 Animal welfare and 1080

Concerns about the use of 1080 have been expressed by animal welfare agencies in Australia (ANZFAS 1996; Oogjes 1996; RSPCA 1999). Most recognise that there is no suitable alternative presently available and encourage research into more humane alternative methods of controlling foxes.

The exact mechanism of fluoroacetate poisoning is still not completely understood, but it is known that energy metabolism and cellular function are impaired, leading to the depletion of energy resources and gross organ dysfunction (Kun 1982). There is no effective antidote for 1080 poisoning, although because of the slow action of 1080 there has been some success in symptomatic treatment in domestic dogs (Howard and Schmidt 1984; Seawright 1989). In carnivores, death is typified by severe central nervous system (CNS) disturbance, convulsions, hyper-excitability, vocalising and ultimately respiratory failure (Eason et al. 1994). These signs of 1080 poisoning can be distressing to an observer and can be readily associated with pain and distress (Marks 1999). Gregory (1996) indicates similarities between 1080 poisoning and human conditions symptomatic of convulsions, mental disorientation and unconsciousness. Because the latter were not associated with pain in humans he concluded that the signs of central nervous system (CNS) stimulation caused by fluoroacetate poisoning were probably not an indication of suffering. In the absence of studies that objectively assess pain perception in foxes poisoned by 1080, this extrapolation is inconclusive (Saunders et al. 1995; Marks 1999).

Assessment of the pain perceived by animals poisoned with 1080 is made more difficult, as the severe CNS disruptions alter behavioural indicators of pain that would be otherwise useful in such assessments (Anon 1989, as cited in Marks et al. 2000). Perhaps at odds with this observation, Jongman (2001) tested the effectiveness of analgesic–1080 combinations in foxes using evoked response potentials, which are part of electroencephalograph patterns.

'The use of analgesic, sedative or anti-anxiety agents combined with 1080 has been proposed as a way of accounting for any suffering associated with baiting.'

The use of analgesic, sedative or anxiolytic agents combined with 1080 has been proposed as a means to decrease or limit the suffering that may be associated with 1080 poisoning (Marks 1996; Oogjes 1996). Marks (1996) also suggested a number of additional advantages in including an analgesic in baits. These include reduced bait regurgitation (with associated reduction in non-target risk), reduced likelihood of taking multiple baits before toxicosis sets in, and improvement in the early detection of non-target bait consumption (e.g. by farm dogs).

Marks et al. (2000) compared such agents (carprofen, diazepam and clonidine) in a trial involving captive foxes. Diazepam appeared to be the most promising, reducing the overall activity of foxes from dosage until death and abolishing the symptoms of retching and manic running in the early stages of poisoning. In a further field study on dingoes, diazepam was found to significantly reduce the activity of trapped individuals, but tooth and limb damage scores were no different from those in the placebo group (Marks et al. 2004a). In her study, Jongman (2001) also concluded that an unspecified, non-steroidal, anti-inflammatory analgesic showed similar promise.

Clearly, this is an area that requires further research, particularly in assessing the field efficacy of incorporating analgesics with 1080 baits. Cost factors need also be considered. If the use of analgesics becomes a reality (and/or a requirement) of fox baiting, non-commercial preparation of baits may become redundant because of restrictions on the handling and use of such chemicals. This will have benefit–cost implications but might also bring uniform standards into fox bait production.

8.2 Animal welfare and other control methods

The views of various animal welfare agencies on other forms of fox control are varied. Animals Australia opposes the use of 1080 for fox control (Sharp and Saunders 2003). The RSPCA (1999) accepts shooting if it is done using proper procedures and by skilled personnel. Techniques such as dogging, fumigation and leg-hold traps are generally considered acceptable only under certain circumstances. Sharp and Saunders (2005) summarised the humaneness, efficacy, cost-effectiveness and target specificity of fox control methods (see Table 8.1).

8.3 Research and animal welfare

Perceptions of humaneness of pest animal control techniques can hinder the research and development of more cost-efficient (and humane) means of controlling fox and other pest animal populations. Passage of research applications through animal ethics committees (AECs), for example, is often hindered and receives increased scrutiny because the desired outcome is often the killing of animals.

Some procedures considered acceptable to the animal welfare community have been documented. Examples are documented in the 'Animal Care' publication of NSW Agriculture (1997) and the booklet on 'Feral Livestock Animals' produced by the Standing Committee on Agriculture, Animal Health Committee (1992). Neither of these sufficiently documents the procedures used to be widely accepted by AECs and others as Standard Operating Procedures. They are also limited to broadscale measures such as 1080 baiting or aerial shooting and are management-oriented, rather than including animal welfare concerns involving research methodologies.

There is a need for nationally accepted Standard Operating Procedures for all techniques currently employed in pest animal research (similar to those written for management techniques). Wildlife or pest animal research must be done in accordance with the Code of Practice and (in New South Wales specifically) the *Animal Research Act 1985* and Animal Research Regulation 1995 (similar acts apply in other States). Part Two, Schedule 1, of the Animal Research Regulation 1995 deals specifically with free-living animals being used for scientific purposes and Section 5 of the sixth edition of the Code of Practice, 'Wildlife Studies'. Enshrined in the principles of the Code of Practice is the concept of the 'Three Rs': reduction, replacement and refinement of animal use. Codes of Practice and Standard Operating Procedures for research techniques used in pest animal management would need to be guided by these principles.

[a] Unmodified steel-jawed traps are inhumane and prohibited in most States. Traps can be modified with rubber pads to reduce injury to animals. [b] Whilst cage trapping is more humane (provided traps are sheltered and checked regularly), trapping in general is regarded as being labour-intensive and ineffective for broadscale population control.

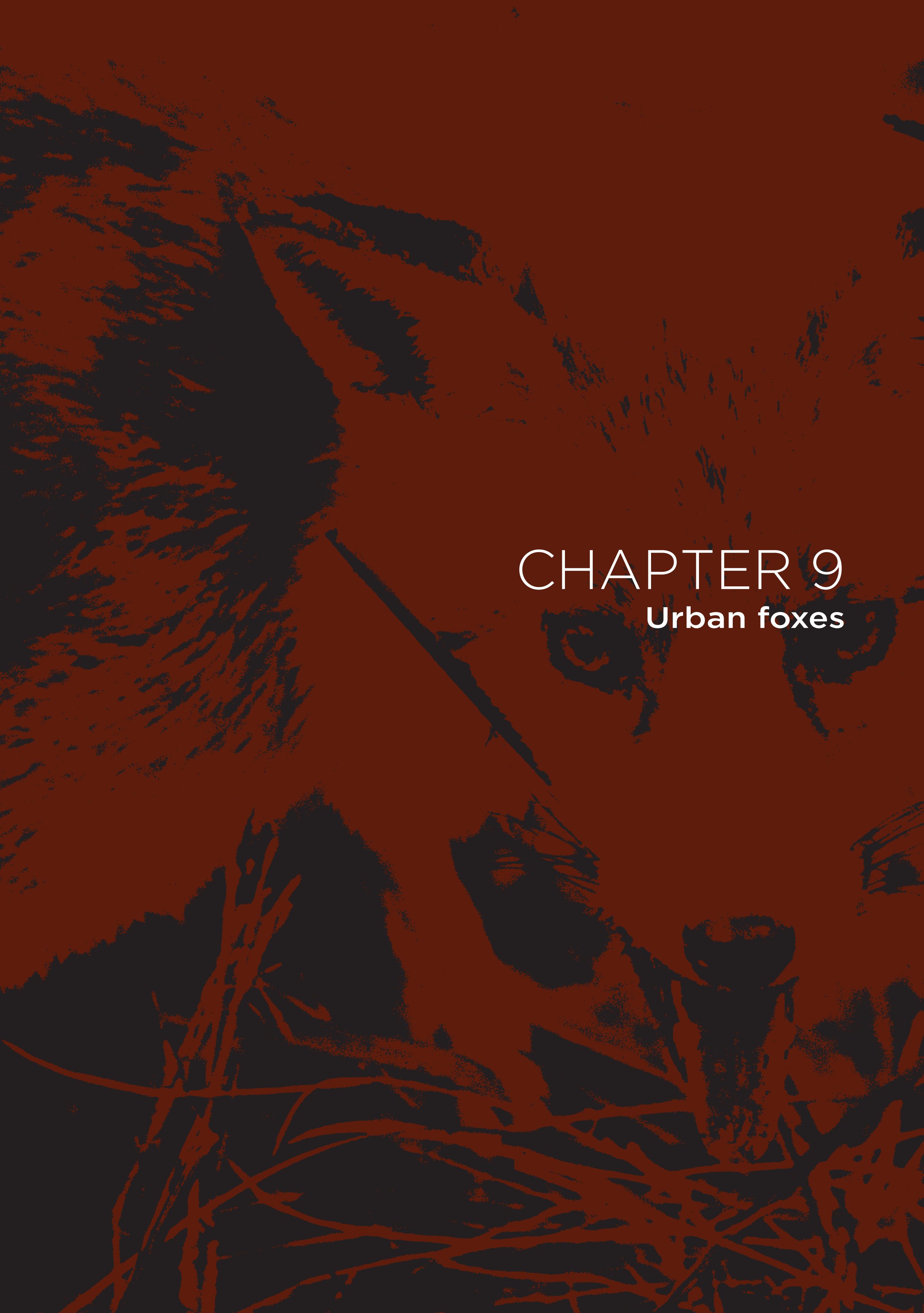
Sources: [a] Steve Lapidge, Invasive Animals CRC and [b] Glen Saunders, NSW DPI

Table 8.1 *Humaneness, efficacy, cost-effectiveness and target specificity of fox control methods (after Sharp and Saunders 2005).*

Control technique	Acceptability of technique with regard to humaneness*	Efficacy	Cost-effectiveness	Target specificity	Comments
Fertility control	Conditionally acceptable	Unknown	Unknown	Depends on agent used.	No products currently registered.
Exclusion fencing	Acceptable	Limited	Expensive	Can be in certain situations.	Useful for protection of threatened wildlife species and other valuable animals. Expensive and therefore impractical for broad-scale application.
Guard animals (e.g. dogs, alpacas, llamas, donkeys)	Acceptable	Unknown	Unknown	Guard dogs may chase or attack non-target animals e.g. native wildlife, pet dogs, livestock.	Likely to be effective only for small to medium-sized enterprises.
Ground baiting with 1080	Conditionally acceptable	Effective	Cost-effective	Potential risk of poisoning non-target animals. Strategic ground baiting uses fewer baits than aerial baiting programs. Uneaten baits can be collected and destroyed.	Currently the most cost-effective technique available. 1080 ingestion can also kill non-target animals, including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
Aerial baiting with 1080	Conditionally acceptable	Effective	Cost-effective	Potential risk of poisoning non-target animals. Uneaten baits cannot be collected. Dried-meat baits remain toxic for longer periods than fresh meat.	Effective for broad-scale control in remote areas. 1080 ingestion can also kill non-target animals, including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
Strychnine baiting	**Not acceptable**			Potential risk of poisoning non-target animals.	**Inhumane and should not be used. Alternatives are available.**
Ground shooting	Acceptable	Not effective	Not cost - effective	Target-specific.	Labour intensive, suitable only for smaller scale operations.

Control technique	Acceptability of technique with regard to humaneness*	Efficacy	Cost-effectiveness	Target specificity	Comments
Den fumigation with carbon monoxide	Conditionally acceptable	Not effective	Not cost-effective	Target-specific if den is monitored for non-target use before fumigation.	Useful for localised fox problems where baiting and shooting are not options; not effective for broad-scale control. Carbon monoxide is toxic to humans; operators need to take precautions to safeguard against exposure.
Cage traps	Acceptable	Not effective	Not cost - effective	May catch non-target animals, but they can usually be released unharmed.	Useful only in urban areas for problem animals.
Eco-traps®	Acceptable	Not effective	Not cost - effective	May catch non-target animals, but they can usually be released unharmed.	May be useful in urban areas for problem animals, where baiting is inappropriate or where live-capture is required for research purposes.
Padded-jaw traps	Conditionally acceptable	Not effective	Not cost - effective	Risk of catching non-target animals.	May be useful for problem animals but are inefficient for general control. Effectiveness depends on skill of operator.
Treadle snares	Conditionally acceptable	Not effective	Not cost - effective	Risk of catching non-target animals.	May be useful for problem animals but are inefficient for general control. Difficult to set. Need to be checked even more regularly than padded-jaw traps

* 'Acceptable' methods are those that are humane when used correctly. 'Conditionally acceptable' methods are those that, by the nature of the technique, may not be consistently humane; there may be a period of poor welfare before death. Methods that are 'not acceptable' are considered to be inhumane; the welfare of the animal is very poor before death, often for a prolonged period.



CHAPTER 9
Urban foxes

9. Urban foxes

Key issues

- *Urban foxes are becoming more common as pest animals in Australia's major cities.*
- *Evidence of the impact of foxes in urban landscapes, particularly on wildlife, remains anecdotal or equivocal.*
- *If urban fox control programmes are to continue, evidence (other than circumstantial) has to be provided that fox numbers are being reduced and prey species are recovering. Without such evidence it will be increasingly difficult to convince anyone losing a family pet that its death was justifiable. Public support can be quickly lost in such circumstances, thus jeopardising successes previously achieved in reducing fox numbers.*
- *An immediate problem is that of hydatids (at least in south-eastern Australia) and even though foxes have a low incidence of hydatid infection they are a risk to human health in urban areas.*
- *Control of urban foxes is made complex by their interactions with, and proximity to, humans.*
- *Effective lethal baiting of foxes in urban environments has been demonstrated. Similarly, some reductions in reproductive output have been reported by baiting at urban fox den sites with a fertility control agent.*

Since the 1940s, urban foxes have become common in British cities (Harris and Rayner 1986). Lloyd (1980) conjectured that, in Britain between the wars, the fragmentary sprawl of residential areas into green-belts left many islands of agricultural lands that then served as foci for peri-urban colonisation of surrounding developed areas by foxes. As these remaining agricultural lands themselves became developed, foxes were forced to survive exclusively in the urban landscape. It is not clear why the same did not occur as early and at the same rate elsewhere, particularly in Europe. It has only been since the early 1980s, when fox populations started to recover from the rabies epizootics of the 1960s and 70s, that foxes started colonizing many European cities to the same extent as in Britain (Christensen 1985; Gloor et al. 2001). In more recently developed countries where the red fox is common, such as Canada and Australia, the same processes that saw foxes successfully colonise urban Britain are probably under way but at a less advanced stage.

'Foxes are becoming a more common pest animal in Australia's major cities.'

Foxes are certainly now becoming a more common pest animal in Australia's major cities, causing problems such as predation on pets and small livestock. Estimated mean densities in urban Melbourne are as high as 16 foxes per square kilometre (Marks and Bloomfield 1999b); this is comparable with populations in Britain, although in some instances the latter can be as high as 60 foxes per square kilometre (Baker et al. 2001b). Evidence of the impact of foxes in urban landscapes, particularly on native wildlife, remains anecdotal or equivocal (e.g. Augee et al. 1996).

The greatest potential risk posed by foxes inhabiting urban areas is frequently portrayed as the role they might play in rabies transmission. This risk is no doubt real but has been overplayed in recent publications: the probability of fox rabies ever being introduced to Australia is extremely low (Saunders 1999). A more immediate problem (at least in south-eastern Australia) is that of hydatid tapeworms (*Echinococcus granulosus*), and even though they have a low incidence of infection, foxes are a risk to human health where they occur in urban areas (Jenkins and Craig 1992). The increasing presence of foxes in urban landscapes throughout the northern hemisphere is also causing

Foxes are becoming more common in Australia's major cities.

Source: Laurent Geslin

concerns over the potential transmission to humans of the zoonotic tapeworm (*Echinococcus multilocularis*) (Eckert and Deplazes 1999). This is an increasing zoonotic risk because of the close proximity of humans and pests (Hofer et al. 2000). Antihelmintic baiting strategies for foxes are being developed to deal with this particular urban fox problem (Hegglin et al. 2003; Hegglin et al. 2004). Canine heartworm (*Dirofilaria immitis*) has been detected in urban foxes in Melbourne, so there is concern that the widespread fox population could offer potential for a sylvatic cycle of canine heartworm within the urban area (Marks and Bloomfield 1998).

Control of urban foxes is made complex by their interactions and proximity with humans. O'Keeffe and Walton (2001) suggest that people are a major part of urban pest problems, and in order to deal with the pest it is as equally important to educate the human population. As a consequence, urban pest managers are increasingly called upon to participate in conflict resolution.

Marks and Bloomfield (1999a) dosed baits with a biomarker (tetracycline) in Melbourne and achieved bait uptake rates of 80–97% at three sites treated at 8 baits per hectare offered over three days. Baits were distributed in areas of open space (parks and reserves, riparian zones, vacant land and lawns). This compares with a similar trial in Bristol, England (Trewhella et al. 1991), where bait uptake varied from a low of 27% in winter to 56% in autumn. The proportions of recovered foxes that had consumed bait (identified using a biomarker) were 26% in summer and 25% in winter. Over 70% of these baits were placed in exposed habitats, as in the Melbourne trial, but offered over seven or eight days at a greatly reduced density of 0.32 baits per hectare. Comparison between the two studies is made difficult by the many differences between site and baiting strategy. The Melbourne trial suggests that effective lethal baiting of foxes in urban environments is theoretically achievable. Similarly, Marks et al. (1996) reported some reductions in reproductive output by baiting at urban fox den sites with a fertility control agent.

Indirect evidence of fox predation on important populations of the long-nosed bandicoot (*Perameles nasuta*) and the southern brown bandicoot (*Isoodon obesulus*) led to the call for an urban fox control programme in and around remnant bushland on the northern suburbs of Sydney (Mason and Olsen 2000; Olsen et al. 2005). The programme initially involved a collaboration between six local councils, the NSW NPWS and the Moss Vale Rural Lands Protection Board, but it has now expanded to 12 councils in addition to Taronga Zoo, Macquarie University and NSW Forests. Initial attempts were made to trap foxes in cage traps, although few foxes were caught in this way and the programme began to lose momentum due to lack of success.

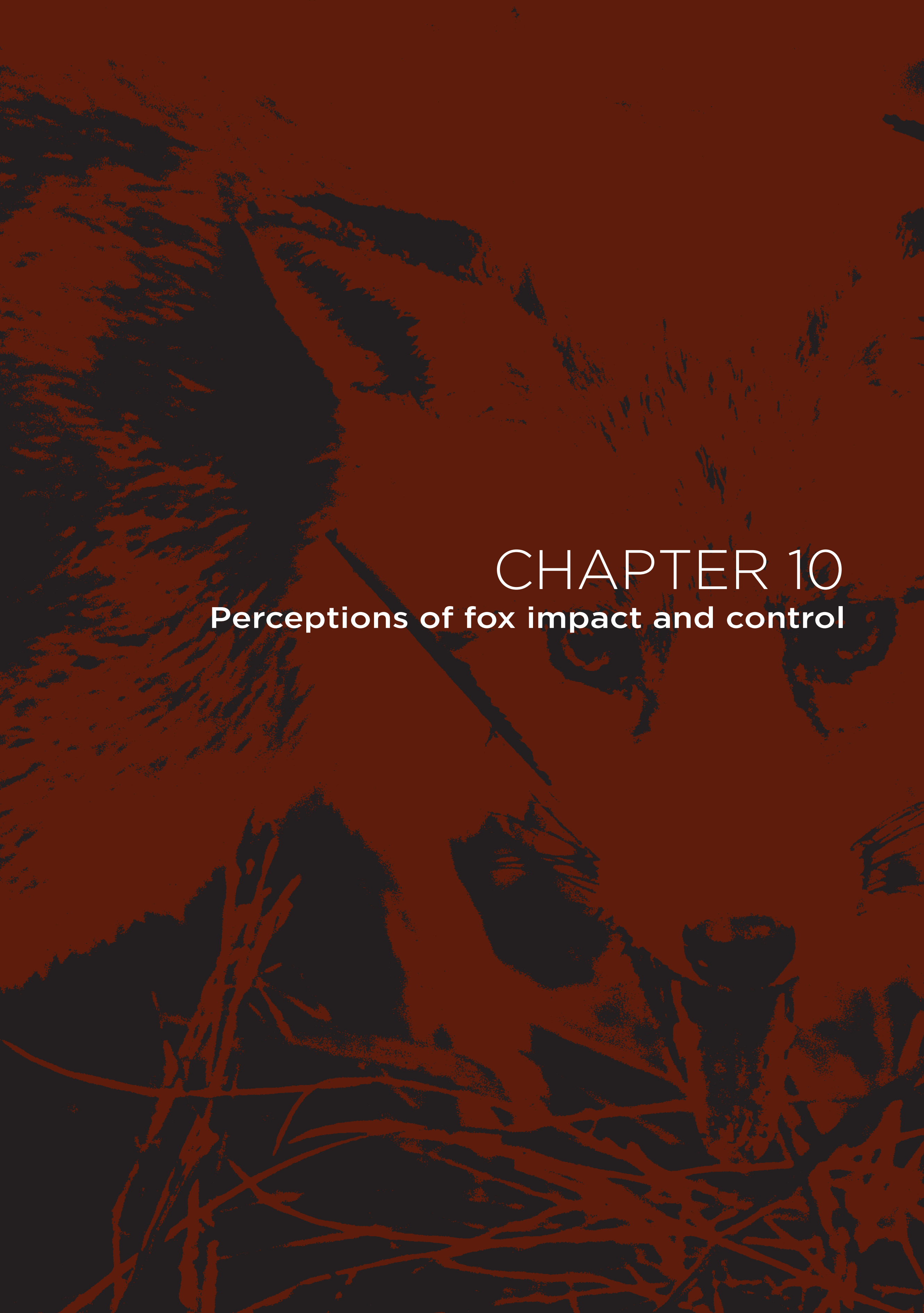
In 1998 it was decided that the only way to proceed was to obtain a special off-label permit to reduce distance restrictions and employ the use of 1080 baits. Approval was obtained and baiting began in February 2000.

The programme has required a considerable extension effort, given the number of ratepayers potentially affected by any 1080 baiting programme. Community response to the programme has been good, and after its fifth year the programme can claim measurable achievements. Both agency fauna surveys and anecdotal evidence from feedback from the community have supported claims that local wildlife populations have increased. The long-nosed bandicoot has been sighted in areas after a long absence (Olsen et al. 2005).

The distance from habitation at which 1080 baits could be laid for this programme was reduced from 500 metres to 150 metres. Although this distance was necessary if fox control was to be successful in such close proximity to high density housing, there was an associated element of risk, particularly in terms of domestic dogs. Overall the programme can claim an excellent safety record, with only one incident occurring where a family pet was poisoned. Although not proven, it was likely to have been the result of eating vomit from a fox that had eaten a bait.

Valuable working dogs are also infrequent casualties in fox-baiting programmes on rural lands. The benefits accrued in such programmes must be weighed up against such unfortunate instances. The fact that only one dog has died in the Sydney programme is an indication of its good organisation and level of public awareness and support. However, if such programmes are to continue, evidence has to be provided that fox numbers are being reduced and prey species are recovering. Without such evidence it will be increasingly difficult to convince anyone losing a family pet that its death was justifiable. Public support can be quickly lost in such circumstances, thus jeopardising successes previously achieved in reducing fox numbers.

Potential control options for urban fox problems might, in future, include the use of cabergoline and immunocontraception (Section 7.3) and M-44s (Section 4.6). Cage trapping (Baker et al. 2001a), and the Collarum™ trapping device (Shivik et al. 2000) may also be of use in some circumstances (Section 4.1).



CHAPTER 10
Perceptions of fox impact and control

10. Perceptions of fox impact and control

Key issues

- *The decision by early settlers to introduce the fox into Australia merely as an 'honoured object of the chase' is, today, extremely difficult to comprehend.*
- *The rapid spread of foxes across the continent after their release in the 1870s and associated predation on newborn lambs quickly earned the fox an official pest status.*
- *Its widespread distribution and abundance, lack of specialised dietary requirements, presence as the only medium-sized predator, potential for involvement in exotic disease outbreaks, potential for transmission of endemic parasites and diseases, annoying raids on poultry sheds and harvesting in large numbers for the fur trade have historically entrenched the fox in our psyche as perhaps only second to the rabbit in Australia's long list of introduced pest animal species.*
- *Surveys suggest that the fox problem is increasing, with the most cited cause being the non-viability of commercial harvesting as a management strategy.*
- *Most landholders believe the fox problem is recurring despite their control efforts.*
- *The main cause of these recurring problems is thought to be the immigration of foxes from non-controlled areas.*
- *Although 1080 baiting is the most commonly used technique, its effectiveness is not universally accepted.*
- *Many landholders see the importance of group baiting but lack the knowledge, time and motivation to participate, suggesting that more involvement through organisations such as Rural Lands Protection Boards and Landcare is needed.*
- *Understanding what motivates landholders to participate in group baiting, or conversely why they fail to participate, would help programme organisers to improve the effectiveness of baiting programmes.*

"The fox is of a wild and ferocious disposition and since the beginning has been famous for his cunning and his arts. He feeds indiscriminately on lambs, fowls, hares, rabbits and small birds and his fondness for grapes renders him of great annoyance in the vineyards of France. The fox seldom fails to establish his habitation near some farm or village so that he may the more easily attack the poultry and he often commits great depravations destroying in a single evening everything that has life" (Goldsmith 1774).

The perception of the fox being a killer and pest can be traced back to biblical times. Given these long-held beliefs, the decision by early settlers to introduce foxes into Australia merely as an 'honoured object of the chase' is, today, extremely difficult to comprehend.

Many factors contribute to the reputation of the fox as a significant pest in rural Australia. Although records are lacking, its rapid spread across the continent after release in the 1870s and associated predation on newborn lambs quickly earned the fox an official pest status (Rowley 1970). Its widespread distribution and abundance, lack of specialised dietary requirements, presence as the only medium-sized predator, potential for involvement in exotic disease outbreaks, potential for transmission of endemic parasites and diseases, annoying raids on poultry sheds and harvesting in large numbers for the fur trade have historically entrenched the fox in our psyche as perhaps only second to the rabbit in Australia's long list of introduced pest animal species. Although supporting evidence for the extent to which the fox affects agricultural production is lacking, recent studies that have established its impact on native wildlife have further enhanced this reputation.

Numerous studies have been conducted in the UK to determine the status of foxes in the rural landscape and the perceptions of landholders. These have recently been summarised in government submissions triggered by the parliamentary review of fox hunting (White et al. 2000; Macdonald et al. 2000; Moberly et al. 2003). Although there are many obvious disparities between the UK and Australia, outcomes from these studies still provide useful insights. White et al. (2000) provided mean outcomes from all the studies combined, as presented below.

Some of the reasons cited for controlling foxes in the UK were to reduce abundance (69%), to reduce predation on stock (59%), as a good neighbour policy (44%), to reduce predation on game (41%), and for sport (35%). Estimates of landholders practising fox control ranged from 44% to 90%. The rabbit was ranked as number one pest by 52% of landholders, followed by corvids and foxes in equal second (33%). Some studies asked landholders to estimate fox abundance: the results appeared to be 5–18 times greater than known densities. White et al. (2000) concluded that this latter misconception could easily lead landholders to believe that they had too many foxes and that culling was necessary. Macdonald et al. (2000) similarly concluded that the perceived pest status affected a farmer's tendency to control foxes, independently of the reported damage.

'Surveys suggest that the fox problem is increasing.'

A State-wide survey of landholders in New South Wales was conducted in 1996 to determine landholders' perceptions of the fox problem and control issues (Saunders et al. 1997). A total of 4500 surveys were distributed, with 829 respondents. In estimating the extent of the problem, 11% believed they were incurring no loss of production to foxes, 36% perceived 0–5% lost production, 33% perceived 5–10% lost production, and 20% perceived greater than 10% lost production. In response to a question about perceived trends over the past ten years, 46% of respondents reported the fox problem as getting worse, 32% thought the fox problem was the same, and 22% reported foxes less of a problem. The most common reason given for the problem getting worse was the lack of shooting owing to the reduction in fur demand (66% of responses).

Of the landholders who responded that their fox problems had declined, 95% attributed their success to regular control effort (with 75% nominating baiting as the major reason); the other 5% gave varied reasons, including the better nutrition of their ewes, the use of herding dogs and (in one case) cessation of lamb production. Only 40 landholders attempted to estimate the density of foxes on their properties. These estimates varied from 1–10 foxes per square kilometre.

Of responding landholders, 86% practised some form of fox control. The majority of respondents (65%) used a combination of shooting and baiting as their main forms of control, with 51% rating the effectiveness of this combination good, 46% moderate, and 3% unsatisfactory. Only 11% used shooting alone as the main form of control, with 25% rating the effectiveness of this method good, 49% moderate, and 26% unsatisfactory. None of the 24% landholders who used baiting only as the main form of control was dissatisfied with the effectiveness, with 74% rating the effectiveness of this method good and 26% moderate. Secondary forms of control included den destruction, exclusion fencing, habitat destruction and trapping.

A total of 84% of landholders said their fox problems were recurring despite their control efforts. Even though 66% of landholders considered the fox problem had increased in the past ten years owing to the reduction in fur demand and the lack of shooting, only 5% gave a similar reason for the recurrence of their own fox problems despite their control efforts. The main reason why landholders saw their fox problems recurring was the migration of foxes from uncontrolled areas (including neighbours and National Parks): 51% of respondents giving this reason.

From the total responses, 24% of landholders were not going to bait in that year, 38% were baiting on one occasion, 25% on two occasions and 13% on more than two occasions. From the landholders that were going to bait, 42% were baiting individually, 43% baiting with their neighbours and 15% in a group baiting programme. The majority of groups were organised through Landcare (71%), with others through RLPBs (12%), footrot control areas (6.5%), fire brigade areas (6.5%), local farmers (2%) and National Parks (2%).

The majority of landholders (93%) timed their baiting with their lambing or kidding, whether with their neighbours, in a group programme or by themselves. There were a small number (5%) who baited in conjunction with their neighbours or in a group, regardless of their own enterprise (i.e. either not close to their lambing/kidding, or only baited because their neighbours or group wanted them to). A further 2% did not bait at lambing/kidding, but baited instead when they considered fox numbers to be high, or they lost poultry, or (in one case) when a baiter became available. Of landholders that baited, 43% used a scent trial when laying their baits, 3% of landholders free-fed before baiting, and 62% said they buried their baits.

Thirty-three percent of respondents said that they thought that 1080 baits were effective and not dangerous if used correctly, 27% were concerned about the danger to farm dogs, and a further 5% worried about other non-target species. Eighteen percent of respondents said they would try any alternative control when available if shown to be as effective, as cost-efficient, and/or less dangerous than 1080, and 12% wanted an alternative that acted faster than 1080 (suggestions were cyanide and strychnine), as they wanted to see the results (i.e. a dead fox) or they thought death from 1080 poisoning was slow and cruel.

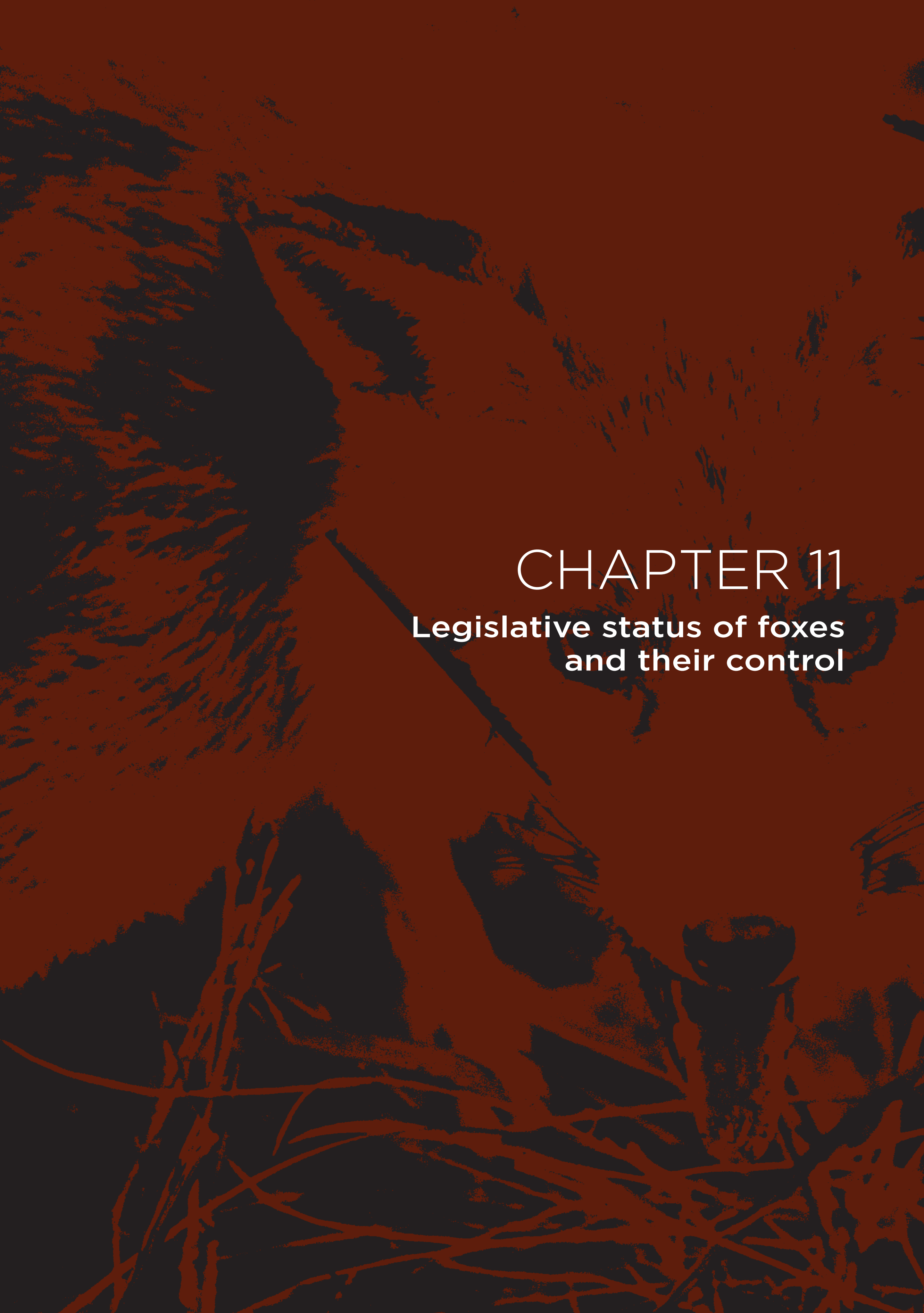
Landholders' main expectations from their fox control were to keep foxes down to low numbers (51% of respondents) or to keep fox damage down to a 'manageable' level (40%). Only 8.5% wanted to remove all foxes from their farms. Of the landholders that expected the removal of all foxes from their farm, 76% had not achieved this in past years. Of the landholders that expected to keep foxes down to low numbers, 28% had not achieved this in past years. Of the landholders that expected to keep fox damage down to a manageable level, 30% had not achieved this in past years.

Landholders believed that the benefit of fox control to native animals outweighed the control foxes exerted on rabbits and other agricultural pests. Twenty-five percent thought that native wildlife would benefit from the reduction in fox numbers, with a further 20% specifically nominating ground-dwelling birds (e.g. quail, ducks, emu chicks) and/or reptiles. In general, all landholders agreed that the increase in productivity greatly outweighed the cost and effort in outlay.

'Understanding what motivates landholders to participate in group baiting will improve the effectiveness of baiting programmes.'

Some comments highlighted the need for education about baiting in general, techniques used for baiting, and general fox ecology. Many landholders saw the importance of group baiting but lacked the knowledge, time or motivation to participate, suggesting the need for more involvement through organisations such as RLPBs and Landcare. Understanding what motivates landholders to participate in group baiting, or conversely why they fail to participate, would no doubt help programme organisers to improve the effectiveness of baiting programmes.

The Queensland government has also conducted a survey to assess the attitudes and knowledge of primary producers and residents of regional centres and country towns towards pest animals, including foxes (Oliver and Walton 2004). A greater percentage of primary producers in the south of the State were concerned with foxes as a major pest, compared to other areas, a reflection on primary producer activity (greater percentage with sheep) as well as fox distribution in the State. State-wide, foxes were ranked the fifth pest of concern, behind wild dogs/dingoes, feral pigs, macropods and rabbits. The survey of town and regional centre residents indicated that less than one percent rated foxes as a major pest concern. Domestic cats, dogs and birds were perceived to be the major pests in these areas.



CHAPTER 11

Legislative status of foxes and their control

11. Legislative status of foxes and their control

Key issues

- *It should be a priority, with legislative support, to maintain the fox-free status of key islands around Australia such as Kangaroo Island.*
- *The present Tasmanian situation with foxes apparently becoming established, is a potential environmental disaster and every effort, with legislative support, should be taken to ensure foxes are eradicated from this State.*
- *There are a number of problems, based on ecology of the species and ability to implement control, which will always make the legal declaration of foxes as pest animals difficult to implement.*
- *The legislation covering traps and trapping is inconsistent among States which needs to be addressed.*
- *There are many inconsistencies between States over the use of 1080 for fox control. Recommendations to address these problems have been proposed by the Vertebrate Pests Committee (Anon 2002b), which need to be adopted.*

Current fox management strategies and techniques are governed or affected by various Commonwealth, State and Territory laws.

The Commonwealth Government (under the *Environmental Protection and Biodiversity Conservation Act 1999*), along with several State governments (see below), has proclaimed fox predation as a key threatening process. This has implications for the Commonwealth and relevant State conservation agencies and their policies towards fox management, but it does not affect the legal obligations of private landholders. In the case of foxes, the Commonwealth listing required the Department of the Environment and Water Resources (DEW) to prepare a National Threat Abatement Plan (TAP). The Commonwealth must then implement the plan where it applies in Commonwealth areas or seek the cooperation of a State or Territory where it applies outside of Commonwealth jurisdiction.

The objectives and actions that were established by the DEW for the Commonwealth Fox TAP aim to promote the recovery of nationally listed threatened species, prevent further species from becoming threatened, and reduce the impact of foxes to non-threatening levels. These aims are to be achieved by implementing currently available fox control techniques and by providing for the development of new ones and the collection of information to improve our understanding of foxes and their impacts. They also establish the direction the Commonwealth will follow in considering the funding of projects to achieve those aims, but they do not impose any direct authority over State or Territory management strategies and techniques.

'Current fox management strategies are governed by various Commonwealth, State and Territory laws and therefore often vary across Australia.'

In March 1995, all responsibilities for registering pesticides and issuing permits for off-label use were transferred from the States to the Australian Pesticides and Veterinary Medicines Authority (APVMA) in Canberra. The APVMA administers the *Agricultural and Veterinary Chemicals Code Act 1994*. Under this Act, all pesticides possessed, sold, supplied or intended for use in Australia must be registered. An off-label permit may be issued by the APVMA to use a pesticide contrary to its registered use, or to use an unregistered pesticide. However, each State has its own legislation to cover the supply and use of pesticides.

The most common toxicant used against foxes is compound 1080, which is listed as a Schedule

7 substance (a 'restricted chemical product' under Regulation 45 of the Agricultural and Veterinary Chemicals Code Regulations of the Commonwealth). Schedule 7 poisons require special precautions in manufacture, handling, storage or use, or special individual regulations regarding labelling or availability. Individual States have legislation controlling the supply and use of 1080 within their own jurisdictions. Table 11.4 (see the end of this Chapter), summarises the main conditions and directions for the use of 1080 in pest control, as specified in each State's legislation. The use of other toxicants such as strychnine and cyanide is less common and is discussed separately in Section 3.2. Below, the legislative status of foxes and the techniques used in their control are summarised for each State and Territory.

The general use of firearms is covered under various State laws. In New South Wales, for example, this is the *Firearms Act 1996*.

11.1 Australian Capital Territory

Fox status

Pest animal management is now covered by the *Pest Plants and Animal Act 2005*. Under this bill foxes are declared pest animals in the Australian Capital Territory (ACT), and need to be managed according to a developed pest management plan. Fox control is covered by a code of practice (Code of Practice for the Humane Control of the Fox), written in accordance with the *Animal Welfare Act 1992*.

Trapping

All steel-jaw traps are prohibited in the ACT under the *Animal Welfare Act 1992*. Trapping with soft-jaw traps and cage traps is permitted but rarely used for fox control and is covered by a code of practice (Code of Practice for the Humane Control of the Fox). Although not prohibited, the use of treadle snares and snares is not recommended.

Compound 1080

The use of 1080 is primarily controlled by the *Environment Protection Act 1997* and is administered by the Environment Management Authority. Currently there are no registered 1080 products that are approved for the control of foxes in the ACT. Thus the supply and use of 1080 is done under an off-label permit obtained from the APVMA and in accordance with the NSW Department of Primary Industries' (DPI) *Vertebrate Pest Control Manual*.

Baits must be supplied only by authorised officers of the ACT Parks and Conservation Service employed by Environment ACT in the Department of Urban Services. Authorised officers may supply 1080 fox baits to owners, occupiers, managers and authorised agents of property. These recipients must comply with strict guidelines such as distance restrictions, notifying neighbours, and displaying signs as stipulated in the off-label permit. The recipients must also sign an indemnity form.

Current use of 1080

The amount of 1080 used for fox and dog control in the ACT in 2005 was 8.9 grams. This is a similar amount to previous years (N. Webb, Environment ACT, pers. comm. 2006).

Implementation of management strategies and techniques

The pest management plan required under the *Pest Plants and Animal Act 2005* is currently being prepared (K. Styles, Environment ACT, pers. comm. 2006).

11.2 New South Wales

Fox status

Part 11 of the *Rural Lands Protection Act (1998)* allows the Minister for Primary Industries to make orders declaring certain species of animals and insects, which are not protected fauna or threatened species, to be pests on designated public and private land. Pest control orders can be made on the Minister's own initiative after consultation with the State Council of RLPBs or following application to the Minister by an individual RLPB. The Act requires all occupiers of land to control 'fully and continuously suppress and destroy' pests. There is currently no such order for foxes and therefore no legal obligation to control them. Nevertheless, RLPBs do coordinate fox control programmes and supply 1080 baits to those land managers who wish to use them.

The current situation does not preclude the possibility that foxes may become declared pests in the future. Foxes may be kept in captivity because they are not gazetted pests, but few people keep them because of their unsuitability as pets. It is illegal to liberate foxes and other non-native species in New South Wales *(National Parks and Wildlife Act 1974* Section 109*)*. This Act also requires the preparation of a plan of management for each reserve managed by the NPWS. The conservation of wildlife, including the conservation of threatened species, is a goal of each plan. This provides a process for examining the occurrence and distribution of various pest species (including the fox), investigating management strategies and setting priorities for control programmes (NSW National Parks and Wildlife Service 2001).

Predation by foxes is listed as a key threatening process in the *Threatened Species Conservation Act 1995*. This Act aims to conserve biological diversity and to prevent extinction and promote recovery of listed species, populations and ecological communities. The Act provides for the preparation and implementation of species recovery plans and threat abatement plans.

Trapping

All steel-jaw traps and snares are prohibited in New South Wales under the *Prevention of Cruelty to Animals Act 1979* (Section 23). However, the use of soft-jaw traps and cage traps is permitted for fox control. A Code of Practice has been published for the use of cage and soft-jaw traps in New South Wales for fox control (Sharp and Saunders 2005).

Compound 1080

In New South Wales, 1080 is tightly controlled under the *Pesticides Act 1999*, as well as by Commonwealth legislation. Only Authorised Control Officers (ACOs), usually employees of RLPBs or government agencies such as NSW DPI and NPWS, are allowed to obtain, handle, prepare and supply 1080 prepared baits. A 1080 Poisons Register must be kept by each agency that handles 1080. As 1080 is a restricted chemical product, the supply and use of 1080 bait is restricted under off-label permits issued by the APVMA according to the *Agricultural and Veterinary Chemical Code Act 1994*. In New South Wales, pesticide control orders are issued to implement this APVMA policy and specify the manner in which pesticides can be used in New South Wales. The current pesticide control orders relating to 1080 and fox baits are the Pesticide Control (1080 Fox Bait) Order 2002, Pesticide Control (1080 Fox Bait within Gosford City Council) Order 2004 and Pesticide Control (1080 Fox Baits) Amendment Order 2005.

Currently, the only baits allowed on off-label permits for fox control in New South Wales are the registered manufactured Foxoff Fox Bait®, Foxoff Econobait®, De-Fox™, Yathong baits (used exclusively by NPWS) and Authorised Control Officer (ACO)-prepared fowl eggs and meat baits made from fowl heads, chicken wingettes, boneless red meat, 'Densing' pre-made sausage baits that are dyed blue or green, or pieces of offal such as tongue, kidney or liver. With the exception of fowl heads, fowl eggs and chicken wingettes, all other baits prepared by ACOs and requiring injection must weigh about 100 grams.

ACOs may supply 1080 fox baits to owners, occupiers, managers and authorised agents of property within their district once the ACO is satisfied that all obligations of the off-label permit are met. These recipients must comply with strict guidelines, such as distance restrictions, notifying neighbours and displaying signs as stipulated in the off-label permits, which are issued before 1080 baits are received (Schedule 1 under the Pesticides Control (1080 Fox Bait) Order 2002). Recipients must also sign an indemnity form. A new procedure for the keeping of records on pesticide applications came into force in July 2002 (Pesticides Amendment (Records)

Regulation 2002 of the *Pesticides Act 1999*). Where 1080 fox baiting is conducted, this will require the recording of who laid the baits, when, where and how they were applied, and the type of baits used. The records must be made within 24 hours of baiting and kept for a minimum of three years.

A maximum of 50 baits can be issued per property, unless the baiting programme is planned and approved by an ACO. The baits must be laid a minimum of 100 metres apart (suggested distance 200 to 500 metres), and only ten baits can be used per kilometre of track. The exception to this is when the technique of mound baiting is used; in this case multiple baits (typically three) can be used, provided that the total number of baits does not exceed one per hectare. Baits laid on properties smaller than 100 hectares must be checked within three days of laying, and all untaken baits must be destroyed within one week. Replacement baiting is allowed for baits that continue to be taken during the allocated baiting period. There are distance restrictions for rural users (no baits laid within 500 metres of a habitation), but under Schedule 2 of the Pesticides Control (1080 Fox Bait) Order 2002 and the Pesticide Control (1080 Fox Bait within Gosford City Council) Order 2004, these distances have been reduced to 150 metres to allow baiting in sensitive bushland areas in the northern Sydney and Gosford regions.

Ground baiting with 1080 is permissible using either baits prepared by ACOs or manufactured Foxoff® or De-Fox™ baits (both 3.0 milligrams of 1080 per bait), but the baits must be buried and (if practicable) tethered. Aerial baiting is not permitted under the general off-label permits, but the NPWS has previously had an off-label permit that allowed aerial baiting for foxes in certain areas using its own baits (specifically, in Yathong Nature Reserve, in western New South Wales). Off-label permits require that 1080 baits be transported in resealable containers that display adequate notice of the contents.

Current use of 1080

The use of 1080 in fox control has dramatically increased since the early 1980s. This has been particularly well demonstrated in New South Wales, where use went from an annual total of around 57 grams in 1980 to 4815 grams in 2000 (see Figure 11.1). This is equivalent to a change in bait numbers from around 19,000 to 1.6 million. Since 2000 the annual total has declined slightly, down to around one million fox-bait equivalents. This could be coincident with a severe drought, which would have also limited fox numbers and the resources required to control them.

Implementation of management strategies and techniques

The major Act dealing with pest management on private and agricultural land in New South Wales is the *Rural Lands Protection Act 1998,* which governs the operation of RLPBs. The NPWS also manages pest animals on lands under its jurisdiction, in accordance with the *National Parks and Wildlife Act 1974*. Only ACOs have the authority to prepare and supply 1080 products.

Most RLPBs encourage group control of foxes at least once a year, with those participating in programmes such as 'Outfox the Fox' recommending twice a year. The commencement and duration of these group programmes varies within and between Board areas, and usually depends on farm management practices (particularly the timing of lambing), as well as on the perceived targeting of fox behaviour (dispersal of juveniles). Baits are sold to individual landholders all year round.

Since the fox is not a declared pest animal, the coordination and implementation of fox baiting is a service that RLPBs provide to landholders. There is some variation between districts in the level of resources applied to fox control programmes, reflecting differences in landholder and district priorities as well as in the skills, background and enthusiasm of an ACO or RLPB. Some RLPBs will promote coordinated baiting programmes and provide incentives to encourage group coordination and participation. Many of

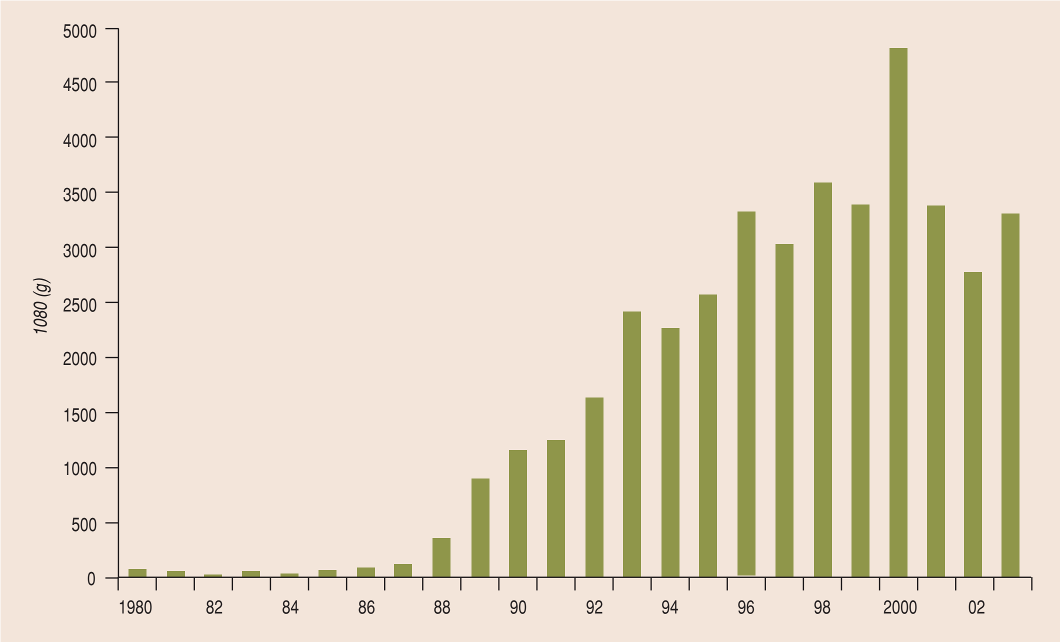


Figure 11.1 *Amount of 1080 (grams) used for fox baiting in NSW from 1980 until 2003 (Source: 1080 Register, NSW DPI).*

them target established groups to help them run the programmes (e.g. Landcare, bushfire-control and footrot-control groups) and actively participate in information evenings to help keep groups up-to-date and motivated.

The Pesticide Training Regulation from the *Pesticide Act 1999* came into force in September 2005. This regulation requires that every pesticide user has to hold a chemical user certificate. This includes all landholders who purchase and use 1080 fox baits. At the point of sale, landholders must also have their obligations and responsibilities explained to them (e.g. storage, distance restrictions, signage, advising neighbours), along with potential risks, occupational health and safety procedures and best practice. They must sign an indemnity form every time they purchase baits. Landholders are limited to 50 baits at a time, unless the programme is approved by the ACO.

Monitoring of fox numbers by spotlight counts is recommended, both before and after baiting, but no organised follow-up or recording of this monitoring takes place. Evidence of the effectiveness of a baiting programme is commonly measured anecdotally by the number of baits taken or by changes in lamb-marking percentages. Most RLPBs measure the success of baiting programmes by the size of group participation.

The NPWS conducts regular fox-baiting programmes on parks and reserves and also participates in management activities on adjacent lands. As a requirement of the *Threatened Species Conservation Act 1995*, NSW NPWS have prepared and implemented a State Threatened Abatement Plan (TAP) for foxes (NSW National Parks and Wildlife Services 2001). This document includes the specific objective of ensuring that fox control programmes are effective in minimising the impacts of fox predation on threatened species and other native fauna across New South Wales. The plan identifies species most at risk from fox predation and the localities where the benefits of fox control will be greatest. Eighty-one priority sites for fox control have been identified across New South Wales, providing recovery actions for 34 threatened species (11 mammals, 15 birds and eight reptiles). This agency encourages group participation by coordinating fox baiting with neighbouring landholders, and in some instances by providing incentives in critical areas, such as paying for baits.

The recently introduced *Game and Feral Animal Control Act 2002* (the Game Act) has added a new dimension to the control of pest animals, including foxes, in New South Wales. As part of this legislation, The Game Council of New South Wales was established. It has 16 members, including two wildlife scientists, and eight members appointed on the nomination of hunting organisations (to be prescribed by the Regulations). Five other members will be appointed on the respective nominations of the State Council of the Rural Lands Protection Boards, the Australian Veterinary Association, New South Wales Aboriginal Land Council, the Minister administering the *Forestry Act 1916*, and the Minister administering the *Crown Lands Act 1989.*

The Game Act will regulate hunting under an enforceable code of conduct and consolidates current hunting permits issued by State Government agencies. This Act does not give hunters unfettered access to public land, and the code of conduct will contain mandatory requirements on animal welfare, firearm safety, access to land, and recognition of target species. Failure to observe these provisions will be grounds for cancellation or suspension of a person's game hunting licence. These requirements will be monitored and enforced by inspectors. What remains to be seen is how the introduction of this legislation will affect ongoing pest animal control activities in New South Wales, especially on public lands. One known example is that the Minister for Primary Industries will have to consult with the Game Council before declaring a game animal listed in Section 5(1) of the Game Act to be a pest under the *Rural Lands Protection Act 1998*. The fox is currently listed as a game animal.

Ideally, the Game Act will simply coordinate the activities of hunters and increase their value as a useful adjunct to conventional pest control programmes. In some situations, hunting, as supported by this legislation, may be seen or promoted as the more effective option, regardless of any cost–benefit comparisons. Unfortunately, such comparisons are limited and are often presented only in terms of the numbers of animals shot rather than the reduction of impact (also see Section 4.3 on bounties). One of the advantages of using hunters in pest control is that the cost of labour is either heavily discounted or absent, given that participation is mostly a form of recreation. This often makes hunting an attractive option to land managers regardless of long-term outcomes, negative consequences or alternative options such as coordinated baiting programmes. There is a need to undertake studies on the effectiveness of hunting; there should be opportunities presented for such studies by the introduction of this Act.

11.3 Northern Territory

Fox status

The fox is a declared feral animal under Section 47 of the *Territory Parks and Wildlife Conservation Act 2000*. A feral animal is defined under the Act as a species that is not indigenous to Australia (or, if it is indigenous, its natural habitat is not in the Northern Territory), whose population or presence in a particular area in the Northern Territory is not able to be easily controlled. Section 48 states that the Minister may declare an area of land in respect of the wildlife, habitat, ecosystem, vegetation or landscape to be a feral animal control area. Under Section 49, the Director may, by notice in writing, direct the owner or occupier of land in a feral animal control area to control or eradicate a declared feral animal on the land, and penalties apply for non-compliance. Section 51 states that a conservation officer (appointed under Section 92 of the Act) may enter a feral animal control area at any time to control or eradicate a declared feral animal in the area.

Trapping

Foxes may be controlled by soft-jaw traps or snares (Section 18 of the *Animal Welfare Act 1999*). Steel-jawed traps are prohibited.

Compound 1080

In the Northern Territory 1080 is controlled by the Department of Primary Industry, Fisheries and Mines (DPIFM), under the *Agricultural and Veterinary Chemicals (Control of Use) Act 2004*. Compound 1080 is classed under this Act as a restricted chemical product, making it illegal to possess or use the substance unless authorised under the *Agricultural and Veterinary Chemicals Regulations* (the *Regulations*). Schedule 2 of the *Regulations* states that the possession and use of 1080 is restricted to a person:

(a) who has successfully completed a training course approved by the Parks and Wildlife Service; and,

(b) whose possession and use of the product is in accordance with the Standard Operating Procedures (SOP) for the product developed by the Service.

1080 authorisation is issued by the Chemicals Coordinator (DPIFM) to applicants deemed to have genuine and sufficient reason to possess and use the product, are competent to handle the product and where the use of the product would not pose an unacceptable risk to the health and safety of the applicant or to the environment. The *Regulations* require records to be kept of all 1080 usage for a minimum period of two years when used for the purpose of pest control.

The Parks and Wildlife Service SOP for using 1080 to control foxes in the Northern Territory prescribes that all officers using 1080 must have current Chemcert III accreditation. The SOP also stipulates that landholders must:

- provide 5 days advance warning of 1080 baiting to all neighbours and occupants of the land to be baited
- display warning signs at all public access points for a minimum period of 28 days
- sign an indemnity form stating all bait locations.

Both Foxoff® and fresh meat baits are used (3.0 milligrams of 1080 per bait). Aerial baiting is allowed, but actively discouraged.

Current use of 1080

Not available.

Implementation of management strategies and techniques

There is virtually no direct landholder involvement in fox control, although some foxes are poisoned as a result of dingo or wild dog baiting operations. In areas where threatened species release programs are being conducted, foxes have been managed using 1080 baiting. A prototype device allowing only fox access to baits (excluding dingoes) is currently being tested and will be used for threatened species management in conjunction with relevant land managers in sensitive areas (G. Edwards, NT Parks and Wildlife Commission, pers. comm. 2006).

11.4 Queensland

Fox status

Foxes are declared pest animals under the *Land Protection (Pest and Stock Route Management) Act 2002.* Under this Act landowners have an obligation to take reasonable steps to keep their land free of these pests. It is also an offence under the Act to introduce, feed, keep, release or supply a declared pest, other than under a declared pest permit. A pest control notice can be issued where landowners are not complying with their obligations, and in case of non-compliance, control measures can be conducted by the local government and costs recovered. Although this places the responsibility of control on the landholder, it has never been enforced (C. McGaw, Queensland Department of Natural Resources and Water, pers. comm. 2003).

Table 11.1 *Number of Foxoff® baits used for fox and wild dog control in Queensland.*

Year	Foxoff®*
1999	20 526
2000	22 382
2001	18 904
2002	28 084

* It is suspected a significant number of these baits would have been used for wild dog control and not specifically for fox control.

Trapping

Foxes (as a declared pest animal) are conditionally exempt from offences of the *Animals Care and Protection Act 2001.* Their control, however, must be performed in a way that causes the animal as little pain as is reasonable and does not involve use of a prohibited trap. Currently steel-jawed traps are not prohibited (a policy currently under review), however they are not recommended without modifications such as rubber jaws or strychnine cloths (M. Gentle, Queensland Department of Primary Industries and Fisheries (QDPIF), pers. comm. 2006).

Compound 1080

The main legislation covering 1080 usage in Queensland is the *Health (Drugs and Poisons) Regulations 1996*. These regulations cover the possession, sale and use of 1080 and baits, which must contain 1080 at a concentration no greater than 0.03%. Only authorised officers (mainly regional operational staff of QDPIF and local government staff) are able to obtain, possess, supply and use 1080 and baits containing 1080. Authorised officers may supply prepared baits to another person (the user) only under the written conditions given to the user by the authorised officer. The user must comply with these written conditions.

Fresh meat baits (125 to 250 grams) containing 3.0 milligrams of 1080 per bait, or manufactured Foxoff®, also containing 3.0 milligrams of 1080 per bait, are used. The *Health (Drugs and Poisons) Regulations 1996* cover the safe possession, supply, use and storage of 1080. Baits must be transported in an approved labelled bag supplied by QDPIF.

Current use of 1080

Currently in Queensland the data for bait use in fox control programmes are recorded together with those on wild dog control. The combined figures for Foxoff® use in 1999–2001 are given in Table 11.1. A very small quantity of fresh meat baits was also used but no details were available.

Implementation of management strategies and techniques

Foxes are not seen to be as great a pest in Queensland as they are in other States. There are few specific coordinated fox control campaigns. The main planned control programmes are conducted on National Parks and other 'protected' areas in order to protect native species. In the rural situation foxes are usually secondary targets during wild dog control campaigns. There is an increasing call for fox control in urban and rural residential areas where foxes prey on poultry, small livestock and native wildlife and where landholders often lack the knowledge, techniques, experience and resources to conduct control themselves. There is also a reluctance to admit that foxes 'live' on their land, rather it is always someone else's problem (C. McGaw, Queensland Department of Natural Resources and Water, pers. comm. 2003).

Landholders are usually required to provide the meat used for any baiting activity and all costs for any other control methods. Local governments and landowners are responsible for delivery of on-ground control activities. QDPIF or local governments supply the bait preparation service for free. Local governments pay QDPIF a 'precept' that is used to provide the 1080, training and extension material.

Monitoring before and after general control activities is not common practice, with assessment of the effectiveness of fox control campaign relying on anecdotal evidence from the landholder(s) involved. However, both fox and native species population numbers are monitored during the control programmes on protected areas by the Environmental Protection Agency.

11.5 South Australia

Fox status

Foxes are declared animals under the *Natural Resources Act 2004*, which is administered by the Natural Resources Management Boards (NRMBs). It is an offence to move, keep or release foxes in South Australia. Foxes are also proclaimed under Section 182 of the Act, which says (in part) that foxes must be controlled and remain controlled across the State. Although NRMBs could enforce landholder responsibility to control foxes, it is accepted that compliance is not enforced, because control techniques and assessments are experimental or difficult to measure (Linton 1999).

Trapping

Under the *Prevention of Cruelty to Animals Act 1985*, small steel-jaw traps are prohibited in South Australia, and large steel-jaw traps are prohibited in most areas, with the exception of use for dog control along the dingo fence and for research purposes. The large steel-jaw traps must be bound with cloth soaked in strychnine or modified.

Compound 1080

The use of 1080 is controlled by the Department of Health under the *Controlled Substances (Poison) Regulations* 1996 (Regulation 16). The Department of Water, Land and Biodiversity Conservation (DWLBC) has a licence to possess and supply 1080. Authorised staff employed by the South Australian Government (in both the NRMB and DWLBC) are the only people authorised by the Department of Health to prepare and sell 1080 products. The DWLBC has developed 'Directions for Use' for 1080 fox baiting. These directions form part of the label, and as such, are legally binding.

Current recommended and required practices for handling 1080 are contained in the 'Directions for Use' and 'Fox Control Programmes in SA' fact sheet. Both of these documents are given to landholders when they purchase 1080 fox baits. In providing 1080 poison bait to land managers, government officers must be satisfied that all criteria under the Department of Health licence have been met and that label directions and instructions for use have been explained to land managers and understood. Although government officers have the responsibility for distributing 1080 poison to land managers, the land managers have the responsibility for distributing baits on their properties.

In South Australia, three forms of 1080 delivery are available for fox control: fresh meat baits manufactured by NRMBs (2.7 milligrams of 1080 per bait); Foxoff® baits, manufactured by Animal Control Technologies (3.0 milligrams of 1080 per bait); and DeFox™ manufactured by PAKS National Pty Ltd, which can be purchased only through NRMBs. Transportation of 1080 is governed by the *Road Transport Reform (Dangerous Goods) Regulations 1997*.

Current use of 1080

In 1993, 1080 was made available for fox control in South Australia, replacing strychnine as the preferred toxin for fox control. The number of baits used in the period 1993 to 1998 is given in Table 11.2. Demand for fresh meat baits has steadily increased since 1993. Foxoff® baits were first sold in South Australia in 1994 and now comprise 35–40% of all fox baits distributed. Bait materials commonly used are mutton, kangaroo, fowl heads, liver, fish and eggs.

In 1993, the use of 1080 for fox control was a relatively new concept. A total of only 2390 fresh meat baits were laid across the State, with the Riverland area accounting for over 70% of all baits distributed. The main areas targeted involved mallee fowl (*Leipoa ocellata*) protection at Mantung–Maggea and tortoise protection around Lake Bonney. Some baiting trials were conducted on large sheep properties. By 1994, fox bait use had increased 20-fold, and this dramatic increase continued for the next few years as more areas became involved. Since 1996 the total number of baits has remained relatively steady at just over 180,000 a year.

Table 11.2 *Number of 1080 fox baits used in South Australia since the introduction of 1080 as a fox control agent in 1993.*

Year	No. of meat baits	No. of Foxoff® baits	Total no. of baits
1993	2 390	0	2 390
1994	41 869	4 036	45 905
1995	76 244	57 416	133 660
1996	120 068	66 833	186 901
1997	110 694	70 394	181 088
1998	121 885	65 210	187 095
2004/05	154 132	99 277	253 409

The number of landholders involved in fox-baiting programmes increased between 1993 and 1997 (from 19 to 2602); these numbers had dropped by 1998 (1371), although the number of baits distributed remained comparable to that in 1997. Anecdotal evidence from local officers to explain this reduction in landholder participation suggested that the depressed sheep market and the passing of the novelty factor for fox baiting were to blame. Another reason might have been that fox numbers were low because of a reduction in rabbit numbers in the wake of a calicivirus outbreak or the previous year's fox baiting, thereby reducing the perceived risk of fox damage.

Implementation of management strategies and techniques

Linton (1999) reports that most NRMBs encourage group control of foxes at least once a year. The most common time for programmes to run is in autumn, as this fits in with farm management practices (autumn or early winter lambing) as well as perceived targeting of fox behaviour (dispersal of juveniles). The commencement and length of the programmes vary from district to district. Baits are sold to individual landholders all year round, but there is little coordinated baiting outside the autumn period.

For the coordinated autumn baiting program mes, NRMBs generally advertise in the local paper or their own (or council) newsletter, announcing the time and duration of the programme and where baits can be obtained. To encourage groups, many NRMBs will take the point-of-sale to a local community location. A few NRMBs subsidise the bait service on a particular day to encourage group coordination (e.g. baits injected for free on one day across the whole district). NRMBs also target established groups to help them run the programmes (e.g. Agricultural Bureau, Landcare groups). Many officers are actively involved with established groups and organise information evenings to help keep groups up-to-date and motivated.

Most NRMBs see fox baiting as a service they can provide to landholders, but there may be little analysis of the outcomes or benefits. There is quite a variation between NRMBs in terms of the level of resources applied to fox control programmes, reflecting the skills, background and enthusiasm of an officer or an NRMB, as well as the district priorities (e.g. some districts have particular wildlife priorities that tend to draw more heavily on resources).

Landholders do not require formal training (e.g. farm chemical users' courses, 1080 handling certificate) to purchase 1080 fox baits. At the point of sale, they have their responsibilities explained to them (e.g. storage, signage, advising neighbours), along with the potential risks, occupational health and safety procedures and best practice. They must sign an agreement form every time they purchase baits which (amongst other things): specifies how long they can store the baits (i.e. a use-by date); and, confirms that they understand the 'Directions for use' and agree to abide by all instructions (or be in contravention of a number of Acts).

Board officers have no statutory power to investigate whether baits are handled and stored correctly or disposed of by the use-by date, neighbours advised correctly, or the programme evaluated. Follow-up occurs only if a complaint is made (e.g. non-target poisoning of a domestic dog). Little is known about the practices employed by individuals in fox-baiting programmes. No organised monitoring takes place. Most landholders measure the effectiveness of their baiting programmes by the number of baits taken, although many will also report increases in lamb-marking percentages. Local officers often hear this anecdotal evidence about the effectiveness of fox control, but most of the information is not recorded.

There are several ongoing, large-scale, collaborative fox control programmes in South Australia. The West Coast Integrated Pest Management Program (WCIPMP) is a community-based programme managed by a partnership between the Eyre Peninsula NRMB, the SA Department for Environment and Heritage, and a community steering committee (WCIPMP 2005). This programme was begun in 2000 to support reintroductions of brush-tailed bettongs (*Bettongia penicillata*) at Venus Bay Conservation Park. Since then, the number of participating landholders has expanded from 30 to 330. The focus of on-ground activities to date has been fox control, but with the emphasis on an integrated approach, rabbit and weed control have been incorporated, and a variety of best practice pest management methods are encouraged (WCIPMP 2005).

Operation 'Bounceback' is an 'ecological restoration' collaborative programme between SA Department for Environment and Heritage and their neighbouring landholders in the Flinders Ranges National Park (FRNP). This project commenced in 1992 with the initial aim to protect local populations of yellow-footed rock wallaby. Intensive fox baiting, using 1080 dried-meat baits, around the wallaby colonies soon expanded to cover the whole park and a buffer zone on neighbouring properties. Since 1994, ground baiting has occurred four times a year with 4–5 baits per square kilometre, buried along set transects. Application was successfully made to the Natural Heritage Trust for funding to expand the programme, and 'Bounceback 2000' was launched in May 1998. This new programme is aiming to build on the gains in FRNP and expand to Gammon Ranges National Park (Anon 1999c; Holden 1999; De Preu 2000). An aerial baiting programme, similar to that used in Western Australia and at Yathong National Park in New South Wales, has been developed (De Preu 2000).

11.6 Tasmania

Fox status

Foxes are declared 'vermin' under the *Vermin Control Act 2000*, and their destruction can be ordered by the secretary of the Department of Primary Industries and Water (DPIW). They are also prohibited animals under the provisions of the *National Parks and Wildlife Act 1970*, and not even the Minister can issue a permit for their importation.

Until recently, the last known fox to have been killed in the wild was a young vixen in 1973 (Saunders et al. 1995). An adult-sized fox was observed (and confirmed by footprints) escaping off a ship from Melbourne in Burnie dock in May 1998, but despite an extensive search the individual was never located.

In 2001, reports of fox introductions and a spate of sightings stimulated the government to set up a fox task force to investigate. It was subsequently believed that fox cubs were caught in Victoria in 2000 and illegally transported to Longford near Launceston. These foxes were raised (reportedly on native fauna to enhance survivorship) and released. This process was repeated in 2001, with the total number of foxes released believed to be between 11 and 19. The motivation for these alleged illegal activities is unclear. There were also claims during this period of other events such as a fox escaping an imported shipping container which was opened on farmland.

By 2007, over 1000 sightings of various quality had been reported, fox footprints, scats and blood confirmed, and four carcases recovered — one with an endemic species in its gut and another a ten week-old pup suggesting successful local breeding. In March 2002, the Tasmanian Government offered a $50,000 reward for information leading to the prosecution of the persons responsible for bringing the foxes into Tasmania. The government also approved measures to deal with the fox incursion, including awareness and training programmes and the implementation of a broadscale 1080 baiting programme.

Some Tasmanians remain sceptical about the presence of foxes in the State, and this has made it difficult to fully implement control programmes and some landowners in key areas have not provided access for fox control activities (Emms et al. 2005). The coincidental dramatic decline in the Tasmanian devil (*Sarcophilus harrisii*) population due to Devil Facial Tumour Disease has probably aided the establishment of the fox population due to reduced competition and possibly reduced predation of fox cubs.

The situation with foxes in Tasmania was recently reviewed including recommendations for on-going control activities (Saunders et al. 2006). These recent events in Tasmania suggest lessons for other Australian islands. It should be a priority, with legislative support, to maintain the fox-free status of key islands around Australia such as Kangaroo Island. The Tasmanian situation is a potential environmental disaster and every effort should be taken to ensure foxes are eradicated from this State.

Prior to the current fox eradication campaign, all reported sightings of foxes were investigated by DPIW and its predecessors (N. Mooney, DPIW, pers. comm. 2000). However, in recent years, the sheer volume of reports has meant that only high quality recent sightings can be investigated, and most effort now goes into responding to physical evidence of fox presence.

Trapping

All leg-hold traps are banned in Tasmania under the *Animal Welfare Act 1993*. Padded leg-hold traps may be used with ministerial approval, and large cage traps may be freely used as part of the fox eradication programme.

Compound 1080

The use of 1080 in Tasmania is regulated under the *Agricultural and Veterinary Chemicals (Control of Use) Act 1995*, the *Poisons Act 1971,* the *Animal Welfare Act 1993* and the *Police Offences Act 1935*. Until the recent introductions of foxes it was not legal to use 1080 in Tasmania for any form of predator control. A code of practice for the use of 1080 against foxes under the current emergency situation and within the responsibilities of the above legislation was released in June 2002.

An amendment to the *Agricultural and Veterinary Chemicals (Control of Use) Act 1995* was passed by the Tasmanian parliament in 2004, making it unlawful for government agencies to poison native wildlife using 1080 beyond December 2005. A separate sunset clause, which expires in October 2006, provides an exemption to any person employed as part of the Fox Task Force, ensuring that fox control can continue.

Current use of 1080

Under the Tasmanian fox eradication campaign, baits were initially dosed with 2.5 milligrams of 1080, but this was increased to 3 milligrams of 1080 in 2002/03 as it became clear that the non-target risks posed by the buried baits were minimal. Fox baiting figures are: 5621 baits (14.1 grams of 1080 in total) laid in 2002/03; 17,170 baits (51.5 grams of 1080) in 2003/04; 23,152 baits (69.5 grams of 1080) in 2004/05; and, 17,340 baits (52.0 grams of 1080) in 2005/06.

Implementation of management strategies and techniques

To deal with the current situation, 1080 concentrate may be either stored or used only by officers authorised as Competent Officers by the Registrar of Chemical Products or the Secretary of DPIW, under the provisions of the *Poisons Act (1971).* Locally produced baits containing less than 0.04% 1080 are registered for sale under conditions specified by the APVMA. In addition, Foxoff® baits and dried meat baits can be used in Tasmania under an APVMA permit. A poisoning service will not be supplied until the landholder or their agent has completed and signed an 'Application to Use Poison' form. Where baits are employed, an Authority to Purchase and Use 1080 Bait must be issued under the provisions of the *Poisons Act (1971)* by the Competent Officer. The Competent Officer may impose any conditions deemed necessary. Landholders using 1080 poison must give written notification of their intention to lay poison, with the proposed date, to all neighbours on adjoining properties and to every neighbour whose property boundary lies within 500 metres of the intended poison line; this notification must be made at least four working days before the poison is laid.

The *Police Offences Act (1935)* requires the occupier of property where 1080 poison is used to display on gates and other conspicuous places on the property, notices advising that 1080 poison has been laid. These notices are to be in a format approved by DPIW and will be issued by them and must be displayed for a minimum of 28 days. Uneaten baits must be collected and removed from the property within 21 days, or as instructed by the Competent Officer. The Fox Free Taskforce exceeds these requirements for notification and also loans dog muzzles to further reduce any risk of poisoning domestic dogs.

11.7 Victoria

Fox status

Foxes are declared established pest animals under the *Catchment and Land Protection Act 1994.* This Act specifies (Part 3, Section 20) that land managers of both public and private lands are responsible for managing pest animals on their land. Under Section 75 it is also an offence to import, keep or sell a fox in Victoria without a permit. Amendments made to the *Catchment and Land Protection Act 1994* in 2003 also make it an offence to release a pest animal in Victoria.

Predation of native wildlife by foxes is listed as a threatening process under Schedule 3 of the *Flora and Fauna Guarantee Act 1988*. Thus fox management is part of the objectives of flora and fauna conservation in Victoria (Section 4 of the Act).

Trapping

Large steel-jaw traps and neck snares are prohibited in Victoria under the *Prevention of Cruelty to Animals Act 1986*. Snares and soft-jaw traps are permitted, and small steel-jaw traps, which have a code of practice covering their use, are permitted for rabbit control.

Compound 1080

The use of 1080 in Victoria is regulated by the *Agricultural and Veterinary Chemicals (Control of Use) Act 1992*, which is administered by the Department of Primary Industries, Victoria. This department employs authorised officers, who are the only people allowed to prepare and sell 1080 products in Victoria. Any person using 1080 must have a valid Agricultural Chemical User Permit issued under Schedule 1 of that Act, or be acting under the direct and immediate supervision of a person holding this permit, and written records of this use have to be kept for two years, as detailed in the Agricultural and Veterinary Chemicals (Control of Use) Regulations 1996. The regulations for the use of poison baits are controlled under Part 10 (Section 95) of the *Catchment and Land Protection Act 1994* and under Department of Sustainability and Environment (DSE) policies and guidelines.

There are three fox bait products registered for use: the commercially manufactured Foxoff® and De-Fox™ baits; and, a DSE-registered bait made from no more than 250 grams of deep-fried liver containing 3.3 milligrams of 1080 per bait. All land managers intending to carry out 1080 fox control programmes must obtain their baits from an authorised officer by written application and must demonstrate a genuine need for the poison. It is up to the land manager to be aware of, and understand, the conditions of use specified on the label and to ensure that all safety requirements, legislation and operational requirements are fully met (e.g. they must provide written notification to all neighbours at least 24 hours before the laying of baits and erect poison warning signs at all entry points to the poisoned area). These obligations are detailed in the Landcare notes 'Directions for Use of Commercial Fox Baits in Victoria *and* 1080 Poison Baits for Pest Animal Control.'

Containers used to transport baits must comply with the provisions of the *Drugs, Poisons and Controlled Substances Act 1981* and must be approved by an authorised officer.

Current use of 1080

For current usage in Victoria see Table 11.3.

Table 11.3 *Number of 1080 fox baits used in Victoria (99% of the baits used are Foxoff®; R. Williamson, Department of Sustainability and Environment, pers. comm. 1999).*

Year	No. of fox baits
1995–96	204 881
1996–97	216 357
1997–98	158 694

Implementation of management strategies and techniques

The *Catchment and Land Protection Act 1994* is administered by DSE. The Department employs authorised officers who have authority under the Act and are the only people allowed to prepare and sell 1080 products in Victoria.

The DSE's position on fox control is that it provides private benefit. The Department provides limited funding for fox management through the Pest Management Programme. Coordinated group control programmes are encouraged, and advice and a bait-issue service are provided. DSE will advise on technical and planning actions for integrated fox management, which may include advice on baiting as well as other alternative controls.

Fox numbers should be assessed both before and after control. The methods recommended are spotlight counts in the early hours or identification of fox signs such as tracks or scats. Free feeding for seven days before the laying of poison bait is also advised. This ensures that target bait-take is occurring and is claimed to result in maximum bait-take.

11.8 Western Australia

Fox status

Foxes are declared under Category A5 of the *Agriculture and Related Resources Protection Act 1976*. This declaration means that foxes must be controlled. Despite this declaration, landholders are rarely forced to control foxes on their land.

Trapping

Under the *Animal Welfare Act 2002* steel-jaw traps are not permitted for controlling foxes in Western Australia unless modified or padded. A permit must be obtained from the Department of Agriculture and Food Western Australia (DAFWA) to trap within certain municipalities listed under the *Agriculture and Related Resources Protection (Traps) Regulations 1982*. Neck snares are illegal under the *Wildlife Conservation Regulations 1970*.

Compound 1080

Section 69 of the *Agriculture and Related Resources Protection Act 1976* gives DAFWA and the owners and occupiers of land the authority to lay poison for controlling foxes. Regulations for the use of 1080 in Western Australia were covered by the *Health (Pesticides) Regulations 1956*, made under the *Health Act 1911* and the *Poisons Act 1964*, both administered by the WA Health Department. The Regulations have recently been reviewed and updated, and the Pesticide Regulations relating to 1080 have been repealed and replaced by the *Poisons (Section 24) (Registered Pesticide 1080) Notice 1999*.

Under this new legislation, 1080 products can be used for purposes approved by the Chief Executive Officer of an authorised government department (DAFWA or Department of

Environment and Conservation (DEC)), or for purposes approved by the Commissioner of Health, depending on the circumstances. Only authorised officers from DAFWA and DEC can authorise the supply and use of 1080 products to landholders in Western Australia. Landholders may possess and use 1080 only when authorised. Licensed retailers may possess 1080.

Field-injected dried-meat baits (3.0 milligrams 1080 per bait) and fowl eggs (3.0 milligrams 1080 per egg) for fox control may be prepared only by staff from an authorised Department or by a licensed Pest Control Operator. 1080-impregnated oats (3.0 milligrams 1080 per single oat grain) may be obtained by landholders for use in preparing fox baits. Factory-prepared fox baits may also be purchased by authorised landholders.

Before 1080 baits are supplied, a landholder must satisfy an authorised officer that foxes are a problem, that the baits can be used with minimal non-target risk, and that they will comply with all of the imposed conditions, as detailed in Anon (2003b). A landholder must be trained in the safe use of 1080 and its security (as stipulated by the Commissioner of Health). If satisfied, the authorised officer issues the landholder with a voucher that enables the landholder to purchase up to a defined number of baits within a specified time period. Vouchers will usually not be issued to hobby farms and farms close to densely settled areas.

The *Poisons Act 1964* includes requirements for the sale of 1080 (detailed sale records, signature at the point of sale, detailed records of amounts of 1080 on hand) and for packaging and labelling. The 1080 baits must be transported and stored under effective security to comply with the *Dangerous Goods (Transport) Act 1998* and *Dangerous Goods (Transport) Regulations 1999,* the *Poisons Act 1964* and the *Health (Pesticides) Regulations 1956*. Both DAFWA and DEC have their own policies relating to the transport of 1080 products.

Current use of 1080

DEC uses approximately 770,000 dried-meat fox baits a year, mainly for its 'Western Shield' programme. Landholder use in 2001–02 in agricultural and pastoral areas was approximately 51,000 dried-meat baits and 8000 field-prepared baits (mostly meat, some eggs) for foxes. Unknown numbers of Foxoff® baits were also used in these areas. The direct government cost of baiting is in the order of $0.25 per hectare per year, using the four times a year, one bait per 20 hectare prescription. The total cost of baiting programmes, including the costs of research, fauna monitoring and public relations and education, would be about double this. Besides State Government financial support, DEC receives significant corporate sponsorship (e.g. from Alcoa and Tiwest) to help in the baiting and captive breeding programmes.

Implementation of management strategies and techniques

The *Agriculture Protection Board Act 1980* (APB Act) and *Agriculture and Related Resources Protection Act 1976*, administered by DAFWA and the APB, contain the main regulatory powers for fox control on agricultural land. The *Conservation and Land Management Act 1984*, administered by DEC, deals with fox control on public land. When DEC wishes to bait private land for conservation purposes, a DEC officer may act as an agent of the landholder to bait the landholder's property.

DAFWA recommends a range of control options for landholders, described in their Farmnotes *Options for Fox Control* (Anon 2001) and *Fox Baiting* (Anon 2003a). Although fox control is advised only when there is a problem or to pre-empt a potential problem (e.g. before lambing), the most effective period is thought to be during winter and spring, when foxes are less mobile and food demands are high. Baiting as part of broader control programmes is encouraged, along with other attention to livestock husbandry methods, exclusion fencing, fumigation, shooting and (in some instances) trapping. Community campaigns are encouraged to reduce costs and increase effectiveness. There has been varying success in getting these types of programmes occurring in a consistent and ongoing manner. A programme initiated in 2004, 'Red Card for the Red Fox' has grown to involve 700 wheatbelt farmers in 2005. The programme is a joint effort between various catchment groups and DAFWA. It has been well supported by landholders and is expanding into additional regions in 2006.

In designated 'High Risk Areas' (in special rural zones, on hobby farms, and on farms and reserves close to town sites and closely settled areas), meat baits must always be buried one to two centimetres deep or tethered by a length of light wire or similar. In 'Low Risk Areas' (typical rural properties with low numbers of people) meat baits can be buried, tethered or hidden under vegetation, rocks or fallen timber. In all areas, egg baits should be buried 2–10 centimetres deep, although burying with a light covering of soil is normal practice. Baits should be left out for at least ten days.

DEC currently baits approximately 3.5 million hectares under its 'Western Shield' fox control programme. Most of this is done using aerial baiting, four times a year. Any area smaller than 20,000 hectares is baited monthly to address fox reinvasion. Ground baiting of small areas (<20,000 hectares) is done on existing tracks, where baits are placed at 200-metre intervals (approximating 5 baits per square kilometre) every four weeks. DEC encourages coordinated campaigns with landholders and does undertake baiting on behalf of other government agencies that have large land holdings contiguous to their own that would benefit nature conservation objectives (e.g. defence land or vacant Crown land).

DEC measures the success of these fox control programmes in terms of the fauna response to fox control. Fauna monitoring is done at least once a year at established sites or transects across the baited targets. In areas where fauna re-introductions have taken place, monitoring is more intensive initially.

11.9 Other Issues

Strychnine and cyanide

The use of strychnine as a toxicant is being phased out in most States, although it is still registered for use against foxes in Queensland and for wild dogs in most States (mainly for the binding of leg-hold traps to hasten death and prevent prolonged suffering). Cyanide is not a registered vertebrate pesticide in any State in Australia. Limited-use permits may be obtained for research purposes.

Urban management

Because of restrictions on the use of baiting and shooting near settled areas, there are problems with using conventional control methods against foxes in urban areas (see Chapter 9).

11.10 Consistency between State legislation

Although the fox is categorised differently under each State's legislation, the control implications appear similar across the nation. In States where foxes are present and declared as pest that must be controlled or eradicated (e.g. in South Australia, Victoria, Western Australia and Queensland) enforcement is uncommon, and fox control is largely a voluntary activity. In New South Wales and the Australian Capital Territory, where the fox is not a declared pest that must be controlled, fox control is also a voluntary activity. The legislation of the Northern Territory differs slightly from that of other States in that the fox is a declared pest animal but control is not necessary unless an area is declared a pest control area. Currently there are no declared areas for fox control in the Northern Territory, so fox control is a voluntary activity.

Comparison of legislation and control effort among States suggests that there is little need for the legislative requirement to undertake fox control, with the possible exception of the present situation in Tasmania. There are a number of problems associated with the legal declaration of foxes as pest animals, and this explains why fox control across the nation is mostly voluntary, regardless of legislation. These problems include:

Criteria for assessment. How does a statutory body assess that a particular area of land has a fox problem? Foxes are cryptic animals and are extremely difficult to census. Spotlight counting is the only practical method: sand pads and den counts are too labour intensive. Spotlight counts can indicate the presence of foxes, but at what level do counts indicate that foxes are at pest proportions?

Fox ecology. Foxes, like other canids, use dispersal as a mechanism to ensure that there is a constant turnover of the population and a supply of individuals to inhabit vacated territories. This means that there is usually a rapid replacement of any animal that dies by poisoning or other causes. Foxes are also highly mobile animals and move over territories that can include many properties. This is particularly the case in resource-rich areas, where foxes are at their highest densities. In these circumstances, who has ownership of the pest problem?

Control techniques. At present, 1080 baiting is used as the only practical broadscale and cost-efficient fox control technique. Other methods have been shown to be ineffective or inefficient. In many cases 1080 baiting produces short-term benefits. However, on a regional or State-wide basis, control recommendations would probably not withstand scrutiny if proof of cost-effectiveness were required. If foxes were legislatively declared a pest, numerous issues would arise in urban fringe areas. Research has already identified potential problems with existing bait distance restrictions.

Crown lands. How could such legislation be enforced in Crown lands? The problem could be considered case-by-case in a National Park, for example, but this would create difficulties with surrounding properties, given the mobility of foxes.

Wild dogs. These could be used as a precedent to have foxes declared. The wild dog issue has many of the same problems mentioned above. There is some historical precedent with wild dogs, but it should not be used as justification to classify foxes in the same way (as declared pests). Wild dogs also tend to be a much more localised problem where the damage is immediately apparent (e.g. large kills in one night) and a sufficient incentive for landholders to undertake control.

Using New South Wales as an example, the present powers, (e.g. regional declaration as a pest animal) are sufficient to deal with a specific and localised fox problem. This is a more realistic option than a State-wide declaration (and obligation to control), which could probably be successfully challenged in court.

The Commonwealth Government, along with several State Governments, has proclaimed fox predation as a key threatening process. This has implications for the relevant conservation agencies and their policies and fox management strategies, but it does not affect the legal obligations of private landholders.

'Currently fox control is essentially a voluntary activity in most regions of Australia.'

The legislation covering traps and trapping is inconsistent among States. Some States have prohibited steel-jaw traps entirely, other States permit their use with some modifications for some species, and some States still legally permit the use of this type of trap without specific restrictions. Alternative traps, such as soft-jaw traps, cage traps and treadle snares, are permitted in all States except Tasmania. Considering the animal welfare issues and the general availability of more humane alternatives, the inconsistency associated with the use of steel-jaw traps needs to be addressed.

The dose rates of 1080 in fox baits is inconsistent among States, despite the recommendation of a standard fox dose rate of 3.0 milligrams in the 1993 report to the Vertebrate Pests Committee on the national standardisation of 1080 dose rates (Thompson 1993). Standard dose rates need to be adopted as part of an overall package of quality assurance to ensure the continued availability of 1080 to control foxes and other pest animals. For example, it is difficult to present a consistent case for non-target risk minimisation if dose rates vary across the nation. This is regardless of regional differences in the tolerance of native wildlife to 1080. In the more recent report of the 1080 working group of the Vertebrate Pests Committee (Anon 2002b), the recommendation is for dose rates of between 2.5 and 3.2 milligrams of 1080 per bait.

There are general consistencies in bait materials used for fox baiting. The differences that do exist reflect the availability, cost and preference of bait materials (e.g. kangaroo, beef or mutton used if landholders supply their own bait; offal if an abattoir is nearby), along with the method of baiting used (aerial versus ground) and the presence or absence of non-target species (e.g. size of bait, dried or fresh baits and the method of bait preparation). Although current and future research may indicate which bait materials are most appropriate, selection should be left to individual States and agencies on the basis of local experience. Some bait materials may be inappropriate in terms of 1080 leaching rates, attractiveness to non-targets, cost-effectiveness and other regulatory issues. Ongoing research and evaluation should be carried out to determine whether any of the presently used bait materials should be withdrawn. The 1080 working group of the Vertebrate Pests Committee has recommended that fox bait materials should be registered prepared baits, fresh red meat or liver, chicken wings or eggs. Where other baits are not successful, fish is an acceptable bait material. Minimum weight for fresh meat and liver baits should be 75 grams (Anon 2002b).

'Dose rates of 1080 vary among the States. It has been recommended that these rates should be standardised to between 2.5 and 3.2 mg of 1080 per bait.'

The inconsistencies in the requirements and depth of burial for baits (see Table 11.4) reflects not only the presence of non-target species, the type of baits used and the method of baiting, but also the lack of strong scientific evidence to support the various strategies.

Baiting density has been investigated for aerial baiting programmes in Western Australia, with a density of 5 baits per square kilometre found to be effective for fox densities ranging between 0.5–1.0 adult foxes per square kilometre. The distance between baits in ground baiting programmes, particularly in the eastern States, has been increased over the past few years after observations of multiple uptake of baits by individual foxes and studies of bait caching by foxes. Although effective baiting density is thought to be dependent on many factors (such as the density of fox populations, the type of habitat, the seasonal conditions and the method of laying the baits), there have been no scientific studies directly investigating this aspect of ground baiting. The wide range and variation in recommended baiting densities probably not only reflect differences in fox densities and habitat but also this lack of scientific knowledge.

Most States specify that one bait should be laid at each bait station. In New South Wales the practice of mound baiting is allowed where multiple baits (arbitrarily three) can be placed at one bait station. If this technique for baiting is used, the total number of baits must not exceed one per hectare.

'Variations between States exist in the conditions and directions of use of 1080 baits for fox control.'

Variations between States exist in the conditions and directions of use of 1080 baits for fox control (summarised in Table 11.4). The 1080 working group of the Vertebrate Pests Committee has recommended that the minimum distance should be standardised at 150 metres or greater from a dwelling unless written permission is obtained from the resident, 20 metres from specified watercourses, 5 metres from boundary fences for ground baiting and at least 5 metres from formed public roads (Anon 2002b).

In each State there is a general requirement for notice to be given to neighbours and the general public. However, the timeframe in which this notice must be given varies, as does the specification of who is notified (from people within 500 metres of the baiting to all neighbours or even the general public in the area). The 1080 working group of the Vertebrate Pests Committee (Anon 2002b) has recommended that written notification should be given to all adjoining landholders at least 72 hours before baiting, unless under special circumstances.

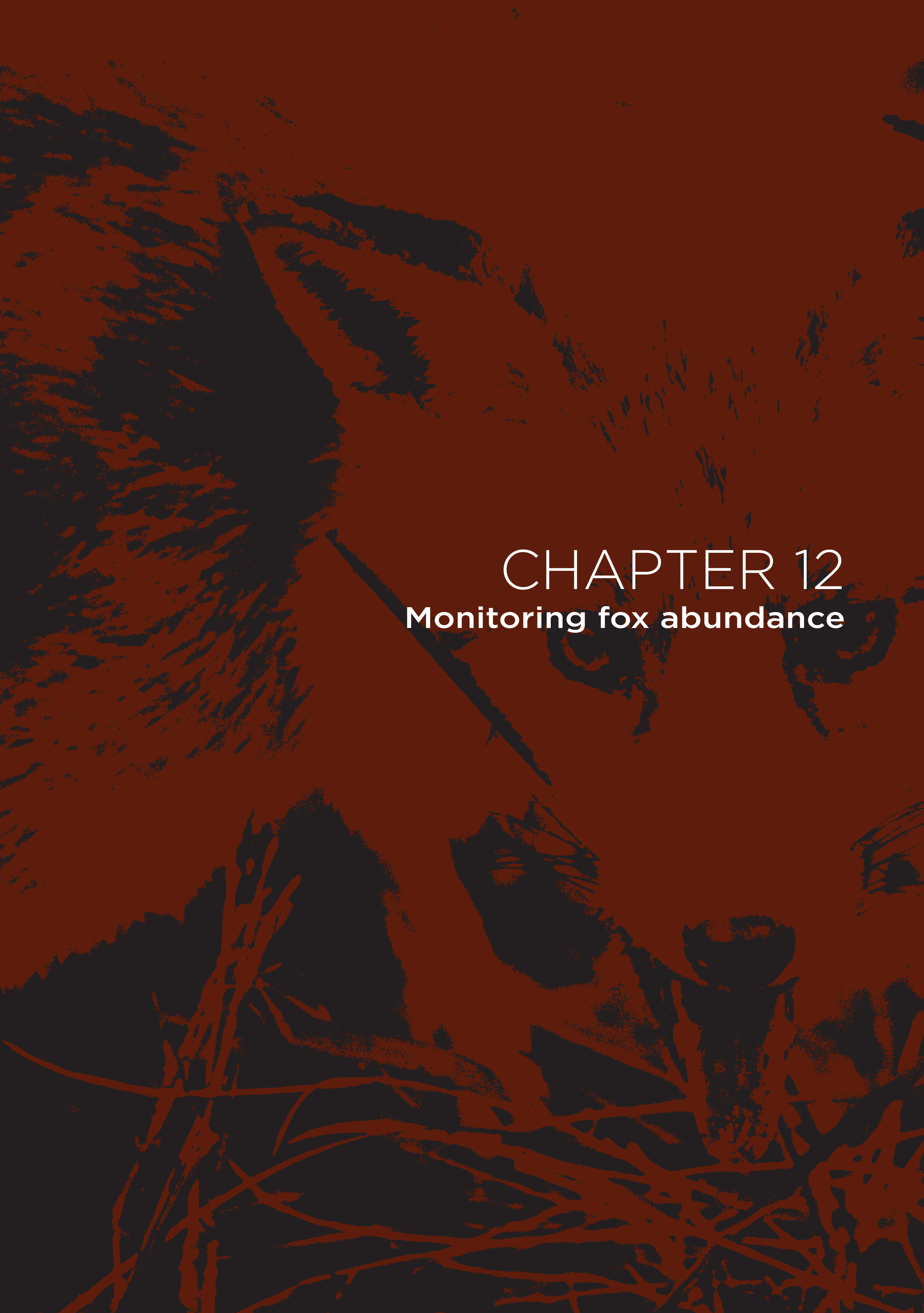
There is also variation in the placement of warning signs from State to State. Some require signs only on land that is accessed by the public, whereas other States require all land where baits are laid to display warning signs. The time period for the displaying of these warning signs also varies, with some States not setting any specified period (see Table 11.4). Again, the 1080 working group of the Vertebrate Pests Committee has recommended that signage should be compulsory for all lands where baiting occurs and should be for a minimum of 28 days after baiting. Each sign should include the date laid, which toxin has been used, and for which pest animal, and contact numbers for further queries.

Only South Australia and Queensland specify a minimum size for properties that are allowed to use 1080 baits (5 hectares and 40 hectares, respectively). In Western Australia, an assessment (which takes into account distance requirements but not necessarily property size itself) is made by the authorised agent to determine the risks posed by 1080 baiting. In New South Wales and the Australian Capital Territory there is no limit on property size but distance restrictions must be met, which precludes smaller properties, and strict rules apply to baits laid on properties less than 100 hectares. In Victoria no limit on property size is specified (although approval to bait must be obtained from the authorised officer, who would require distance restrictions to be met). Baiting with 1080 is not allowed in urban/residential areas.

Table 11.4 *Conditions and directions for baiting using 1080 baits, as specified in State legislation. In Queensland these are not direct legislative requirements but are linked through legislation to written instructions.*

State or territory	Depth of burial (cm)	Distance apart (m)	Specified minimum distances: ground baiting	Specified minimum distances: aerial baiting	Neighbour notification	Warning signs	Checking of baits	Replacement of baits
ACT	5–10	200–500	Boundary fence 5 m Habitation 500 m Domestic water supply 10 m	Not applicable	72 hours before baiting	All entry points From start of baiting for minimum of 4 weeks	Check regularly	Replace every 2 or 3 days until bait take is minimal
NSW	5–10	200–500; min. 100	Boundary fence 5 m Habitation 500 m Domestic water supply 10 m	Not applicable	72 hours before baiting Emergency situation: just before baiting	All entry points From start of baiting for minimum of 4 weeks	Check regularly	Replace every 2 or 3 days until bait take is minimal
NT	Not applicable	200-500 in bait station	Dwelling 1 km Watercourse 20 m Public highway 250 m Rest area on highway 2 km	Not applicable	5 days before baiting	Prominent position on property and all public roads before baiting	Regularly	As required
Qld	Not specified	Not less than 250	Boundary fence 5 m Habitation 2 km Declared road 50 m Town area 5 km	As for ground baiting	72 hours before baiting	All entry points Kept for a minimum of 1 month after baiting	Check regularly	Replace for 2–3 weeks or until bait-take drops off

State or territory	Depth of burial (cm)	Distance apart (m)	Specified minimum distances: ground baiting	Specified minimum distances: aerial baiting	Neighbour notification	Warning signs	Checking of baits	Replacement of baits
SA	5	500	Habitation 500 m	Not applicable	7 days before baiting	All entry points Not more than 3 weeks before and not less than 2 weeks after baiting	Check regularly	Continual replacement not recommended until follow up assessment. If still foxes present replace baits at weekly intervals. Stagger / pulse baiting if high levels of caching suspected.
Vic	8–10	500–1000	Boundary fence 20 m Habitation 150 m Domestic drinking water supply/watercourse/ permanent water 20 m	Not applicable	24 hours before baiting	All entry points For duration of baiting	Check at least every 2 days	Continual replacement until no more baits are removed.
WA	Meat, buried 1–2 or tethered. Eggs, buried only, 2–10	200 (5 baits/km^2)	Agricultural areas: Habitation 100 m Boundary fences 20 m Roads/reserves/public places 20 m Dams/watercourses 20 m Picnic/recreation sites 500 m Pastoral areas: Towns/settled areas/ dwellings 5km Roads/public places 1 km	Agricultural areas: Roads 250 m Boundary fence 500 m Recreation area 500 m Pastoral areas: Towns/settled areas/dwellings 5 km Roads/public places 1km	72 hours before baiting	Not covered by State legislation, but the policy of Ag WA and CALM is all entry points. For duration of baiting and kept for a minimum of 1 month after baiting.	Not applicable	Not applicable



CHAPTER 12
Monitoring fox abundance

12. Monitoring fox abundance

Key issues

- *As the fox is generally a secretive animal that often occurs at low densities, obtaining accurate estimates of its abundance still remains a challenge.*
- *Complete counts are rarely possible for foxes (or any other wildlife species).*
- *The evaluation of fox control programmes in Australia will continue to rely mostly on using indices of abundance, which are relatively cheap and straightforward to collect. Further experiments using density estimates are needed to help us better interpret the accuracy and application of indices.*
- *Studies that measure abundance in a variety of ways should be encouraged. Estimates by line transect counts and DNA sampling need to be further investigated under Australian conditions.*

To completely assess the need for fox control and to monitor the effectiveness of management programmes, we need to measure changes in the impact of foxes. Quantifying such impacts is usually difficult and costly, so fox abundance is often used as an approximate indicator. Where the objective of a fox control programme is to reduce the impact of fox predation, a more appropriate measure of effectiveness is always the response of the prey species (see Chapter 13).

12.1 Counting foxes

Methods of counting foxes to monitor population abundance fall broadly into two categories: complete counts and incomplete counts. Complete counts directly measure the total population size, or density, either within a study area or within a sub-sampled part of the study area (e.g. a quadrat or strip transect). Incomplete, or partial, counts mean that not all individuals within the sampled area are counted. Incomplete counts can be further partitioned into methods that do not attempt to correct for incomplete detection (relative estimates or indices) and those that do. For the latter, statistical methods are most commonly used to account for incomplete detection. As the fox is generally a secretive animal that often occurs at low densities, obtaining accurate estimates of its abundance still remains a challenge (Caughley and Sinclair 1994; Vos 1995).

'Estimates of total population size are difficult to obtain and are often unnecessary to assess biological significance.'

Estimates of total population size are usually difficult and costly to obtain and in many cases are unnecessary, as a density estimate of a population, rather than its total size, is usually enough to assess biological significance. Estimates of density can also be difficult to obtain and may not be necessary. An index of abundance is usually the simplest and most easily obtained and in some cases may be the only viable alternative (Caughley 1977; Thompson et al. 1998; Schwarz and Seber 1999).

A complete count is a census. There is no variance associated with this kind of estimate, since it is assumed that all individuals in the population have been counted and that, if the count were repeated, exactly the same number of individuals would be counted. Complete counts are rarely possible for foxes (or any other wildlife species), and because of their limited applicability they will not be considered further here. Marlow et al. 2000 provide an Australian example of the use of complete counts.

The skills of experienced fieldworkers are a valuable resource in wildlife research. These skills should not be overlooked because they can help improve rates of detection, as well as the interpretation and power of surveys (Wilson and Delahay 2001).

12.2 Monitoring populations: incomplete counts

The relationship between the observed count of animals (O) and the true number of animals (N) in a population is dependent on the probability of detection (p). For the simplest case, where all individuals in a population are counted (i.e. a complete count), $p = 1$ and $O = N$. The relationship between O and N is more complicated when not all individuals are counted, in which case an estimator of detection, ($\hat{p}$), must be calculated (e.g. Field et al. 2005), giving an estimated abundance ($\hat{N}$) of:

$$\hat{N}_i = \frac{O_i}{\hat{p}_i}$$

where i is a sample in space or time. (The carets above N and p indicate that they are estimated values.)

Whichever method is chosen, it is vitally important that, if the results are to be interpreted with any biological relevance, the assumptions underlying the method are biologically realistic and have been tested for validity before they are used as a part of a monitoring programme (Thompson et al. 1998).

12.3 Indices of abundance

It can be assumed that an index of abundance is correlated with the true abundance in some way. If a constant proportion of animals is counted across time and space, then there is a reasonable chance that the index will detect the true trend of a population, although the trend statistic may still be biased (see Barker and Sauer 1992). The popularity of indices as measures of population trends is generally due to the fact that they are easy to use compared with alternative counting methods that try to account for observation error. There is also a widely held belief that if the protocol of counting is standardised, the constant proportionality assumption will be satisfied. As Thompson et al. (1998) point out, standardising the protocols will not ensure that this critical assumption is met, and the chosen counting method should always be tested for validity.

The following Section describes existing and potential indices for estimating changes in fox populations.

Breeding den counts

Population estimates based on active breeding den sites assume that the number of active breeding dens per unit area is a function of the number of adult animals in that area. If O_i is the observed number of breeding dens, $\hat{F}_i$ is the estimated average number of foxes per den and A is the area of the study site then:

$$\hat{D}_i = \frac{O_i \hat{F}_i}{A}$$

where D_i is the index of density.

Australian studies that have used this technique (e.g. Coman et al. 1991, Berghout 2000, Gentle 2005) have assumed that the average number of adult foxes per den is two (one male and one female, i.e. a monogamous pairing) and that the average surviving litter size is three or four cubs. Marks and Bloomfield (1999b) used intensive ground searches aided by a media campaign for help from the public to estimate family group density in urban Melbourne. Other techniques used to locate fox dens have included aerial surveys (Sargeant et al. 1975), following radio-collared foxes back to dens (Storm et al. 1976), and placing transmitters in prey items taken back to dens (Voigt and Broadfoot 1983). Active dens are readily identified by visual observations, evidence of freshly dug soil, strong odour, footprints, scats, or food items including bones and feathers and surrounding trampled grass. Deserted dens usually have plant material and cobwebs at their entrances and no fox odour.

Problems affecting the accuracy of this method include the possibility of:

- not locating all active den sites (Lloyd et al. 1976);
- the existence of alternative social groups other than monogamous pairing (Macdonald 1981);
- different litter sizes and cub mortality rates (Coman et al. 1991);

Piles of logs provide good harbour for foxes and their dens (photos [a] and [b]).

Prey remnants at the entrance suggests that the den is 'active' (photo [c]).

Sources:

[a] Queensland Department of Primary Industries and Fisheries

[b] and [c] Steve Lapidge, Invasive Animals CRC

- alternative sites for the rearing of cubs (i.e. the use of more than one den per litter) (Nakazono and Ono 1987);
- the presence of itinerant foxes (Marks and Bloomfield 1999b);
- foxes moving cubs to a new den site if disturbed by humans (Harris 1981);
- reproductive failure or abnormal mortality rates before the cubs emerge from the den (Sadlier et al. 2004); and
- surveying for dens too early or too late in the breeding season, meaning that dens used by early or late breeders could be missed (Berghout 2000).

Any of these problems will lead to a biased index of abundance. The method is time consuming and suitable only for small areas. The presence of thick vegetation can also limit the ability to locate dens. The accuracy of den counts depends on the time of year, as fox populations show an annual cycle of highest numbers in spring at breeding and lowest in winter just before the onset of breeding (Lloyd et al. 1976). Dens are generally occupied only during the breeding season.

Spotlight counts

Foxes are counted with the aid of a spotlight from a slow-moving vehicle following a fixed route (transect) at night. A typical standard method is for counts to be conducted over three consecutive nights using a 4-wheel-drive tray-top vehicle, travelling at 5–10 kilometres per hour along set tracks and with a 100-Watt spotlight (e.g. Greentree et al. 2000). A rule of thumb when determining the number of counts is for the standard error (measure of the accuracy of the mean) of the counts to be within 10% of the mean over the three nights, but Field et al. (2005) suggest that, because of the low detectability of foxes, at least five (and as many as nine) repeat visits might be required. This method can be used as an index (e.g. numbers counted per transect kilometre or per unit of time), or with additional information and the use of line transect theory (Buckland et al. 1993) an estimate of density can be calculated. This Section describes the use of spotlight counts as an index of abundance.

The advantages of this method are that it is relatively quick and simple, large distances or areas can be sampled, and many different habitat types can be covered. Several studies (e.g. Stahl 1990; Weber et al. 1991; Greentree 2000) have found no significant differences among fox counts done at different times of night; therefore, the starting time of these counts (provided it is dark) is not as important as for other species. A number of studies have compared the reliability of spotlight counts with other measures of fox abundance (e.g. Mahon et al. 1998; Heydon et al. 2000; Sharp et al. 2001b), with varying outcomes.

Disadvantages of this technique include (e.g. Ables 1969; Stahl 1990; Weber et al. 1991; Mahon et al. 1998; Molsher 1999; Field et al. 2005):

- counts can be highly variable when different observers are used;
- fox activity from one count to the next can be affected by weather and seasonal conditions, and by prey availability and fox foraging behaviour;
- sightability can be affected by vegetation or habitat type; and
- sightability can be affected by fox behaviour (spotlight-shy foxes), population age structure (young foxes are likely to be less shy of a spotlight) and abundance (foxes are more difficult to detect in low-density populations).

Corrections for these variations in activity and sightability are possible to some extent. Field et al. (2005) give details of a method of correction by zero-inflated modelling, which can improve the accuracy of inferences made from such monitoring data. Bloomfield (1999) claims from research in Victoria (details not specified) that for every fox seen by spotlighting there are another four present. Because of variability, data cannot be compared among seasons (Stahl and Migot 1990) and are not reliable for doing censuses of short-term trends (e.g. Greentree

Although spotlight counts are quick and simple, they may be highly variable and repeat counts are required to assess this variability.

Source: Gecko Photographics

2000). The sampling period takes into account only a small slice of the fox's activity and hence a small sample potential (see Edwards et al. 2000). The reliability of spotlighting can be improved by repeated counts, longer transects, and standardising when and under what prevailing conditions the technique is used (Wilson and Delahay 2001). Spotlight counts also tend to use formed roads and tracks for vehicular access. In some studies it may be necessary to ensure that transects incorporate all habitats in proportion to their availability across a study site.

Presence-absence methods

The presence–absence index (or frequency index) is based on the proportion of sampling units that contain at least one individual, or at least one sign that an individual has visited the unit. Physical signs, such as tracks, have been used to provide information on spatial distribution, habitat preference or relative abundance (e.g. Thompson et al. 1989; Kurki et al. 1998; Mahon et al. 1998; Thomson et al. 2000). In some circumstances (e.g. when there is a complete cover of fresh snow), track density can be converted to absolute population density provided that the movement of individuals is random and the mean daily cruising distance of individuals is known (Priklonskii 1973, as cited in Kurki et al. 1998). Sign counts that are passive (animals are detected in the normal course of their movements) often generate sample sizes that are too low to adequately monitor population changes (Fleming et al. 2001).

Stimuli such as scent lures or baits can be used to attract individuals to sampling units (e.g. sandplots) to increase the likelihood of detecting animals at low density (e.g. Gurtler and Zimen 1982; Roughton and Sweeney 1982; Conner et al. 1983). This technique is often used to assess the short-term effectiveness of control programmes (e.g. Thompson and Fleming 1994). A bait or track station usually consists of a one square metre raked sandplot that enables the identification of footprints or other signs of visits. Stations are placed along a set transect over a minimum of three nights, and indices are expressed as the mean number of stations visited or the mean number of baits taken per night. Transect length and frequency of stations has varied among studies: for example, Thompson and Fleming (1994) used stations 100 metres apart and upwards of 100 stations per transect in a temperate rainfall area, whereas Thomson et al. (2000) used 40 kilometre transects with 1-kilometre station spacings in a semi-arid area.

As a variation on using plots, where often a suitable sandy substrate has to be brought in, tracks can be measured in more uniform habitats using swept sections of dirt roads (e.g. Mahon et al. 1998; Edwards et al. 2000). The problem of one animal being recorded on multiple occasions can potentially be overcome by the spacing of plots, although how far apart eliminates this problem is mostly a subjective assessment. Sargeant et al. (1998) used lines of stations as the sampling unit, rather than individual stations, to overcome this problem. Glen and Dickman (2003b) found that remote photography was less open to misinterpretation and could be used as an audit tool for assessing the accuracy of sandplots, but there is much debate in the European literature as to whether using remote cameras lowers the rate of bait removal by foxes (Hegglin et al. 2004).

Although the presence–absence index has been used in many studies of foxes, interpretation of the index is highly dependent on the relationship between the number of animals per sampling unit and the index (Thompson et al. 1998). As true density increases, the relationship between mean density per plot and the proportion of plots containing physical signs will be nonlinear. When animals are distributed randomly, the mean frequency per plot, f, can be transformed to the mean density per plot, $\bar{x}$. Using a Poisson distribution, the proportion of plots containing one or more animals is:

$$f = 1 - e^{-\bar{x}}$$

from which $\bar{x}$ can be determined (after Caughley 1977).

This type of functional relationship will most likely lead to underestimation bias. Even under ideal conditions, animals will not be randomly

Tracks, and possibly motion-activated photopoints, can be used to provide an index of fox abundance.

Sources:
Tracks – David Croft, NSW DPI;
Photopoint – Sam Vine, Pest Animal Control CRC

distributed, and clumping will tend to amplify the non-linearity of the function. Caughley (1977) suggested that the presence–absence index may be useful when the monitored species occurs on less than 20% of the sampling units. Factors that can affect the frequency of visitation (see Thompson and Fleming 1994) include spacing of stations, use of attractants, differences between sites, frequency of operations, length of the index period and quality of tracking surfaces. Standardisation (e.g. comparison of similar habitats and fox densities) may improve accuracy (as derived from other methods), but given the problems associated with the method it is likely that true density shifts could be misinterpreted. Thomson et al. (2000) urged caution in interpreting relative changes in fox density from raw sandplot data after they observed that the method underestimated densities by a factor of four.

'Scent lures or baits can be used to attract individuals to sampling units to increase the likelihood of detecting animals at low density.'

When baits are used at stations, learning by association and immigration of new animals into a baited area could also result in progressively higher frequencies of bait interference (Thompson and Fleming 1994). When seasonal conditions are poor and animals are physiologically stressed, this influence is likely to be more pronounced than when alternative food sources are readily available (Allen et al. 1996). The use of attractants at stations may also be subject to seasonal and density-dependent variations in activity or biases in rates of attraction, depending on the social status, nutrition and prior experience of animals (Allen et al. 1996; Edwards et al. 2000).

An alternative presence–absence method involves measuring the number of scats per unit area during some defined sampling period. Given the ranging behaviour of foxes and the likelihood of detection, calculating the standing crop of faeces in a given area as an absolute estimate of abundance is probably beyond the resources of most studies. Scat counts can be used to derive an index of abundance by measuring the rate at which scats accumulate. There are a number of factors that can confound the use of scats as a survey technique (see Wilson and Delahay 2001; Sadlier et al. 2004). These include:

- the number of scats produced can vary with the diet;
- diet can vary opportunistically (e.g. plagues of mice and plague locusts);
- the persistence of scats will vary with weather conditions and content;
- the pattern of deposition will vary with season and habitat;
- the identification of species from scats is prone to error;
- seasonal variations in scent-marking behaviour will result in changes in the distribution and accumulation of scats;
- removal of scats may influence subsequent defaecation rates;
- scats can be obliterated by human and animal activity;
- defaecation rates can vary according to the age structure of the population; and
- observer skills in detection and identification can vary.

Some of these potential sources of error can be addressed by experimentation (Wilson and Delahay 2001; Sadlier et al. 2004; Webbon et al. 2004). Laboratory animals can be used to determine the number of scats produced per given diet, although some caution should be used in transferring this to wild animals. Decay rates of scats under different environmental variables can be estimated. Standardisation of surveys by season and by detection probabilities in different habitats would permit population comparisons. Sources of scats (e.g. fox versus dog) can be determined by microscopic examination.

After quantifying many of these variables, a national survey of fox density was conducted in the UK across a random stratified sample of 444 one-kilometre squares (see Sadlier et al. 2004 for details). The scale of this survey required the participation of many paid and unpaid helpers. Data from the sampled squares were used to extrapolate national estimates of absolute fox densities.

Baker et al. (2002) and Webbon et al. (2004) conducted similar large-scale surveys in Britain to evaluate whether there had been any relative change in the numbers of foxes as a result of restrictions on hunting with hounds during an outbreak of foot and mouth disease. Both studies used randomly selected one-kilometre Ordnance survey squares (the former study surveyed 160 while the latter surveyed 444). Surveys were conducted just before cubs were born (i.e. when the adult population was at its most stable). Each selected square was surveyed using walked transects, the mean total transect length was 6.9 and 6.6 kilometres, respectively. All fox scats were removed from the transects on the first visit and then fresh scats were counted on the return visit, 2–6 weeks and 1–4 weeks later, respectively.

The study of Baker et al. (2002) made no adjustments for those variables listed above. Fox density for each transect for each sampling period (F) was calculated as:

$$F = S / KD$$

Where S is the number of scats counted on the second visit, K is the transect length in kilometres, and D is the number of days between visits.

Webbon et al. (2004) did make some adjustments for defaecation rate and habitat type. Fox population density for each transect for each sampling period (F) was calculated as:

$$F = \frac{SL_t}{L_n DNP}$$

Where S is the number of scats counted on the second visit, L_t is the total length of linear features in the one-kilometre square, L_n is the length of linear features walked, D is the number of days between visits, N is the defaecation rate (as determined from captive animals) and P is the proportion of scats present in the square found along linear features.

Factors such as the scale of these surveys, resources available, availability of correction factors, prevailing habitat and the time scale will determine how useful this technique might be under Australian conditions. Sharp et al. (2001b), in western New South Wales, found that a fox scat index had the potential to provide a reliable measure of abundance of relatively stable fox populations. The same index was found to perform poorly when there was a rapid turnover of individuals. The advantages of this method are that it can be used in difficult terrain and the sampling schedule can be flexible and sampling can be done during the day. All of the fox's active periods are sampled, giving a larger sample potential (see Edwards et al. 2000). The technique is probably most useful in examining long-term trends in populations, as in the above UK studies. The use of scat counts to determine short-term changes such as pre- and post-control programmes should be treated with more caution, given the various confounding factors.

'Use of a fox scat index can provide a reliable measure of abundance for relatively stable fox populations but not when there is a rapid turnover of individuals.'

Hunting records

In Europe, an index method based on hunters' returns is sometimes used to estimate fox density (e.g. Bogel et al. 1974; Vos 1995). This index is calculated from hunting statistics and is described by the number of foxes shot or trapped annually per unit area. It is most reliable when based on data from large areas. This method provides a useful measure of apparent changes in fox density within the broadly defined areas, but it cannot be used to make comparisons between different areas. The hunting pressure must be constant (Bogel et al. 1974), which is rarely the case.

'Hunting statistics are not reliable enough in Australia to be used as indices of abundance.'

Hunting statistics are not reliable enough in Australia for this type of index to be calculated. The size of the fox harvest in Australia is constrained by overseas demand, reflected in the price paid for fur (Ramsay 1994). In the past, most fox shooting was done by professional or experienced amateurs given the rights to take foxes from individual properties. With the reduction in the fox fur trade and the absence of bounties in most States, the numbers of professionals have diminished, leaving landholders and enthusiastic amateurs to do the bulk of the shooting (Saunders et al. 1995). The recording of hunting statistics from organised hunting groups and sporting shooters would not be reliable enough to reflect any widespread changes in fox populations.

12.4 Density estimation

Methods that account for observability are almost always more costly and time consuming than methods based on indices. If the underlying assumptions of the method can be satisfied, they will produce unbiased estimators of density or abundance. However, if the assumptions cannot be satisfied then the methods are no better than the use of indices, and in some cases they will be worse if they are assumed to represent the true density of a population. The following sections describe existing and potential methods for estimating the density or abundance of fox populations.

Distance sampling

The three main assumptions of line transect theory (Buckland et al. 1993) are that:

- every individual on the transect is detected;
- individuals are detected at their initial location and do not move before being detected; and
- distance measurements are exact (and 'heaping', a common problem when estimating distances, is avoided).

These assumptions are difficult to meet for counts of foxes and lead to inaccuracies in the estimates obtained by this method. Unless observers are perfect, visibility bias may negatively bias estimates, a problem that can be overcome by using double-count methods with two independent observers (Schwarz and Seber 1999). The variance estimate is highly dependent on sample size. Achieving the required sample size is often difficult for foxes. Most line transect counts of animals involve the use of aircraft, although strip transect counts using spotlight counts of foxes may have some application.

Ruette et al. (2003) compared line and point transect methods to spotlight count foxes along roads and trails. Both methods resulted in similar density estimates, but the researchers concluded that line transects produced better estimates, as point transects were more time consuming and resulted in larger coefficients of variation. The variation in visibility between different habitats, however, and the low frequency of sightings near the centreline, were important problems with the transect method.

Heydon et al. (2000) used line transect counts of foxes and cautioned that visual estimation of perpendicular distances was prone to error. The use of laser range finders may help to overcome this problem, although determining which transects have been driven and which ones have not is probably a greater problem. In most cases transects follow farm roads, which can often have many turns and twists, apart from those in arid or semi-arid environments. Avoiding double counting or accurately determining the true perpendicular from the transect will always be difficult in these situations.

Double sampling

This involves using a 'cheap' method to collect general information from a large selection of sampling units and an 'expensive' method to acquire detailed data from a smaller subset of sampling units (Thompson et al. 1998). This could, for example, involve a spotlight count conducted over a large area, followed by an intensive population removal over a smaller, representative area. The spotlight count could then be calibrated to yield reliable estimates using either ratio or regression estimators. As pointed out by Thompson et al., complete counts of animal populations are rarely achievable at any spatial scale.

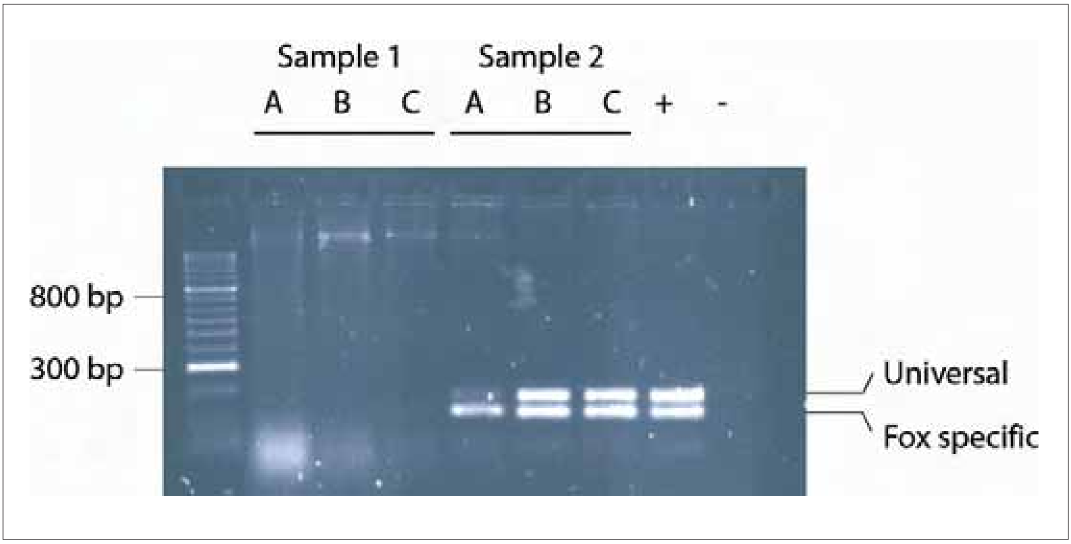
Capture-recapture methods

Capture–recapture methods are based on repeated capture of tagged individuals (see Caughley 1977; Thompson et al. 1998). The methods can be divided into closed population models and open population models. Key assumptions are that:

- All animals have the same probability of being caught. However, this is not the case if there are variations in the trapability of certain population classes (i.e. juveniles may be more likely to be captured than adults), behavioural differences (i.e. trap-proneness versus trap-shyness) and differences in opportunities of being captured (i.e. traps not placed within an animal's home range) (Eberhardt 1969; Baker et al. 2001a).
- All previously marked animals can be distinguished from unmarked animals. If marks are lost or indistinguishable, the number of recaptures will be underestimated and the population size estimate will be inflated.

Closed models assume that the population is 'closed' demographically and geographically to changes (i.e. no births, deaths, immigration or emigration). Corrections for movement can be made if radio-tags are used to record movement on and off the study site (White 1996). Open models do not have this assumption. Closed models are generally more rigorous (smaller variance associated with estimate).

Like active den counts for foxes, capture–recapture methods are expensive, time consuming and suitable only for small areas. Coman et al. (1991) estimated that it took 260 person-hours to capture only 60% of the resident fox population over an area of 240 hectares in their study in rural Victoria. Kay et al. (2000) reported capture rates using traps involving up to 150 trap-nights per fox (Kay et al. 2000). Radiotelemetry can be used to enhance the effectiveness of mark–recapture estimates (Kenward 2001) by allowing confirmation of the presence of marked animals in the study area at



DNA sampling techniques should provide a valuable monitoring tool to support the Tasmanian fox eradication campaign.

Sources: Steven Sarre, University of Canberra

the time of recapture (e.g. Coman et al. 1991) and reducing 'edge effects' (Eberhardt 1990).

The simplest type of capture–recapture model is one in which a sample of animals (n_1) is captured, tagged and released. On a second sampling occasion a further sample of individuals (n_2) is captured. The number of recaptures (m_2) from the first sample is recorded. An estimate of the population size ($\hat{N}$) is then given by:

$$\hat{N} = \frac{n_1 n_2}{m_2}$$

Open models allow estimation of survival rate and immigration/emigration rate. Estimates of population size tend to have higher variance than closed models. The Jolly-Seber method is the best known open model, but it is sensitive to capture heterogeneity (Carothers 1973) and animal behaviour (e.g. trap-shyness) (Nichols et al. 1984). The estimator of survival is relatively insensitive to capture heterogeneity and trap behaviour.

Lefebvre et al. (1982) and Pollock (1982) developed a robust capture–recapture design. Capture–recapture models provide reasonable ways of estimating $\hat{p}$ (in this case the capture–sightability probability) (Nichols 1992). The count statistics (Oi) are the numbers of marked and unmarked animals caught or sighted. There are numerous capture–recapture models available, and with recent advances this method has become an effective tool in animal ecology (e.g. Nichols 1992).

DNA sampling

Recent advances in molecular biology have allowed the use of genetic material from faeces to audit individuals within a given area (see Kohn et al. 1999; Wilson and Delahay 2001). This non-invasive technique offers exciting opportunities for more precise population estimates. It involves systematic collection of faeces from a study site. These are typed for several microsatellite loci to deduce the number of unique multilocus genotypes in the population (Kohn et al. 1999). When a large sample of faeces has been typed, the cumulative number of unique multilocus genotypes can be expressed as a function of the number of faecal samples. The asymptote of this curve can then be determined as an estimate of population size or, alternatively, capture–recapture models can be useful in analysing faecal genotypes (Kohn et al. 1999). Using a similar analysis, Mowat and Strobeck (2000) collected hair samples from bears to estimate population size. In this study, animals were lured to a bait station surrounded by a single strand of barbed wire from which the hair samples were collected. DNA was then extracted from hair follicles to identify individuals. Hair samples have long been used to identify those mammal species present at a particular site, and various methods have been used in the collection process (e.g. hair tubes containing glue strips for small mammals) (Brunner and Coman 1974).

There are still a number of problems associated with this technique, such as the collection and storage of fresh samples; inherent error rates in the PCR process; assumptions that defaecation rates are equal among sexes and age classes and independent of social class; inappropriate sampling strategies; and violation of capture–recapture model assumptions (Kohn et al. 1999; Mowat and Strobeck 2000; Wilson and Delahay 2001). The cost of both sample collection and DNA analyses would also make the technique prohibitive in more routine population assessments.

'DNA collection and analysis costs are prohibitive for routine population assessments.'

Despite these problems, DNA sampling has considerable appeal in the study of fox populations as is currently being implemented in Tasmania (Saunders et al. 2006). Preliminary Australian studies have already indicated that polymorphic canine microsatellite loci can be used successfully in studying fox population structure (Lade et al. 1996; Robinson and Marks 2001). Foxes use scent marking to help in food scavenging and as a means of olfactory communication (Henry 1977; Bullard 1982). Scent marking is done by depositing urine and faeces (Macdonald 1980) and is commonly observed from the depositing of scats at bait stations and sandplots used in fox studies. The ease with which fox scats can be collected for dietary analysis has resulted in numerous published dietary studies from Australia and around the world (e.g. Saunders et al. 1995). Similarly, the collection of hair samples should not represent a great challenge.

Odorous compounds have long been used to draw foxes to traps and bait stations. Chemicals such as synthetic fermented egg (SFE) and valeric acid have been shown to elicit scent-marking behaviour in captive foxes (Saunders and Harris 2000). This could be exploited in the field, particularly during the breeding season when response to pheromones is heightened. When foxes encounter these chemicals they rub and roll themselves on the odour source (Saunders 1992). Deploying these chemicals in the field at stations consisting of an odour dispenser attached to a post or tree wrapped in double-sided tape would seem a logical method of readily collecting hairs from foxes. A similar approach using carpet squares nailed to trees was successful in collecting hair samples from lynx (*Lynx canadensis*) populations (McDaniel et al. 2000).

Manipulation index

Population size can be estimated from a linear index of density measured before and after a known number of animals are added to, or removed from, the population (Caughley 1977). The precision of the estimate depends on the assumption that the population is closed while it is being manipulated. To minimise bias from natural births and deaths within a population, pre- and post- indices should be kept within a relatively short time-frame. The population estimates before and after manipulation are calculated by:

$$N_1 = (I_1C)/(I_2 - I_1) \text{ and,}$$
$$N_2 = (I_2C)/(I_2 - I_1)$$

Where I_1 equals density before manipulation, I_2 equals density after manipulation and C equals the number removed or added to the population.

The number of animals removed or added must be accurately known, and the addition or removal must not affect the index method (i.e. removal of baited foxes may leave bait-shy animals behind, so the index method should not involve the use of baits, e.g. Thompson and Fleming 1994). Similarly, if spotlight shooting is used to remove foxes, indices cannot be established by spotlight counts.

Removal methods

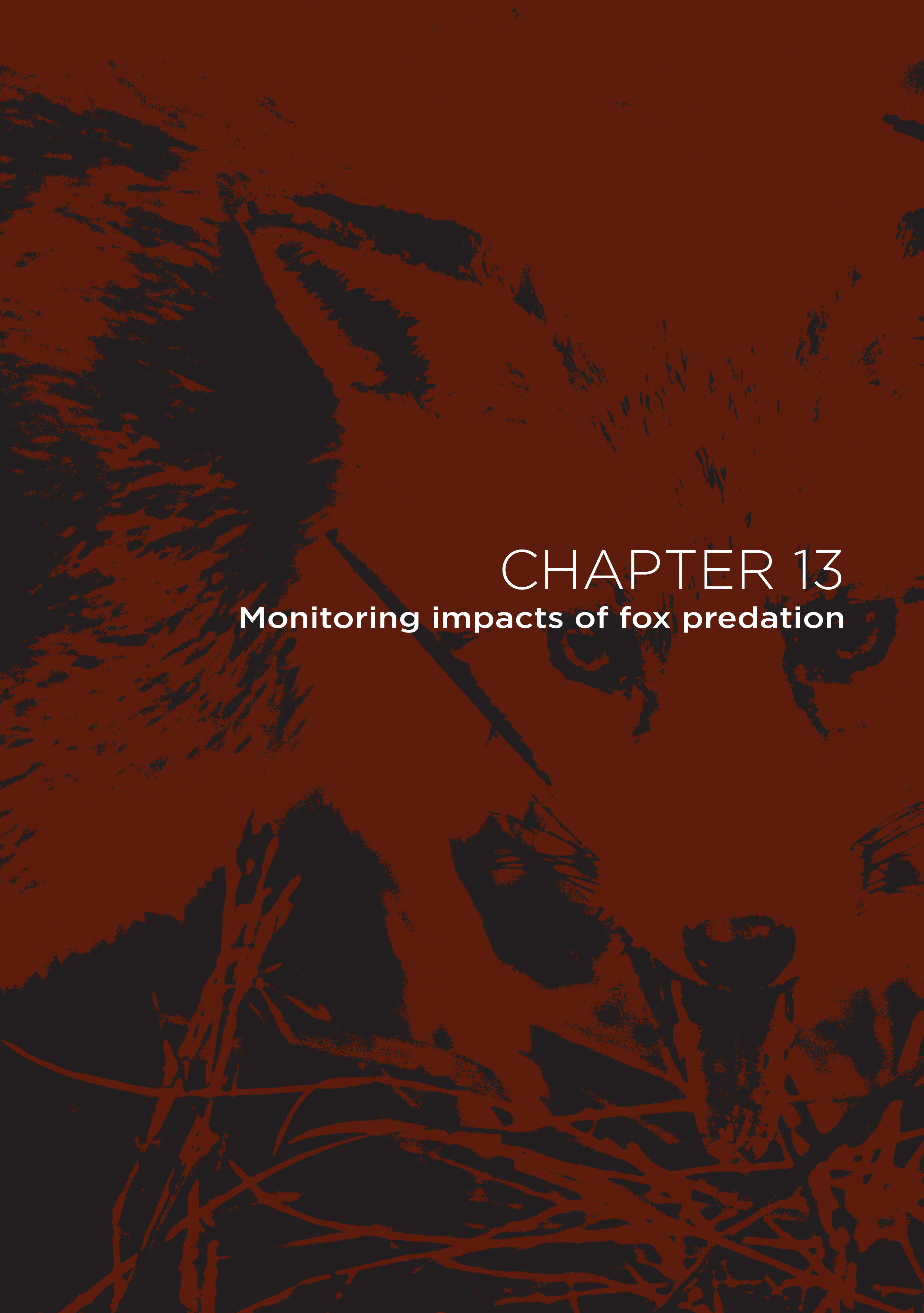
Removal methods are based on the simple premise that as density decreases, the effort required to remove individuals increases. Most commonly this index uses 'catch per unit effort' (CPUE) to generate the functional relationship between the effort required to remove animals and density. Algar and Kinnear (1992) used cyanide bait stations to generate a CPUE index, as represented by the number of foxes killed per 100 bait stations. They set up cyanide bait stations every 200 metres along a transect of set distance. Any fox that took bait died virtually instantaneously and its carcass could therefore be retrieved.

The basic assumption is that this index is proportional to fox density, given a constant sampling effort. The CPUE method assumes that the population is closed except for removed individuals, that all removals are known, that each individual has an equal probability of being caught or killed, and that methods of removal are standardised (see Caughley 1977). When all conditions are met, the regression of absolute density on catch per unit effort is linear through the origin. If there is individual variability in, for example, the acceptance of baits (i.e. not all individuals are equally likely to consume baits), then the method will tend to underestimate density. The other assumptions are also unlikely to hold for many field populations. As with all methods, the assumptions of this method should be tested before the results can be reliably interpreted.

12.5 Other methods

A number of alternative methods of estimating fox populations are potentially available, although most have limited appeal:

- Remote surveillance methods using photographic or video equipment are popularly used to examine the behaviour of individual foxes around bait stations and interactions with non-target species (e.g. Glen and Dickman 2003b). There seems to have been little application of these methods to any form of population analysis, although Vine et al. (2005) reported that the use of remote cameras was the only systematic method they could find to detect collared foxes at very low densities.
- Thermal imaging has also been suggested (Wilson and Delahay 2001, Edwards et al. 2004) although the precision (and cost) of this technique would seem prohibitive.
- Counts of fox road traffic casualties, particularly in urban environments, are useful in determining distribution (Marks and Bloomfield 1999b). However, this technique has many sources of bias (e.g. type of road and volume of traffic) (Baker et al. 2004; Taylor and Goldingay 2004), and is probably not suitable for accurate population estimation.
- Radio-tracking can be used to delimit individual home ranges or size, and this information can then be used to derive population estimates. This requires knowledge of social structure, which in some circumstances can consist of more than just a breeding adult pair (Macdonald 1981), although most observations suggest that the breeding pair is the predominant family group composition in Australia (Saunders et al. 1995). The presence of itinerant foxes, variable territorial boundaries and variable cub production and survival, as well as the overall costs of large-scale radio-tracking studies, again make the application of this technique limited (Sadlier et al. 2004).



CHAPTER 13
Monitoring impacts of fox predation

13. Monitoring impacts of fox predation

Key issues

- *The objective of fox control programmes is to reduce the impacts of fox predation, not to reduce fox populations per se. The effectiveness of fox control programmes should be measured in terms of the response of the threatened population or in the economic return via increased agricultural production, not just by the change in fox abundance.*
- *In fox management programmes that have a conservation objective, effectiveness is measured by the response of the threatened species to fox control. Given that these threatened species are limited by fox predation, effectiveness will depend on the individual predator-prey relationship and will be determined by whether fox densities can be reduced sufficiently and/or whether alternative prey species can be manipulated to allow these threatened populations to increase (NSW National Parks and Wildlife Service 2001).*
- *All land managers and agencies should be encouraged to report their methods and outcomes of the predator control programmes in the scientific literature, especially ones aimed at conservation outcomes. Given that interest in, and support for, predator control programmes remain high at all levels from government to public, it should be a priority to collate information on the methods used and outcomes of all programmes conducted throughout Australia. This will avoid agencies continually repeating the same mistakes and result in more rapid development and improvement in management practices.*
- *The systematic approach taken in New South Wales, under its Fox Threat Abatement Plan, to prioritise actions and to implement and monitor fox control programmes has demonstrated an effective way of using limited resources and may be worth considering in other jurisdictions.*

Monitoring of the outcomes of management programmes is an important aspect that is often overlooked (Braysher 1993; Walker 1998). There are two types of monitoring: operational monitoring (what was done where, and at what cost?) and performance monitoring (did the control meet the objectives?). Monitoring then allows for evaluation of the programme (whether the objectives were achieved or if not, should the management strategy be changed, or should the initial problem and objectives be reassessed), planning, reporting and extension.

Monitoring methods currently used in agricultural programmes measure variables such as participation rates and awareness levels, number of baits laid, and area baited (mapping). Agricultural production figures, such as lambing percentages, observations and perceptions can be collected from participants using questionnaires. The validity of data collected in this manner is, however, affected by the participants' competency in record-keeping, as well as by the number of records returned (response rate) and who actually responds (sample bias) (White et al. 2005).

Because of the difficulties in collecting and quantifying data on the impact of foxes in agricultural programmes, monitoring often includes some measure of the change in relative abundance of foxes over time, (e.g. spotlight counts or bait uptake), despite there being no known consistent relationship between fox densities and the amount predation on livestock (see Section 13.1). Many agricultural-based fox management programmes also contain a conservation element, so the recovery or relative abundance of any native or indicator species in the area may also be measured.

Monitoring of conservation management programmes, like monitoring of agricultural programmes, involves both operational and performance components. Monitoring the effectiveness of conservation management programmes involves measuring the response of the threatened species to fox control.

The commonly used methods of monitoring aim to either measure the density of the threatened species or record an index of abundance (see Section 12), both before and after the intervention. However, monitoring of some species can be difficult, and the lack of a detectable response does not necessarily indicate the absence of a response but may highlight the difficulty of detection (de Tores et al. 2004). Operation monitoring and evaluation of the programmes, determining whether or not the objectives have been achieved, and deciding whether the management strategy should be changed or the initial problem and objectives reassessed are all very important because of the high public accountability of these types of programmes.

This Chapter considers: the theory of pest density and damage; the impact of foxes on agricultural production and threatened native animals; and (by way of case studies) current methods to monitor and evaluate fox management programmes.

13.1 Density-damage relationships

(Based on a draft provided by Steve McLeod, NSW DPI)

The relationship between pest density and damage can be useful for predicting changes in impact associated with changes in pest abundance. Underpinning this idea is the theory that there is a predictable relationship between pest abundance and damage (Fig. 13.1). The simplest relationship is linear (Figure 13.1 (ii)). Pest damage increases at a constant rate with pest abundance, and this will occur when there is no competition between pests for resources. Alternatively, damage may increase at a declining rate as pest abundance increases (Figure 13.1 (i)), a scenario that is thought to occur when pests compete for the consumed resource. Another alternative may occur when there is facilitation between pests (Figure 13.1 (iii)), where the rate of damage increases with pest abundance. Facilitation is most likely to occur when pests search and feed in groups. Foxes, being largely solitary, are likely to have a density–damage relationship that is either linear or increases at a declining rate with pest abundance. Unfortunately, there have been no studies that have been able to determine the shape of the density–damage relationships for foxes.

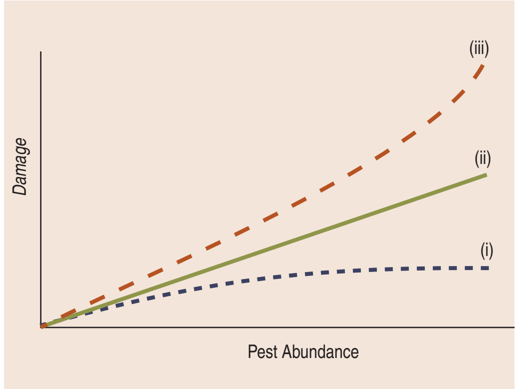


Figure 13.1 *Theoretical density–damage relationships when: (i) the rate of damage declines as pest abundance increases (i.e. competition); (ii) the rate of damage is constant as density increases; and (iii) the rate of damage increases as density increases (i.e. facilitation).*

'No studies have determined the shape of the density–damage relationships for foxes.'

Density–damage relationships can also be more complex than the simple relationships shown in Figure 13.1. Cherrett et al. (1971) suggested that pest damage was a function of four variables:

- the destructive potential of the pest;
- the duration of exposure;
- the resistance of the host or object to attack; and
- the number of pests.

Foxes can vary dramatically in their predatory behaviour (Linnell et al. 1999), with so-called 'rogue' foxes able to cause serious localised losses (Turner 1965; Moore et al. 1966; Rowley 1970; Saunders et al. 1995; Glatz et al. 2005). At low levels of pest abundance, lower levels of predation might be compensated for by increased growth of the predated resource, presumably because of reduced intraspecific competition. Only when pest abundance exceeds a threshold, where compensation does not exceed damage, does damage become apparent (Hone 1994). However, no examples of fox predation leading to increased abundance of the predated resource could be found.

Setting target densities and thresholds

Predation by foxes can affect conservation values and agricultural values. Although the mechanism of impact is the same in both cases (i.e. predation), the thresholds needed to achieve conservation or agricultural goals may be widely different. For example, lambs are vulnerable to predation for only the first few days after birth, after which they are usually too large to be preyed upon by foxes (Saunders et al. 1995), so predation by foxes is often economically unimportant. However, many native species of fauna, the so-called critical weight range species, remain at a body size vulnerable to predation throughout their life (Burbidge and McKenzie 1989). For these species even fox populations at low levels of abundance may cause high levels of damage.

The abundances of predated species are likely to be influenced by factors additional to predation by foxes. Using the density–damage relationship to determine target densities or thresholds for fox control may be useful for meeting tactical objectives (i.e. a short-term goal of resource protection) but other information may be needed to meet strategic objectives (Choquenot and Parkes 2001). Choquenot and Parkes (2001) use the example that reducing predation may increase the recruitment of a prey species, but this information is of limited use if the role of recruitment in the viability of the prey species is not known. Therefore, the usefulness of density–damage relationships should not be judged in isolation but should be considered in the context of broader ecological interactions that may affect conservation or agricultural values.

13.2 Fox impacts on agricultural production

Historically, the fox has been perceived as an insignificant predator of most domestic livestock (Fennessy 1966; Hone et al. 1981), the exception being free-ranging poultry flocks (Lloyd 1980; Moberley et al. 2004a; Glatz et al. 2005). Fox predation has been reported on lambs, kids, piglets, calves, cows in birthing difficulties, deer, ostrich and emu chicks, and free-range poultry, including chickens, ducks, geese and turkeys. Until recently, predation was considered a problem only for small-scale poultry operations, as the larger producers housed their birds indoors; however, with the growth of the free-range poultry industry, susceptibility to predation has increased not only bird losses but also stress-related declines in egg-laying and meat quality (DEFRA 2001; Glatz et al. 2005). The extent of fox predation in other agricultural production areas—particularly on lambs and kids—remains unclear, although it is increasingly perceived by producers as high. The national guidelines for management of fox damage (Saunders et al. 1995) conclude that the role of the fox as a predator of otherwise viable lambs is subject to much controversy and needs to be studied further.

'Most of the important factors involved in poor lambing percentages are inconspicuous, whereas damage inflicted by predators is usually highly visible, commonly leading the sheep-owner to overestimate the importance of predators.'

Although there have been few published studies that show foxes as significant predators of lambs, general causes of lamb mortality have been well documented (e.g. Rowley 1970). These past surveys indicate that the biggest single factor in lamb losses is associated with the birth process or as a result of poor maternal care; predation causing the death of an otherwise healthy lamb is of only minor significance. Rowley (1970) points out that most of the important factors involved in poor lambing percentages are inconspicuous, whereas damage inflicted by predators is usually highly visible, commonly leading the sheep-owner to overestimate the importance of predators.

Dennis (1969) showed that, of 4417 dead lambs collected and inspected in Western Australia, only 2.7% would have survived if a predator had not attacked; starvation accounted for almost half of the mortalities. A similar study in New South Wales (McFarlane 1964) indicated that of some 3000 lamb carcasses examined, almost half were mutilated by predators but an absolute maximum of 9.7% actually died because of predator attack. A proportion of the latter would have been weak or moribund lambs, so only 2% of the total lamb crop was assessed as having been killed by predators.

Not all lamb mortality studies dismiss predation as being of secondary significance, and in some situations foxes and other predators can cause heavy losses (Moule 1954; Smith 1964; Turner 1965; McDonald 1966). However, these unusually high losses can often be attributed to circumstances peculiar to a single flock or a small area of country (Coman 1985). These include a high proportion of twinning, particular lines of ewes that have poor mothering ability, and nearness to optimal fox habitat. There is evidence that individual killer foxes become habituated to killing lambs (Rowley 1970). Such foxes can cause serious losses in individual flocks, and both Turner (1965) and Moore et al. (1966) describe such events.

Studies in Australia show that freshly killed live-stock are an infrequent dietary item. However, feeding on carrion (notably sheep and lamb carcasses) is common, particularly in winter (Catling 1988). For example, Alexander et al. (1967) found that the main fox activity amongst lambing sheep was centred upon scavenging for foetal membranes. There were some timid attempts to attack live lambs, but of 36 fox sightings in the flock, only one attack on a

[a] Foxes and other predators may target lambs that are dead or dying from malnutrition or exposure. Research with tracking collars allows lamb carcasses to be retrieved and the primary cause of death to be determined. Source: Lynette McLeod, NSW DPI

[b] This processed lamb skin shows the puncture marks resulting from a fox attack. Source: David Croft, NSW DPI

[c] Foxes may harass and attack lambs without achieving a kill. Source: Animal Control Technologies

live lamb was recorded. Ewes were generally undisturbed by the presence of the foxes. These findings were supported by a study by Mann (1968), who showed that excluding foxes by fencing did not reduce lamb mortality.

Nonetheless, many of these past investigations probably underestimate the role of foxes as pests in the sheep industry. In dietary studies, identification of soft tissue material from lamb carcasses is difficult unless wool is present. It is also possible that many lambs are killed without being eaten, or killed and cached, to be eaten later as carrion. Pregnancy diagnosis in ewes using ultrasound has become more common, and the early data from these ultrasound studies suggests that fox predation may be much more important than previously believed.

In a study of fox predation on lambs in western New South Wales, Lugton (1993) presented data indicating high losses of otherwise viable lambs to predators, principally foxes. Between 1985 and 1992 Lugton observed lamb production and lamb losses on five properties. He also reviewed information from other sources. On the basis of his own studies and those of others involved in sheep productivity trials, Lugton suggests that, in some sheep-growing areas, predation may account for up to 30% of all lamb mortalities. He concludes that fox predation has a large impact in areas where foxes are common and where lambing is early in the season. High lamb losses can occur where lambing is out of step with, or isolated from, neighbouring flocks.

There are a number of potential predators of lambs, including feral pigs, dingoes and foxes. Predator wounds of lambs vary in characteristics, and it is often difficult to identify the predator from the wound inflicted. Rowley (1970) produced a useful key for identifying predators from wounds on lambs. Taken in combination with the post-mortem techniques developed by Dennis (1965) and others (e.g. Holst 2004), Rowley's key can be used to estimate the damage caused by foxes in the sheep industry. However, the techniques rely on the recovery of all lambs killed and, as explained above, this is not always possible.

13.3 Case studies: agricultural production

The Boorowa lamb predation experiment (New South Wales)

A case study of fox control and lamb predation was conducted around Boorowa in the Central Ranges of New South Wales (Saunders et al. 1997; Greentree 2000; Greentree et al. 2000). This was perhaps the first study involving replicated, experimental manipulations of fox populations aimed at deriving the extent of fox predation on lambing flocks. It is worth reporting here in detail as an example of monitoring agricultural production (lambs) responses to fox control.

The project involved a large-scale, population management, multifactorial experiment using properties and adjacent refuges as experimental units. Sites were selected for homogeneity of habitat, stocking rate, management practices and prey species. Fox densities were maintained by using one of three strategies, with two replicates of each. These were no control, reduction of fox densities at lambing time using RLPB-recommended 1080 baiting strategies, and intensive control throughout the year. Treatments were implemented over three years (1994–1996) although maximum control could be initiated fully only from the beginning of year 2.

Control programmes were conducted over the experimental units and adjacent buffer zones approximately two fox territories in width (1–3 kilometres). Intensive baiting was carried out at critical times in the foxes' biological year:

- when dog foxes are searching for mating opportunities outside their territories;
- during gestation and lactation, when vixens are under food stress;
- before dispersal, when a fox territory contains the highest density of foxes; and
- during peak dispersal, when yearling foxes are making long-distance movements in search of new territories.

The benefits of fox control (measured directly as enhanced lamb survival derived from differences in lamb-marking rates between ultrasound-scanned flocks) and the costs associated with fox control were assessed. These parameters were used to model costs and benefits and optimal levels of fox control. All forms of lamb mortality were monitored so that fox predation could be accurately differentiated from other causes. This involved intensive surveys of flocks at lambing, using established techniques (modified from Rowley 1970 and Alexander 1984) for determining the causes of lamb loss (including other predators).

With the exception of lamb production, which required intensive study over a limited period of time, all other parameters (e.g. fox populations, control effectiveness) were measured three times a year. The effectiveness of baiting programmes and monitoring of fox populations was assessed by spotlight counts using the methods described by Saunders et al. (1995). Counts were assumed to be linear indices of fox abundance. Three counts were conducted over three consecutive nights per treatment site and over transects varying in length from 7–19 kilometres. Counts were conducted pre- and post-baiting.

Lamb post mortems

Over 2000 lamb carcasses were collected for necropsy. Predation by foxes and other causes of death were identified using methods modified from Rowley (1970), Alexander (1984) and Saunders et al. (1995). These causes are summarised as follows:

Type 1: Predation by foxes, with no other obvious cause of death.

Type 2: Fox predation, but because of the absence of organs such as the stomach and kidneys, not possible to determine whether the lamb would have died anyway.

Type 3: Fox predation in addition to factors contributing to lamb mortality, such as difficult birth, exposure, starvation, and mismothering.

Type 4: Normal constraints to lamb survival, including difficult birth, exposure, starvation, mismothering, with no signs of fox involvement.

Type 5: Scavenging of carcasses by foxes (i.e. absence of bleeding around bite wounds), but lamb died from other causes.

The post mortem results over the three years of the study indicated a level of predation anywhere between 0% (Type 1 only) and 33% (combined effects of Types 1, 2 and 3). The ambiguity of these results is consistent with that of previous studies. In particular, how many carcasses of lambs killed by predation were completely removed from the study site by foxes, and what proportion of Type 2 and Type 3 causes of death would have resulted in mortality even in the absence of fox predation? The proportion of total carcasses confirmed as predation Type 1 was 28/2140 or 1.3%, which compares with the results of similar studies by Dennis (1969) (119/4417 or 2.7%) and McFarlane (1964) (88/3039 or 2.9%), although these latter studies did not differentiate fox predation from other forms of predation. The assumed maximum predation rate (Types 1 and 2) in this study was 10.2%.

Analyses of data could be applied only over the two years of study in which all treatments were fully implemented. There were significant effects of fox control (Wald statistic = 6.1; degrees of freedom (df) = 2; $0.025 < P < 0.05$) on the percentage of carcasses classified as fox kills (Type 1) in 1995 and 1996. There were also significant effects of fox control (Wald statistic = 12.5; df = 2; $P < 0.005$) on the maximum percentage of carcasses classified as fox kills (Types 1 and 2) in 1995 and 1996. The causes of death of a total of ten (0.8%) lambs were classified as possible predation with other contributing factors (Type 3); 975 (73.8%) as death from difficult birth, starvation and other causes unrelated to fox predation (Type 4); and 265 (20.1%) as not known (Type 5). The minimum number saved was equivalent to Type 1 deaths and the maximum possible number saved was equivalent to Type 1 and 2 deaths. From this trend, the potential number of lambs saved as a consequence of fox control could be calculated.

Another trend became apparent when the level of predation over time was compared with the indices of fox abundance over time. Declining levels of fox predation appeared to be linked with a similar decline in fox abundance—a not unexpected observation. This suggests that, in any process of decision-making on the implementation of fox control, prevailing fox densities will need to be considered. Such information will not be readily available to landholders.

An important statistic to consider is the comparison between deaths of lambs which could be equivocally associated with fox predation (Types 1-3) and deaths unequivocally caused by non-predation causes of death (Types 4 and 5). Of the 2140 lambs examined post mortem, the deaths of 86.5% were attributable to Types 4 and 5. This suggests that much progress could be made in improving factors associated with lamb survival other than fox predation.

Lamb mortality collars

One of the greatest difficulties in establishing the extent of predation in lambing flocks (and the potential reason for possible underestimates in previous studies) is that an unknown proportion of carcasses are completely removed from the vicinity of the lambing paddock. The survival of newborn lambs in this study, particularly twins and triplets, was closely monitored by using radiotelemetry mortality sensors.

Lamb mortality collars were used on the no-treatment lambing paddocks. Once fitted with collars, the lambs were monitored daily until marking. The collars were used to locate lamb carcasses and determine causes of death, which, in turn, could be used to determine whether any bias occurred in the post mortem analysis. The fitting of the collars to newborn lambs appeared to cause minimal distress to the ewes, as the entire process took less than a minute to complete. On only two occasions did ewes leave their lambs during the observations; both had re-mothered by the next morning and their lambs survived to marking. In the first year of this work, a total of 93 collars were fitted to lambs, of which 25 died from various causes, and in the next year these figures were 94 and 22 respectively. These lambs were examined post-mortem and their deaths classified by type. In both years the results were consistent with those of the overall post mortem studies, suggesting that in these years, at least, there was minimal bias associated with not being able to detect carcasses that had been either hidden or completely removed from lambing paddocks by foxes.

Flock ultrasounding and lamb marking

Flocks of approximately 1000 ewes per treatment were ultrasounded. This technique is commonly used for identifying the number of lambs carried by each ewe in the second trimester (Fowler and Wilkins 1982). Pregnant ewes were marked with spray paint as bearing singles, twins or triplets. Dry (non-pregnant) ewes were also identified. At around two months after lambing, lambs were drafted from the flock and counted. This is traditionally used as a measure of flock productivity (i.e. the percentage of lambs produced per 100 ewes).

The calculation of observed lambing percentage was based on the numbers of ewes and lambs at marking—not the difference between ultrasounded lambs and lambs at marking nor the more traditional difference between the number of ewes at joining and the number of lambs at marking. This was done to identify the most likely levels of predation by foxes on newborn lambs. Many ewes died before having a lamb or at lambing. Ewes mother to their lambs at lambing and will (in most cases) reject alien lambs that try to suckle, therefore lambs whose mothers have died would not survive to marking—for our purposes equivalent to not being born.

The mean number of lambs at ultrasound was 138 per 100 pregnant ewes, and the mean number of lambs at marking was 113 per 100 ewes that lambed. There were no significant effects of fox control (Wald statistic = 5.7; df = 2; $0.10 > P > 0.05$) on the difference between the number of lambs at ultrasound and marking. Similarly, there were no significant effects of fox control (Wald statistic = 1.3; df = 2; $P > 0.50$) on the number of lambs per 100 ewes at lamb marking.

Variation between sites within each treatment was high. This could have been a result of weather fluctuations—e.g. 80 lambs died in one flock over two cold, wet, windy days. These lambs were born five days earlier than at most other sites, where few weather-related mortalities were observed.

'Fox predation in lambing flocks may have been grossly underestimated in many studies because of a lack of knowledge of the fecundity of ewe flocks.'

Fox predation in lambing flocks may have been grossly underestimated in many studies because of a lack of knowledge of the fecundity of ewe flocks (Lugton 1993). This can be clarified only by ultrasounding flocks. This technique identifies the exact number of lambs that should be born—usually much greater than the traditional expectations of landholders. Lugton goes on to say that only with regular collection of carcasses and knowledge of the fate of all carcasses that go missing (a fate he assumes is mostly due to predation) will the proper understanding of the level of predation be understood. However, in the Boorowa study, ultrasounding alone did not give us any greater understanding of fox predation.

Fox abundance

The mean index of fox abundance over all treatments in spring was 1.3 (+/–0.2 SE) foxes per kilometre of spotlight transect. There was no significant difference between the fox abundance ($F = 0.452$; df = 2, 3; $P > 0.25$) at the time of the experimental treatments in 1994 and that before the start of the experiment. There were no significant effects of fox control (Wald statistic = 3.9; df = 2; $0.25 > P > 0.10$) on the log-transformed index of pre-baiting fox abundance in spring in 1995 and 1996. The percentage reductions in fox populations in this study were low (mean = 29.8%) compared with those in other studies (see Section 2.9). This may have resulted from rapid immigration of foxes after each poisoning event, despite the fact that buffer zones were also baited.

Conclusions

This study failed to conclusively demonstrate that lamb production was significantly affected by fox control. Fox predation of lambs occurred in the presence and absence of fox control, although significant reductions in the incidence of predation were related to the higher levels of control. The application of 1080 baits by using typical and enhanced management practices had no significant impact on fox abundance. The low and variable effect of fox control on lamb production may have simply been a result of the fact that insufficient foxes were killed to show detectable increases in lamb production in the face of the many other causes of lamb mortality. The effect of fox control on lamb production may have been clearer with further replication of treatments to reduce experimental error and an increase in the size of buffer zones to reduce rates of reinvasion. It would be difficult to find the resources to repeat this experiment on a much larger scale. The South Australian study reported in the next Section provides a useful and less costly alternative.

Many factors can increase the risk of fox predation on lambs. Elimination of these is not always possible within a total property management context, for economic, practical and environmental reasons. Alternatively, the risk associated with these factors could be partly reduced and coupled with a fox control programme in a way that is acceptable and economically viable. Although differences in lamb survival between treatments in this project were non-significant, post mortems of lambs from ultrasounded flocks revealed a trend of reduced fox predation at the once-treated and maximum-treated sites. The extent of this trend was then used to examine the costs and benefits of fox control. This suggested that if ewes were in poor condition or lambs were dying of other causes, the returns from fox control were minimal, as the saved lambs would have died anyway. In this case, resources would be better employed on improving lamb survival in other ways (e.g. by supplementary feeding). If, however, ewes are in good condition, lambs are healthy, and the property has moderate to good potential yields, then fox control may produce useful profits. In this situation, if risk factors are increased then the need for fox control may similarly increase, as will the returns from fox control. Landholders would therefore be advised to assess their exposure to risk factors, reduce them wherever possible, and then consider fox baiting as a means of maximising returns.

Adaptive fox management project (South Australia)

Although the Boorowa project attempted to experimentally measure the effects of fox control on lamb production at a property scale, a project conducted in South Australia monitored the outcomes of fox control at a regional level across the State. This study focused on the current practices of land managers, and it had the advantage of a large sample size to reduce the effect of variation at the property level and include a wide range of management practices and regional variation (Linton 2002).

Objectives

The study had the following objectives:

- to measure the extent of any benefits of fox control for agricultural production;
- to establish the factors associated with variation in the level of fox predation on lambs;
- to provide information for government agencies to make scientifically-based decisions regarding the level of resources they devote to fox control and its promotion; and
- to establish other management factors associated with high lamb production, so as to place the benefits (if any) attributable to fox control into a broader perspective.

This information would allow producers to make informed choices between different courses of action on the basis of the relative costs and benefits that would accrue from them.

Data collection

Property owners provided data on lamb production, fox densities, fox control (type, timing, intensity and cost), estimates of predation levels, sheep management (timing of lambing, marking percentages) and other practices used to improve lamb production for the period 1997 to 1999. Some also provided pre-1997 data. These data were collected every three months by way of distributed questionnaires. Return rates were high (80–97%). The participants (108) were located in 22 regional landholder groups conducting coordinated fox control programmes. Group size varied from 1–18 participants. Not all participants undertook fox control. The researchers had no direct influence over landholder management actions, but used the information provided by the landholders to investigate the consequences of these actions. As an adaptive management project, the focus was on learning from current practices used by land managers.

Statistical analysis

Although over 100 properties supplied data, most of these did not submit complete datasets. This meant it was not possible to conduct multiple regression analyses involving large numbers of explanatory variables. Instead, separate analyses were conducted on relatively large subsets of the data to explore the influence on individual variables. Particular attention was placed on lamb marking percentages in response to fox control and sheep management practices.

Results

The analysis of results proceeded in two stages. The first aimed to explain variations in lambing percentage in the group during the project period (1997–1999), and the second aimed to explain variations in lambing percentage before the groups began fox control. Key findings of the first stage were:

- The increase in lambing percentage resulting from fox control depended on the lambing percentage before fox control. It was highest on properties with low pre-fox-control lambing percentages, and diminished to zero when the pre-control lambing percentage reached 100%. For example, a producer with a lamb marking percentage of 60% could expect to increase this to 85% after fox control, whereas a producer with a lamb marking percentage of 90% could expect only 93% after fox control. This was interpreted as meaning that properties with high pre-control lambing percentages did not have a fox problem to start off with, whereas those with low pre-control lambing percentages did.

- The ewe fat score at joining had a strong influence on lambing percentage, with ewes of condition score 4 performing best, as reported in earlier work on sheep production.
- When a number of properties coordinated fox control, the improvements in lambing percentage were the same on properties controlling foxes as on nearby properties that didn't control foxes. This was interpreted as meaning that foxes moved readily between nearby properties (thereby redistributing the benefits of fox control among *all* properties, not just those undertaking the control work). However, it was also possible that the improvement in lambing was unrelated to fox control and derived from unknown factors.
- The analysis did not explain why some properties had low lambing percentages before fox control (that is, before the project started) whereas others had high lambing percentages.

The researchers tried to resolve the difficulties raised by the last two dot points by constructing and testing a hypothesis based on the inference that foxes moved large distances and redistributed themselves after the control operation. It was reasoned that, before landholder groups began fox control, their lambing percentages might have depended on the level of fox control conducted elsewhere in the district. Districts in which many baits were distributed might have experienced a general improvement in lamb production, this being the result of a significant overall reduction in fox numbers in the district as a whole and the sharing of the benefits of this among all landholders, including those surveyed (who at that time were yet to start fox control themselves).

Data on bait usage within 'Hundreds' in different years was examined. 'Hundreds' are South Australian land administration units with an area of typically 300–500 square kilometres. One to four years' of data on lambing percentages before group fox control began were available for 34 properties. The average lambing percentage before fox control for each of these properties was calculated, and then related statistically to the number of fox baits distributed in the respective 'Hundreds' in the two years before the group began baiting. Lambing percentages rose from an average of 80% on properties where there was no bait usage elsewhere in the 'Hundred', to 95% on properties where about three baits per square kilometre were distributed elsewhere in the same 'Hundred'. This relationship was statistically significant. Three baits per square kilometre was the highest rate of bait usage in the dataset.

Conclusions

The project identified potential gains from regional fox control for sheep producers and also the integrated role of ewe nutrition and fox control in improving lamb marking percentages. It was concluded that the general level of fox baiting within a 'Hundred' determines the 'expected' lambing percentage for that 'Hundred', although the actual figure on any one property will also be influenced by other factors such as seasonal conditions and ewe nutrition. If a group of neighbouring landholders undertakes coordinated fox control, this expected level may then be raised on all properties within the area of the group.

Landholders who opted out of fox control were identified as receiving the benefits of control work undertaken by their close neighbours and by other landholders. The study therefore raises many policy issues relating to equity and to the role of government. Three possible strategies were identified for implementing fox control at a regional level:

- The fox control effort is coordinated and rotated among landholders, with any one individual undertaking fox control on their property every second, third or fourth year.
- A regulatory approach, whereby all landholders are required to control foxes in order to produce benefits for agricultural production and the environment. Such approaches have now fallen out of favour.
- Landholders who are keen to control foxes every year (and by so doing provide a service to both themselves and their neighbours) should receive an incentive (e.g. free baits or monetary compensation). This strategy would require all landholders in the district to agree to participate in a levy scheme to fund the incentive.

There will obviously be anomalies arising from the interpretation of data collected by questionnaire and without any verification or proper experimental controls. The increased lamb marking percentages on properties where no fox control was conducted were explained as the effect of fox movements and lethal control of these foxes elsewhere. They may also have been the result of external factors (e.g. regional climatic variables) that improved lamb marking on all properties regardless of fox control, although the fact that the data were consistent over the three years suggests that this was not the case. This project does demonstrate the need for ongoing, regional fox control programmes.

The Boorowa project concluded that properties with low lamb marking percentages would more likely derive economic benefit by addressing aspects of flock management and lamb survival other than fox control. Properties with good management practices and high lamb marking percentages were assumed to benefit more from fox control. These assumptions were in part based on the post mortems of some 2000 lambs for cause of death. The South Australian project concludes the opposite, although no post mortems were reported. More detailed appraisals of both projects may be required to determine which assumptions are correct.

Southern New England Landcare coordinated fox control programme (New South Wales)

The Southern New England Landcare coordinated fox control programme began in 1994 with a few Landcare groups. It is now a joint venture between several local and government agencies (NSW NPWS, Southern New England Landcare and Armidale RLPB). This programme involves around 800 landholders baiting during the winter months, with a smaller number baiting over autumn as well (Pollard 2000; Southern New England Landcare Coordinating Committee (SNELCC) 2002; S. Williams, SNELCC, pers. comm. 2005). Monitoring and evaluation of this programme are seen as important components, not only in meeting reporting requirements but also in ensuring maximum effectiveness. The coordinators have ideally aimed for a long-term monitoring programme that can be affordable, repeatable and comparable over years. They have trialled several methods over the time of the programme's operation, including spotlight counting, recording the number of baits laid, mapping of participating properties, use of bait uptake data sheets, and performing landholder feedback surveys.

Spotlight counts were used to monitor fox population numbers before and after the baiting programme. Coordinators found that fox populations were difficult to monitor effectively using this method. This, coupled with a lack of resources, led them to conclude that spotlighting was an unsatisfactory method to implement over the long term (SNELCC 2002). The collection of number of baits laid information was comparably easy to achieve, but it was only an arbitrary indicator of participation, with an increase in baits laid not necessarily meaning an increase in the efficiency of the programme (SNELCC 2002). Mapping of participating properties provided a spatial overview of the programme and a good comparison between years. It helped to identify gaps within and between groups, but, again, it was only an arbitrary indicator of participation and efficiency.

In 2002, the coordinators attempted to develop a suitable bait uptake sheet that could be used in conjunction with the pesticide recording requirements. This method, which relied on the landholders completing the form correctly and returning it in a timely manner (SNELCC 2002), was discontinued in following years, as the information collected was patchy and incomplete (S. Williams, SNELCC, pers. comm. 2005). In recent years landholder feedback surveys has been used to collect information on fox numbers and damage. Information has been collected verbally from landholders throughout the programme, as well as from the area coordinators at an organized dinner at the end of each programme. It is hoped that this *ad hoc* manner of information collection will be formalised by way of a written survey given to all participants in the 2006 programme (S. Williams, SNELCC, pers. comm. 2005).

'OutFox the Fox' programme (New South Wales)

'Outfox The Fox' is a strategic, coordinated fox-baiting programme incorporating over one-fifth of New South Wales' pastoral regions (Balogh et al. 2001). The programme began in September 1999, with 700 landholders participating, and has now grown to over 1400 participating landholders, and several NSW NPWS Regions, State Forests, Crown Land and Reserve Trust areas. It is promoted and operated through the RLPB system. Because foxes are not declared pest animals in New South Wales, the RLPBs see their involvement as a service to all ratepayers. Initially, participating landholders were asked to complete a survey questionnaire to assess the adoption of the best practice techniques and any gaps in extension. In more recent years, monitoring of the programme has been left up to the individual RLPBs and their rangers.

Most boards measure the success of the programme by the number of participants, or groups involved in baiting, along with landholder comments and personal observations. Some boards also conduct fox population counts in small areas. These are usually associated with local conservation projects (e.g. mallee fowl in Dubbo RLPB—de Jongh et al. 2005; bush stone-curlew in Forbes RLPB—Hazell 2005).

Jones et al. (2006) conducted an economic evaluation of the 'Outfox the Fox' programme. They used the economic surplus model and also conducted a benefit–cost analysis. The lamb industry was identified as the main beneficiary of this group fox control programme and, according to the results from the economic surplus model, the change in annual economic surplus due to this programme was $3.4 million. The benefit–cost analysis showed that the project provided a significant return on public investment with a mean net present value of $9.8 million and a mean benefit–cost ratio of 13:1. Probability analysis indicated there was a very low probability that this group fox control programme would provide a negative economic return.

13.4 Fox impacts on threatened species

The fox has long been recognised as a serious threat to populations of native wildlife (Saunders et al. 1995). Obvious, indirect evidence of the probable importance of foxes was apparent from islands where small mammals that were rare on the mainland thrived in the absence of foxes (Marlow 1958). Finlayson (1961) described how, over a 25-year period, Central Australia was being stripped of its smaller wildlife species by increasing populations of foxes. Finlayson thought it probable that the colonial distribution of marsupials, in particular, made them vulnerable to fox predation: small groups were systematically and rapidly hunted out of existence before they had any time to develop defensive mechanisms.

Some 30 years after the initial releases of foxes, their predation was implicated in the decline of species such as the brush-tailed rock-wallaby (*Petrogale penicillata*) on mainland Australia (Le Souef and Burrell 1926). Wakefield (1954) also surmised that rock-wallabies began to disappear from the Southern Highlands of New South Wales and Victoria around the early 1900s, and that foxes were responsible for killing out them and many other animals. Marlow (1958), in his survey of marsupials in New South Wales, concluded the following:

'There are no data available that help to provide a direct assessment of the importance of fox (and feral cat) predation on marsupial fauna. Evidence that such predation occurs means nothing in itself: all herbivorous species are subject to predation, and with rare exceptions are well adjusted to it. There is presumptive and indirect evidence, however, that at any rate the introduced fox may have been a factor of critical importance in the reduction of small and medium-sized marsupial species.'

Unfortunately, few of the earlier studies attempted to measure the effect of fox predation. Frith (1959) was an exception and identified foxes as the greatest source of egg loss (377 out of 1094) in a study of mallee fowl (*Leipoa ocellata*). Whether or not more studies such as the latter would have accelerated action against foxes and helped save some native species from local extinction is debatable. Nonetheless, it was not until after relatively recent studies, such as those of Kinnear et al. (1988) and Priddel (1989), quantified the extent of fox impact on wildlife that land managers began to call for more effective management of foxes.

Compared with the damage in other continents, the damage to Australian wildlife since European settlement has been catastrophic and unparalleled, with the exception of some island faunas. At least 20 species of Australian mammals have become extinct, with a further 5 species restricted to small offshore islands (Department of the Environment and Water Resources (DEW) 2005). This represents about half of the world's mammal extinctions in the last 200 years; a further 88 species are judged to be either endangered or vulnerable (DEH 2005). The causes are complex and involve a number of threatening processes, such as habitat loss, habitat change and degradation, impact of introduced animals and plants, disease, exploitation and climatic change (Short and Smith 1994; Short and Turner 1994; Lunney 2001; National Land and Water Resources Audit 2002).

Foxes can have a major impact on a wide range of native animals including turtles, possums and bandicoots.

Source: Paul Meek, Forests NSW

13.5 Case studies: threatened species

'Western Shield' programme (Western Australia)

The results of pioneering research work on fox predation on rock-wallabies in Western Australia in the 1970s and 1980s (Kinnear et al. 1988; Kinnear 1990, 1992; Kinnear et al. 1998) initiated a series of fox removal trials on other sites supporting populations of other rare and endangered species in that State (Burbidge and Friend 1990; Friend 1990; Kinnear et al. 2002). These trials became the genesis of the 'Western Shield' programme, a large-scale wildlife recovery programme based on fox baiting, initiated in 1996 and covering nearly 3.6 million hectares, primarily conservation estate situated in the south-west of the State (Burbidge et al. 1995; Bailey 1996; Armstrong 1998, 2004). Fox control is achieved by regular baiting with 1080 dried-meat baits. The baits are laid by aerial or ground operations at least four times a year at an intensity of 5 baits per square kilometre (Bailey 1996; Armstrong 1998; Orell 2004).

Monitoring of fauna recovery is largely focused on the south-west of the State, with around 40 monitoring sites established in this region (Orell 2004). The effect of baiting is monitored by trapping and field counts (spotlighting, nest boxes, hair tubes) of native animals at specific experimental sites. The monitoring method and design depends on the species to be monitored and the objectives of the programme in that particular area. Indicator species that are easily observed via simple sample methods and have shown a clear response to fox baiting are used to measure the effectiveness of the fox baiting at selected sites (Orell 2004). Owing to resource restraints, staff training and difficulties in developing reliable monitoring techniques for some native species (e.g. ringtail possums — de Tores et al. 2004; Wayne et al. 2005), monitoring for these species has been restricted at most sites other than research-specific ones (de Tores et al. 2004; Orell 2004).

The programme has had significant success, with the recovery of at least one mammal species present at 22 of the monitoring sites. Three species—the woylie (*Bettongia penicillata*), quenda (*Isoodon obesulus*) and tammar wallaby (*Macropus eugenii derbianus*)—have recovered sufficiently to be removed from the Schedule 1 endangered species listing under the *Endangered Species Protection Act* (Orell 2004). The recovery of a variety of native wildlife species, including mammals, birds and reptiles, after intensive fox control has been reported in the literature (e.g. Kinnear 1992; Morris 1992; Morris et al. 1995; Armstrong 1998; Risby et al. 2000; Orell 2004), as has the successful reintroduction of some species (e.g. Bailey 1996; Vertebrate Biocontrol CRC 1999; Orell 2004). At other sites, subjective assessments and anecdotal accounts have been reported but there are no supporting quantified data (de Tores et al. 2004; Orell 2004).

Despite the success of the intensive fox baiting on some species' populations, there have been other species for which the outcome appears not to be as positive in some areas. The western ringtail possum (*Pseudocheirus occidentalis*) was originally identified as a species likely to benefit from the 'Western Shield' programme (Burbidge et al. 1995); however, a recent review of this species (de Tores et al. 2004) indicates that successful translocation has not been clearly demonstrated and, at the main translocation site, the population has actually declined. Poor monitoring of this arboreal (tree-dwelling) species, probably a reflection on the difficulty of detection (Wayne et al. 2005), is thought to have contributed to the lack of response data.

The quokka (*Setonix brachyurus*) is another species that has not responded as anticipated. Studies on the survivorship of this species in the northern jarrah forests indicate that the population should have recovered after the fox baiting, but no increase has been evident (Hayward et al. 2003; de Tores et al. 2004; Hayward et al. 2005a). Factors other than fox predation, such as habitat structure and behavioural responses, are thought to have major influences on the quokkas' population dynamics (Hayward et al. 2005a, 2005b).

'Project Deliverance' (Victoria)

In Eastern Australia there are few large-scale conservation projects that can be compared with those in Western Australia. One large project operating in the forests of south-eastern Victoria is 'Project Deliverance'. This programme began in 1998 and covers a total area of 33,000 hectares. All baiting is done by ground operations, with baits buried at permanent baiting stations spaced at approximately one kilometre intervals along tracks and roads throughout the study sites. Baiting is continuous, with baits checked and replaced every four weeks (Murray et al. 2005). The six small mammal species of interest are monitored by trapping. Capture rates per trap unit are used to compare population trends, and survivorship is calculated from recapture data. The results from two of the study sites in the five year project indicate that the fox control effort is having significant positive effects on the abundance of two species of small mammal, the long-nosed potoroo (*Potorous tridactylus*) and the southern brown bandicoot (*Isoodon obesulus*), that were considered to be at great conservation risk (Murray et al. 2005). The 'Southern Ark' programme has continued this large-scale fox-baiting programme in partnership with many government agencies and the local community (Victorian Department of Sustainability and Environment 2003).

'Operation Bounceback' (South Australia)

The South Australian Department for Environment and Heritage, in collaboration with neighbouring landholders, developed an 'ecological restoration programme' ('Operation Bounceback') for the Flinders Ranges National Park (FRNP) in 1992. Intensive fox baiting became part of this management programme in 1993, with the initial aim to protect local populations of yellow-footed rock-wallaby. Application was successfully made to the Natural Heritage Trust for funding to expand the programme, and 'Bounceback 2000' was launched in May 1998. This new programme is aiming to build on the gains in FRNP and expand to Gammon Ranges National Park (Anon 1999c; Holden 1999; de Preu 2000).

Fox baiting, using 1080 dried-meat baits, was initially started around the yellow-footed rock-wallaby colonies in FRNP in 1993, but was soon extended to cover the whole park and a buffer zone on neighbouring properties. Since 1994 ground baiting has been done four times a year, with 4–5 baits per square kilometre, buried along set transects. An aerial baiting programme, similar to that used in Western Australia and in Yathong National Park in New South Wales, is being developed (De Preu 2000).

An important aspect of the fox control programme is the monitoring of fox populations. Spotlight surveys began in 1994 and involve volunteers and members from the Hunting and Conservation Branch of the Sporting Shooters Association of Australia (H&CB—SSAA). Currently, these spotlight surveys are conducted every three months. Vehicle transects (a minimum of 50 kilometres per night) are driven over three nights in baited areas, adjacent unbaited areas and distant unbaited areas (Holden 1999; De Preu 2000). The baiting is also augmented with shooting by members of the H&CB—SSAA.

Before fox baiting began in FRNP, fox numbers ranged between 25–100 animals per 100 kilometres (from spotlight surveys). After baiting, foxes were recorded at between 0–15 animals per 100 kilometres (see Figure 4 in De Preu 2000). Fox numbers have also declined in the unbaited areas, although numbers in the distant unbaited treatments are still higher than in FRNP (De Preu 2000). The reason for this decline is not clear. Unfortunately, some unauthorised shooting occurred on the distant unbaited sites and has compromised their intended purpose as acting as control areas removed from the influence of fox control (Holden 1999). Despite this lack of scientific rigour, the impact of rabbit calicivirus disease and the associated reduction in rabbit numbers in the area are thought to have played some part in the fox decline in unbaited areas, along with the dispersal of foxes into the baited areas (Holden 1999, De Preu 2000).

Another measure of the effectiveness of this fox control programme has been the monitoring of the response of the threatened prey species. Yellow-footed rock-wallaby populations in FRNP have increased (from an estimated total of 23 animals in 1993 to 198 in 1999), along with populations of other native prey species (Anon 1999c; Holden 1999; De Preu 2000). Over the three months following the first reintroduction of the brush-tailed bettong in August 1999, nearly half of the individuals were known to have survived and established themselves (Bell-chambers 1999).

'West Coast Integrated Pest Management Programme' (South Australia)

The 'West Coast Integrated Pest Management Programme' (WCIPMP) is a community-based programme that coordinates pest control activities on a landscape scale. The programme is managed by a partnership of four agencies: the Western Animal and Plant Control Board, the Elliston-Le Hunte Animal and Plant Control Board, the Eyre Peninsula Natural Resource Management Group, and the SA Department for Environment and Heritage. However, community input and direction are vital and are provided through a Community Steering Committee. There is also general feedback, as well as results, from all participant landholders (WCIPMP 2005). This programme began in 2000 to support reintroductions of brush-tailed bettongs (*Bettongia penicillata*) at Venus Bay Conservation Park. Since then, the number of participating landholders has expanded from 30 to 330. The focus of on-ground activities to date has been fox control, but with the emphasis on an integrated approach rabbit and weed control have been incorporated, and a variety of best practice pest management methods are encouraged (WCIPMP 2005).

Monitoring measures include relative abundance of pest species, recovery or relative abundance of native species, and community participation and awareness levels. Spotlight transects are completed six times a year at seven locations in the programme region to give an indication of the changes in relative abundance of the fox population over time. Landholders are requested to keep records of bait uptake at each of their bait stations, and if possible to note any animal tracks evident at the bait station. Records are kept of the number of baits obtained by each landholder and dates collected. This provides data on baiting activity for each baiting season, and can be used to map baiting activity in the region as well as to evaluate the expansion of the programme over time. A postal survey has been conducted annually since 2002 and is designed to assess approval levels for the programme, obtain data on lambing percentages, and allow participants to convey opinions and ideas to help direct the programme (WCIPMP 2005).

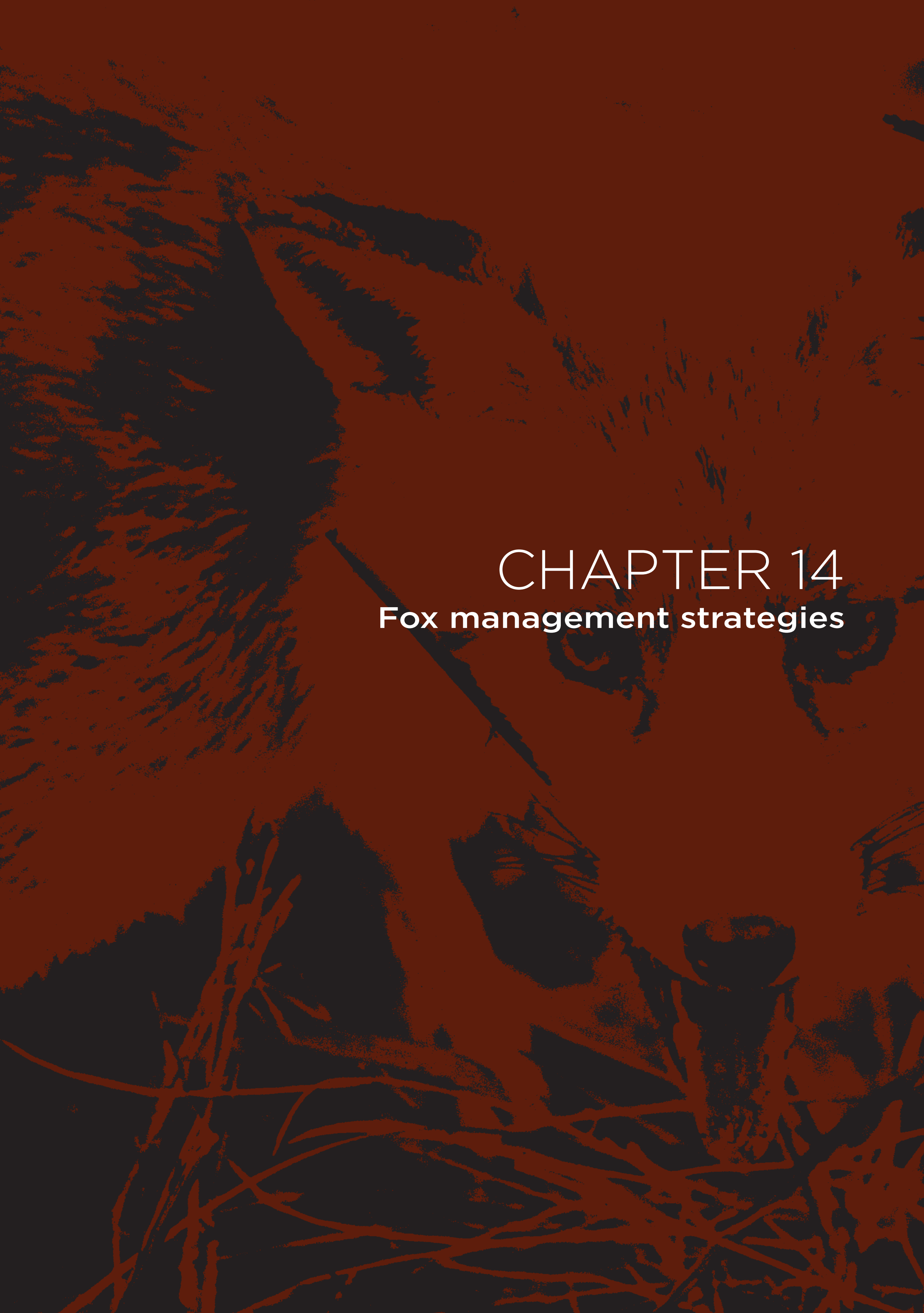
As shown by the results of the spotlight surveys, fox abundance over the programme region has declined since the start of the programme, from an average of seven sightings per 100 kilometres to four sightings per 100 kilometres after three years (WCIPMP 2005). No results have been published on the response of the brush-tailed bettongs or any other threatened species in the region, but details are available from the annual landholder survey. Incidentally, around 63% of landholders who replied to the 2004 survey reported that their lambing percentages had increased, and 95% believed that this increase was due to the fox-baiting programme.

Fox Threat Abatement Plan (New South Wales)

Priorities for fox control for the conservation of biodiversity across all land tenures in New South Wales are identified in the New South Wales Fox Threat Abatement Plan (NSW National Parks and Wildlife Services 2001, see Section 11.2.5). Under the Plan, across tenure fox-control and/or threatened species monitoring has been established at 73 priority sites across New South Wales. The majority of priority sites are comprised mostly of public lands (national parks, nature reserves, State forests and crown land reserves), reflecting the distribution of targeted threatened species. However, control and monitoring also occurs on private lands at some sites. The scale and frequency of control varies significantly reflecting both the potential for fox immigration and logistical constraints. Thus fox control is undertaken three to six times per year over the contiguous areas of up to 1000 square kilometres at priority sites in semi-arid western New South Wales. At coastal sites targeting threatened shorebirds, control is typically undertaken weekly throughout the nesting season, but often on a limited scale reflecting the proximity to urban areas.

Under the Plan, monitoring programmes have been established to measure the response of priority threatened species to fox control. There are 19 species-specific monitoring programmes involving coordinated monitoring of threatened species and foxes across sites and tenures. Where possible, treatment and non-treatment sites have been established for each species. Species targeted include rufous bettong (*Aepyprymnus rufescens*), brush-tailed rock wallaby (*Petrogale penicillata*), yellow-footed rock wallaby (*P. xanthopus*), southern brown bandicoot, broad-toothed rat (*Mastacomys fuscus*), malleefowl (*Leipoa ocellata*), and shore nesting birds such as little tern (*Sterna albifrons*) and the pied oystercatcher (*Haematopus longirostris*). The monitoring programmes will be reviewed as part of the review of the Plan in 2006.

The systematic approach taken in New South Wales to prioritise actions and to implement fox control programmes has demonstrated an effective way of using limited resources and may be worth considering in other jurisdictions.



CHAPTER 14
Fox management strategies

14. Fox management strategies

Key issues

- *Over the last decade, the approach to managing pest animals has changed (Braysher 1993). It is now realised that rather than focusing on killing as many pests as possible, pest management (like most other aspects of agriculture or nature conservation) needs to be carefully planned and coordinated.*
- *It is highly desirable that pest control programmes are sustained so that pest densities always remain at a low level.*
- *Pest animal control is just one aspect of an integrated approach to the management of production and natural resource systems. Most pests are highly mobile and have the capacity to readily replace those that are killed in control programmes. Unless actions are well planned and coordinated across an area, individual control programmes are unlikely to have lasting effects.*

14.1 Developing a fox management strategy

When planning any pest management programme, including those for foxes, there are some important steps that should be considered (after Braysher 1993, Braysher and Saunders 2002):

- What is the trigger to undertake pest animal management? Is there a community or political pressure for action on pests and an expectation that pest animals should be controlled? Pest control is unlikely to be effective unless there is strong local or political will to take action and commit the necessary resources.
- Who is the key group to take responsibility for bringing together those individuals and groups that have a key interest in dealing with the pest issue?
- What is the problem? In the past the pest was usually seen as the problem. Hence the solution was to kill as many pests as possible. We now know that the situation is more complex. First, determine what the problem is. It may be reduced lambing percentage, fence damage, reduced crop yields, complaints from neighbours or emotional stress from worrying about the next attack. Several factors affect each of these problems, and control of pests is often only part of the solution.
- The following questions then help define the problem:
  - Who has the problem?
  - Where is the problem?
  - How severe is the problem?
  - Will the problem change with time?
- Identify and describe the area of concern. Sometimes it helps to remove agency and property boundaries so that the problem can be viewed without the tendency to point blame at individuals, groups or agencies. Property and agency boundaries (see 'nil tenure' below) can be added later, once agreement is reached on the best approach.
- Trying to deal with the complexity of a very large area can be daunting, so it often helps to break the area into smaller management units for planning. These smaller units may be determined by water bodies, mountain ranges, fences, vegetation that is unsuitable for a particular pest, or other suitable boundaries that managers can work to. Although it is best to work to boundaries that restrict the movement of pests, this may not be practicable, and jurisdictional boundaries (e.g. the border of a Landcare group) may have to be used in combination with physical boundaries. Once the management units are identified:

- identify, as best you can, the pest animal distribution and abundance in each management unit; and
- estimate, as far as is practicable, the damage caused by the pest or pests to production and to conservation.

- Gather and assess other relevant planning documents such as Catchment Management Plans, Recovery Plans for threatened species and Property Management Plans. Identify any key constraints that may prevent the plan being put into operation, and identify all the key stakeholders.
- Develop the most appropriate pest management plans for each of the management units.
- Implementing effective and humane pest control programmes requires a basic understanding of the ecology and biology of the targeted pest species and (in some cases) those species affected directly (non-targets) or indirectly (prey species) by a control programme. It is also essential to understand the impact created by the pest (i.e. what is the problem?).
- Strategies used in agricultural protection have been determined mostly by the biology of the livestock being protected rather than by the biology of the fox. As such, these techniques have been mostly employed on a reactionary or short-term basis, without due consideration for sustained reduction. Conservation management strategies focus on alleviating fox predation on wildlife species by culling foxes from an area using poisoned baits and exclusion fencing. By necessity, such control effort must be sustained. There are three essential requirements for a pest control technique: necessity, effectiveness and humaneness. The best strategy is to develop a plan that maximizes the effect of control operations and reduces the need to cull large numbers of animals on a regular basis.

14.2 Developing a fox management plan

Development of a fox management plan involves:

- **Defining management objectives.** Objectives are statements of what is to be achieved, defined in terms of desired outcomes—usually conservation or economic benefits. Objectives should state what will be achieved (reduced impact) where, by when and by whom.
- **Selecting management options.** Select the management option that will most effectively and efficiently meet the management objectives. The options include eradication, containment, sustained management, targeted management, one-off action and taking no action.
- **Set the management strategy.** This defines the actions that will be undertaken: who will do what, when, how and where. It describes how the selected pest management options and techniques will be integrated and implemented to achieve the management objectives.
- **Monitoring the success of the programme against the stated objectives.** Monitoring has two components, operational monitoring (what was done when and at what cost—this determines the efficiency of the programme), and *performance monitoring* (were the objectives of the plan achieved and if not, why not—that is, the effectiveness of the programme).

Much of the above can be found in a set of documents and guidelines called PESTPLAN (Braysher and Saunders 2003), which is a tool to help manage pest animal populations and the damage they cause. It provides a process for groups to tackle pest management planning on the basis of a clear understanding of the pest problem, what can be achieved, and how to implement it at a local level. PESTPLAN can be used by anyone, but it relies on forming a core group usually involving key agency and/or community participants, to initiate and facilitate the process.

14.3 Choosing control techniques

As highlighted earlier in this guide, the scale of problems involving fox predation, ranging in size from a small poultry shed to a large national park or agricultural region, can determine the most appropriate means of control or, conversely, the effectiveness of control in individual situations. For example, aerial baiting would be the most cost-effective strategy over large areas (Section 2.8) whereas the use of guard dogs would be suitable only on a property basis (Section 6.3). Similarly, the use of fertility control would be of little benefit in protecting small-scale enterprises, and cage traps would have little effect in a rural setting (Section 4.1). The cost-effectiveness, humaneness and efficacy of each control technique are useful in deciding the most appropriate strategy. In selecting techniques it is also important to consider whether sufficient resources are available to fully implement a particular technique.

14.4 Collaborative fox control

Historically, the management of fox damage in Australia has relied mainly on sporadic control of foxes at the local level. The fox is a highly mobile and invasive species. Apart from perhaps providing very short-term protection or eliminating a particular rogue animal, isolated efforts at fox control will have a minimal effect on fox populations or on the regional impact caused by foxes. The importance of collaborative fox control programmes for effective management of fox damage has been described by Saunders et al. (1995). They emphasised the need for promoting community ownership of the fox damage issue, particularly when the beneficiary of fox control is usually very difficult to identify, given that foxes can cause damage to both agricultural production and native fauna. Community involvement in the management of the problem, with collaboration from government agencies and private landholders, is a pre-requisite to achieving lasting gains in a cost-effective and measurable manner. Advantages of collaborative effort include:

- training of field staff
- incorporation of research activities aimed at improving outcomes
- peer pressure on normally uncooperative participants
- cross-tenure (private and public) implement–ation of control activities
- project planning
- cost-efficient use of labour and equipment
- limitation of re-invasion rates
- public education and extension
- implementation of best practice
- monitoring of impacts and hence outcomes
- generation of funding opportunities
- increased political support
- adaptive management
- ultimately, better outcomes.

14.5 Concentration of effort

During the nineties, large-scale fox-baiting programmes, involving liaison and cooperation between private and government agencies, were promoted and embraced in all areas of Australia, for both conservation and agricultural purposes. There are many examples from the conservation literature where intensive baiting programmes conducted over long periods have significantly reduced the fox impact on threatened species (see Sections 2.11 and 13.5). However, it is not clear whether agricultural group fox-baiting programmes reduce fox abundance, or (more importantly) whether they reduce the impact of foxes on lamb production.

With the ability to rapidly establish new territories, over both short and long distances, the fox is well adapted to compensate for any form of population reduction. It is therefore critical to assess the desired outcomes of a baiting programme so that the coverage and duration of baiting (concentration of effort) achieves the levels of control that will produce positive production outcomes. Many government-funded experimental, broadscale evaluations of population reductions from lethal baiting suggest high rates of success (>90%) (see Table 2.3). However, the resources, duration and care that go into these studies may not reflect the outcomes expected from conventional control programmes.

Recent preliminary trials suggest that conventional programmes may reduce populations by less than 60%. There is a need for more evaluations of conventional programmes, especially at district and regional levels. It is also important to note that most of the experimental evaluations are also about the control of numbers and not damage. In the absence of reliable information, there is an urgent need to re-evaluate conventional baiting programmes conducted in eastern Australia, especially on the more productive agricultural lands, and with an emphasis on the way baits are deployed. Gentle (2005) modelled the potential for fox immigration after typical group baiting campaigns in central New South Wales and found that the spatial coverage and frequency of baiting was inadequate to prevent fox reinvasion. The size of the area that would have to be baited for any such reduction has been difficult to determine and is currently being investigated. Included in any ongoing investigation should be the study of reasons for land managers to engage or otherwise in such large-scale or group baiting programmes.

14.6 Implementing a fox management strategy

The 'Nil Tenure' Strategy: Brindabella and Wee Jasper Cooperative Wild Dog/Fox Programme

The Brindabella and Wee Jasper valleys in south-eastern New South Wales comprise large areas of private and public land (managed by several different government agencies), ranging from rugged, inaccessible bushland to cleared agricultural productive land. The area has had a long history of wild dog and fox impact on agricultural production, and because the private landholders were considered the main beneficiaries of any control programmes, it was up to them (through the Rural Lands Protection Board system) to provide the major resources for the programmes. However, the traditional view held by the rural industry was that the government-managed lands provided refuges for the pest animals to live and breed in (English and Chapple 2002), and hence that the government should provide the major resources for the control programmes. This led to many years of emotional and political debate (Hunt and Brindabella Wee Jasper Wild Dog/Fox Working Group 2005) and before the implementation of the cooperative wild dog/fox programme in 2001–02, wild dog and fox management was not coordinated and was very under-resourced (Anon 2002a).

This programme was initiated by concerned landholders and managers, who found that a coordinated approach was required to effectively cost and implement wild dog/fox control programmes in the valleys (Anon 2002a, Hunt 2005). Because the problem was regarded as a landscape issue rather than the problem of any one individual landowner, a 'nil tenure' approach was used in the initial planning. This method involves the removal of all land tenure issues from the planning stage and focuses on the problem in a holistic manner, rather than on the basis of land ownership (Fleming and Harden 2003, Hunt 2005). Once the problem had been identified and the proposed control actions defined, the tenure boundaries were reinstated and the resources and costs allocated proportionally or according to some agreed formula (Fleming and Harden 2003). In the case of the Brindabella and Wee Jasper programme, joint funding was provided by the Yass RLPB, the NSW NPWS and NSW State Forests.

The Brindabella and Wee Jasper cooperative wild dog control programme is seen as a great success and has led to the implementation of nil tenure strategies in many other pest animal control situations. Since its implementation there has been a consistent reduction in stock losses, along with a notable improvement in working relations between public and private land managers (Hunt 2005). The success of the first six years has seen a commitment of resources for continuation of the programme by the three main participants until 2010 (Anon 2005). It remains to be seen if the level of resources committed to this programme can be sustained or if such commitments can be similarly made in other areas where wild dog attacks interface with public lands.

The 'PESTPLAN' approach: Goonoo and Coolbaggie Cooperative Fox Programme

The Goonoo and Coolbaggie cooperative pest control programme is an example of using the 'PESTPLAN' approach to implement regional fox control. The programme was triggered by the perceived decline in the local populations of mallee fowl (*Leipoa ocellata*) by local residents (de Jongh et al. 2005). Key players in the group programme are the Dubbo and Coonabarabran RLPBs, NSW NPWS, Forests NSW, NSW DPI and local landholders. The pests identified as having an impact on the mallee fowl were foxes (predation) and rabbits, feral pigs and goats (habitat destruction).

Pest animal surveys conducted by Forests NSW documented information on pest animal distribution and abundance in the district. Foxes were found to be widespread and other pest species locally abundant. Surveys of mallee fowl populations implicated fox predation as the primary cause of decline. Neighbouring landholders also provided evidence that foxes were affecting lambing performance in the area.

The key constraints to success of the programme were identified as:

- lack of communication;
- lack of agreement on the scale of the problem;
- poor organisation;
- no monitoring and feedback of information;
- no participation by some key landholders;
- scepticism because of previous programme failures; and
- lack of resources because of drought feeding operations.

These issues were addressed in the development of a management plan. The programme is centred on the Goonoo and Lincoln State Forests, an area of approximately 80,000 hectares, and includes up to 130 neighbouring landholders covering an additional area of 100,000 hectares (de Jongh et al. 2005). These surrounding areas have been divided into smaller management units using the existing 11 bush fire brigade areas. The area is contained within the Macquarie Catchment Management Blueprint Plan, and partly covered by NPWS Central-West pest management strategy.

The programme is primarily based around the collaborative baiting programmes run by Forests NSW, NSW NPWS and the Dubbo RLPB (de Jongh et al. 2005). The programme activities and management actions are coordinated by a stakeholder committee, which contains members representing all key players and meets on a regular basis. The committee has coordinated the organisation of regular meetings for each of the smaller management groups, the farm and agency baiting programme, and the various monitoring and evaluation programmes, including mapping and data collection. Communication is further enhanced by the production of a biannual newsletter and regular local media releases (de Jongh et al. 2005).

The monitoring and evaluation programmes are important parts of the management plan. The mallee fowl population is monitored with the help of a voluntary group, the Goonoo Lands Bigfoot Programme, which was formed in 2004. This group's aim is to survey 10% of the Goonoo State Forest for nesting mounds, and to date 105 volunteers have surveyed 3.5% of the area, locating 53 new mounds, 3 of which were active (de Jongh et al. 2005). Other monitoring activities include spotlight counts of foxes in the area, bait uptake and lambing record analyses, comparisons over time of farmer participation rates and complaints received, and assessments of participant and community attitudes.

Forests NSW has started a study of foxes in the area, using radiotelemetry and GPS technology. This project is studying the habitat preferences of foxes in the landscape, fox movements within and across tenure boundaries, and fox responses to predator control events. Hopefully the results will both increase the efficiency of the control programme by targeting high activity areas and provide a view of the current population situation, thus helping in the continued monitoring of the pest species (de Jongh et al. 2005).

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16. On-line resources

General websites:

Bureau of Rural Sciences — National Feral Animal Control Programme website: www.brs.gov.au/feral

Department of the Environment and Water Resources — Invasive animals website: www.environment.gov.au/biodiversity/invasive/index.html

Feral animal database website: www.feral.org.au

Invasive Animals CRC website: www.invasiveanimals.com

Specific documents:

Braysher, M. and Saunders, G. (2003). Pestplan — a guide to setting priorities and developing a management plan for pest animals. www.affashop.gov.au/product.asp?prodid=12598

Brindabella and Wee Jasper Valleys Cooperative Wild Dog/Fox plan 2005-2010. www.nationalparks.nsw.gov.au/npws.nsf/content/brindabella+and+wee+jasper+valleys+cooperative+wild+dog+and+fox+control+programme+20022005

Department of the Environment and Water Resources — *Environment Protection and Biodiversity Conservation Act (1999)* administrative guidelines on significance supplement for the Tiger Quoll (southeastern mainland population) and the use of 1080. www.environment.gov.au/biodiversity/threatened/guidelines/tiger-quoll/

Department of the Environment and Water Resources — *Environment Protection and Biodiversity Conservation Act (1999)* — List of Threatened Fauna. www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=fauna

Department of the Environment and Water Resources (1999). Threat Abatement Plan for predation by the European red fox. www.environment.gov.au/biodiversity/threatened/publications/tap/foxes/index.html

Jones, R., Saunders, G. and Balogh, S. (2006). An economic evaluation of a pest management control programme: 'Outfox the Fox'. www.dpi.nsw.gov.au/research/branch/health-science/economics-research/reports/err29

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