Bureau of Resource Sciences

Managing Vertebrate Pests: Foxes

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FOREWORD

This publication, which is one in a series, provides land managers with 'best practice' national guidelines for managing the agricultural and environmental damage caused by foxes. Others in the series include guidelines for managing feral horses, rabbits, feral goats, feral pigs and rodents. The publication was developed and funded by the Vertebrate Pest Program in the Bureau of Resource Sciences. Production of the fox guidelines was aided by financial assistance from the Australian Nature Conservation Agency's Feral Pests Program.

To ensure that the guidelines are widely accepted as the basis for fox management, comment has been sought from state, territory and Commonwealth government agriculture, environmental and resource management agencies. Comments were also sought from land managers and community and other organisations, including the Australian Conservation Foundation, the National Farmers' Federation, the National Consultative Committee on Animal Welfare, the Anangu Pitjantjatjara Aboriginal Land Council and the Northern Land Council. The Standing Committee on Agriculture and Resource Management has endorsed the approach to managing fox damage set out in these guidelines.

Foxes are widely perceived by the wider community and by scientists and conservationists as a threat to native species due to their role as predators. Despite this perception, there is little reliable information on the effects of fox predation on prey populations or of the effect of fox control on the recovery of prey species. The exception is in Western Australia, where some field experiments have shown that fox control can lead to the recovery of native species, including rock-wallabies, bettongs and numbats. Foxes may also detrimentally affect native species such as birds of prey and large reptiles by competing with them for food, but such impacts are speculative as no studies have been conducted.

Less is known about the agricultural impact of foxes, although there is increasing evidence that foxes may inflict severe levels of lamb predation which were previously unrecognised. Foxes are also implicated in deaths and injuries to calves and dairy cattle, although this impact has not been quantified. There is also a small risk that foxes could have a role in the spread of exotic diseases, such as rabies, should such diseases enter Australia.

There are diverse views about fox management. While economists would argue that spending on pest control should be justified in terms of the economic returns on such investments, this is clearly difficult when the impacts of foxes for both conservation and agricultural values, and the responses of prey populations to fox control, are poorly quantified. Those with an interest in conservation place a high value on the protection of native species and often consider fox control to be a priority for endangered species protection. People interested in hunting foxes for commercial use or recreation want to retain foxes as a resource. The crash of fox pelt prices resulting from the actions of the anti-hunting lobby in Europe has reduced interest in fox harvesting in recent years. People concerned with animal welfare hope to ensure that fox control or harvesting is conducted using humane techniques. The authors have attempted to take all these divergent views and values into account in compiling the guidelines.

The principles underlying the strategic management of vertebrate pests have been described in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993). The emphasis is on the management of pest damage rather than on simply reducing pest density. The guidelines recommend that wherever practical, management should concentrate on achieving clearly defined conservation or agricultural production objectives.

These guidelines will help land managers reduce damage to agriculture and native fauna caused by foxes through the use of scientifically-based management that is humane, cost-effective and integrated with ecologically sustainable land management.

Peter O'Brien
Acting Executive Director
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CONTENTS

TABLES

ACKNOWLEDGMENTS

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The draft manuscript was circulated to the following organisations for comment:

- Commonwealth Department of Primary Industries and Energy
- Standing Committee on Agriculture and Resource Management
- Australia and New Zealand Environment and Conservation Council
  - Standing Committee on Conservation
  - Standing Committee on the Environment
- Land and Water Research and Development Corporation
- Meat Research Corporation
- Rural Industries Research and Development Corporation
- International Wool Secretariat
- Australian Conservation Foundation
- National Consultative Committee on Animal Welfare
- National Farmers' Federation
- Murray Darling Basin Commission
- Australian Veterinary Association
- Anangu Pitjantjatjara Land Council

We wish to thank all these groups for their contributions. Many other people, too numerous to acknowledge individually, also gave us the benefit of their experiences by commenting on drafts of the manuscript. The Australian Nature Conservation Agency provided financial assistance.

ACRONYMS AND ABBREVIATIONS

ANCA	Australian Nature Conservation Agency
ANZFAS	Australian and New Zealand Federation of Animal Societies
APB	Agriculture Protection Board (Western Australia)
APCC	Animal and Plant Control Commission (South Australia)
AUSVETPLAN	Australian Veterinary Emergency Plan
AVA	Australian Veterinary Association
BRS	Bureau of Resource Sciences
CALM	Department of Conservation and Land Management (Western Australia)
CCNT	Conservation Commission of the Northern Territory (now Parks & Wildlife Commission of the Northern Territory)
CRC	Cooperative Research Centre for Biological Control of Vertebrate Pest Populations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCNR	Department of Conservation and Natural Resources (Victoria) (now Department of the Natural Resources and the Environment)
DEST	Department of Environment, Sport and Territories
ERIN	Environmental Resources Information Network
ESAC	Endangered Species Advisory Committee
FPP	Feral Pests Program (ANCA)
GIS	Geographic information system
HCAV	Hunt Clubs Association of Victoria
HIPD	Hunting indicator of population density
Landcare	Commonwealth Landcare Program
LandCare	Victorian Landcare Program
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
NLP	National Landcare Program (now part of the Natural Heritage Trust)
PMIS	Pest management information system
RLPB	Rural Lands Protection Board
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SCARM	Standing Committee on Agriculture and Resource Management
VPP	Vertebrate Pest Program (BRS) (now National Feral Animal Control Program)

GLOSSARY

abortifacient: a chemical used to induce abortion

ad hoc measures: specially arranged for the purpose

anticoagulant: a substance that slows or prevents blood clotting. Anticoagulants may be used as poisons to kill pest animals.

attenuated strains: a weak strain of an infectious organism

biltong: strips of sun-dried, lean meat

biocontrol/biological control agent: a living organism (or a virus) used to control the population density of another species

brittilised capsule: a capsule for oral dosing of animals that has been made brittle so it will easily shatter when eaten but is safe to carry

cadastral information: usually includes property boundaries, land tenure and roads

Canidae, canids: the family of animals that includes dogs, foxes and wolves

carcinogenic: cancer causing

carrying capacity: the maximum number of animals that the resources available in an area of land can support

chenopod: plant of the family Chenopodiaceae. In arid areas of Australia chenopods are mostly salt-tolerant shrubs such as blue bush and salt bush.

crepuscular: animals active at dawn and dusk

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

diurnal: animals active during the day

dystocia: difficult birth

endangered species: species in danger of extinction and whose survival is unlikely if the causal factors leading to their decline continue to operate

endocrine function: the release, distribution and effects of hormones in an animal's body

endoparasite: animals that live inside another animal's body, such as tapeworms and the bacteria in the digestive tract

enzootic areas: areas where a disease occurs in wildlife

European rabbit flea: a flea introduced to assist the spread of myxomatosis

family group: occupants of a fox territory, usually composed of a monogamous adult pair and their offspring from the previous breeding season; a dominant adult pair, subordinate adults and offspring, or other common combinations

forb: a soft herb-like plant with a non-woody stem, especially a pasture plant that is not a grass

geographic information system (GIS): acomputer-based system for displaying, overlaying and analysing geographic information such as vegetation, soils, climate, land use and animal distributions

gestation: pregnancy

home range: the area an animal ranges over during its normal daily activities

immunosterility: causing an animal to become sterile by immunising it against one of the proteins or hormones involved in the reproductive process

index, indices: a measure which is correlated with a value but is not an actual estimate of that value. For example spotlight counts give an index of fox numbers but do not give an estimate of total numbers.

intraperitoneal: into the abdominal cavity

intubation: to insert a tube into

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

macropods: animals in the Macropodidae superfamily which includes kangaroos, wallabies, bettongs, rat kangaroos, potoroos, pademelons and tree kangaroos

minimum convex polygon: a simple method for calculating the area enclosed by an animal's home range. It involves drawing the smallest possible convex polygon around the outermost locations or sitings of the animal.

monoestrus: become reproductively receptive only once per year

neophobia: fear of new things

nocturnal: animals active at night

one-shot oats: technique for poisoning rabbits using 1080 and oats whereby only one in one hundred oat grains contain 1080 poison, sufficient to kill an adult rabbit

oral delivery: a dose swallowed in food or drink

parturition: birth

pelt: the skin and fur, either raw or dressed

population turnover: the average time it takes to replace a generation

RD_{50}: the concentration of a sensory irritant which produces a 50% decrease in an animal's breathing rate

recombinant virus: a virus which has been modified by artificial genetic manipulation

relict population: a small isolated population of a species that was once more widespread and abundant

scat: faeces

secondary poisoning: intoxication or death of animals caused by ingestion of other poisoned animals

spotlight traverse: a fixed line of travel over which animals in a spotlight beam are counted

sylvatic: involving one or more wildlife species

tarbaby: a technique for killing foxes where 1080 poison in grease is squirted into a fox den. The fox dies from ingesting the poison grease from fur and paws.

territory: the area an animal or group of animals defends from intruders

tetanic spasms: violent generalised muscular contractions with flailing limbs

transect: a rectangular plot in which data collection occurs

translocation: moving a species to a different place or habitat

ultrasound scanning: use of low frequency sound to investigate the internal structure of an animal without surgery, used for counting foetuses

vectors: organisms or substances that are vehicles to spread a biocontrol agent or disease among animals. For example, mosquitoes are vectors of myxomatosis.

vulnerable species: species believed likely to become endangered in the near future if the causal factors continue to operate

Note: All money values throughout the guidelines are in 1993-94 Australian dollars.

SUMMARY

The introduced European red fox (*Vulpes vulpes*) is widely distributed throughout the southern half of Australia in virtually all habitats, including urban environments. Foxes are seen as a major pest species threatening the long-term survival of a range of native fauna. The review of fox damage undertaken in developing these guidelines confirmed this threat, although scientifically quantified information of fox damage is based mainly on studies in Western Australia. Foxes are also an agricultural pest because they prey on lambs and other livestock.

These guidelines contain a comprehensive review of the history of foxes in Australia, their biology, the damage they cause, and past and current management. The attitudes of conservationists, animal welfare groups, commercial and recreational hunters, and other interest groups are examined. Management techniques and strategies for fox control are recommended and illustrated by case studies. Deficiencies in knowledge, management and legislation are identified.

Why develop national guidelines?

These guidelines for managing the impact of foxes have been developed under the Vertebrate Pest Program (VPP) administered by the Bureau of Resource Sciences (BRS) which is producing a series of pest management guidelines in cooperation with the Vertebrate Pests Committee. The major pests being addressed in the series are foxes, feral horses, rabbits, feral goats, feral pigs and rodents.

The purpose of the guidelines is to assist the development of strategies to reduce the damage foxes cause to production and conservation using the most cost-effective approaches. Ideally, such strategies are based on reliable, quantitative information about the damage caused by the pest, the cost of control measures, and the effect of implementing control on reducing the damage. We have little reliable information of this type for fox management. In developing these guidelines, the authors have used available information, but land managers responsible for fox control will still have to make assumptions about fox impact and the efficacy and cost-effectiveness of control techniques until more reliable information becomes available. It is expected that in planning and implementing fox management, government land management agencies will closely involve community-based groups such as Landcare.

The fox problem

Within 30 years of their initial release in southern Victoria in the 1860s, foxes were proclaimed as a pest in some shires of north-east Victoria. Pest status was based initially on livestock predation, particularly on newborn lambs.

Significant predation by foxes on endangered or vulnerable species has long been suspected; but only in the last decade has scientific evidence been produced which directly incriminates the fox as a major cause of population decline in some species. The best known example is that of the black-footed rock-wallaby (*Petrogale lateralis*), living in small, relict colonies in the wheat-belt of Western Australia. Here, high-level management of local fox populations using poisoned baits resulted in a substantial increase in wallaby numbers. These fox removal experiments have now been repeated in other areas and for other wildlife species. The evidence suggests that in nearly all cases, the removal of foxes results not only in substantial population increases but a wider use of the habitat by the particular prey species concerned. Circumstantial evidence based on fox distribution and faunal abundance consistently indicates that the fox is an important predator of some smaller wildlife species.

The findings concerning fox damage to native fauna outlined in these guidelines

highlight the need for conservation agencies in Australia to assess the extent of fox damage in areas containing wildlife vulnerable to fox predation. Where the damage is significant, they should implement fox management using the appropriate technique and strategy outlined in these guidelines. Further decline or extinction of native fauna may result if this course is not followed.

The economic significance of foxes as predators of livestock is uncertain and subject to debate. Recent studies of ewe fertility using ultrasound scanning for pregnancy and litter-size testing, suggest that the losses of lambs to predators are higher than earlier studies indicated. It may exceed 10% and be as high as 30%. In many instances however, other factors such as starvation, mismothering, difficult birth and cold weather may be of much greater economic significance to the sheep industry. These factors may also increase the susceptibility of lambs to predation by foxes.

Losses of other livestock, particularly poultry, are probably of far less economic significance. However, with a marked rise in the popularity of specialty stock and hobby farms, which have a wider collection of poultry and animals susceptible to fox predation, the cost of such predation by foxes may be significant to individual producers.

The fox in Australia carries no diseases of serious economic or public health significance, although recently foxes have been found to harbour the hydatid parasite, requiring continued surveillance of this situation. Controversy still surrounds the possible role of foxes in Australia as a potential wild reservoir host for the rabies virus. In many parts of the northern hemisphere, the fox is the main reservoir of this disease and, given the widespread distribution of foxes in Australia, the possibility of rabies developing as an established disease in fox populations cannot be dismissed. Fox density and movement data from rabies enzootic areas of Europe and North America are comparable with those obtained from limited studies in some parts of southern Australia. This suggests that conditions are theoretically suitable for the disease to become established and to persist at least in southern Australia. There are, however, many strains of the rabies virus overseas and it is not clear which, if any, of these strains might be suited to a wild animal rabies cycle in Australia which would involve foxes as the main reservoir host. The likelihood of a smuggled animal developing rabies and then infecting a wild fox is low.

There is a close relationship between fox and rabbit numbers. When rabbit populations crash, due to drought, myxomatosis or Rabbit Calicivirus Disease (RCD), there will be a lag period until fox numbers decline and adjust to the reduced prey population. The likelihood of increased predation pressure on native wildlife over this period needs to be considered. Rabbit numbers may also be affected by foxes. Preliminary studies suggest that foxes and feral cats may slow the recovery of rabbit populations after they crash due to drought or disease. The potential role of foxes in rabbit control and the impact of foxes on native wildlife following crashes in rabbit populations needs to be clarified.

Why do foxes prosper in Australia?

A number of qualities have helped the fox to successfully colonise Australia including their wide dietary range covering small to medium-sized mammals, birds, reptiles and amphibians, insects, carrion, fruit, and human refuse. Unquestionably, though, the rabbit has been a major factor. Wherever rabbits are common they are the staple food of foxes. The fox also has high reproductive success. Although litters are small, and females only breed once per year, cub survival is high and most adults appear to breed. With the possible exception of mange and distemper, the fox has few serious diseases. It also has few natural enemies.

Many fox deaths are human induced. Severe mange and the reduction of rabbit numbers due to drought and disease have also caused significant deaths of foxes in some areas. Rural fox density is thought to vary between 0.2–7 per square kilometre, while they can reach 12 per square kilometre in urban areas.

Development of a strategic management approach

Historically, pest control authorities have encouraged management of fox damage to livestock or wildlife in Australia largely by the use of bounty schemes. Although poisoning, shooting and trapping have been employed, these were usually by individual landholders.

Traditional forms of bounty payment have been shown to be ineffective and most fox bounty schemes in Australia have now stopped. The only bounty currently in place is the 'Foxlotto' scheme used in Victoria although this is small scale. Most broadacre control is through poison baits. At a local farm level, shooting, particularly night shooting with spotlights, driving before guns and gassing of breeding dens is carried out, but the reduction in fox density is probably temporary.

Research in Western Australia has demonstrated that foxes can be controlled using 1080 meat baits without risk to native carnivores and omnivores (for example quolls, bettongs, bandicoots and smaller dasyurids). While it is conceded that elements of the Western Australian fauna are 1080 tolerant thus providing a margin of safety, the extent of this advantage may have been overemphasised. The procedures developed in Western Australia are likely to be applicable to other parts of Australia, provided that appropriate risk assessment research is carried out first to determine the species which are at risk from 1080 poisoning.

The effective management of fox damage over large areas requires greater attention to planning and coordination of management. It is recommended that efforts to manage fox damage over large areas primarily be coordinated programs using poisoned baits. These may be laid on the surface or buried depending on circumstances or legislative requirements. Community-based schemes such as Landcare can help to achieve this goal. Foxes rapidly recolonise after control. Therefore techniques must be applied regularly or targeted for long-term control of damage. For example, there may be no point in poisoning foxes to protect lambs at times during the year when no damage is occurring.

Economic frameworks need to be developed to assist land managers assess the relative value of alternative fox management strategies. Such frameworks require: definition of the economic problem; data on the relative costs and benefits; and an understanding of why the actions of individual land managers may not lead to optimal levels of fox control and how such problems can be addressed by land managers and governments.

What is the strategic approach?

The emphasis in these guidelines is not on killing foxes but rather on their efficient and strategic management to reduce the damage they cause to production and conservation values. Foxes are but one factor in a complex and changing environment that includes a highly variable climate, fluctuating commodity prices, other animal and plant pests, farm stock and the profitability of farming businesses, and the viability of conservation reserves. Land managers need to consider investment in fox management in the context of investment in other areas of the land management unit as well as in relation to their impact on natural and semi-natural ecosystems, and on the biodiversity within them.

Achieving a strategic approach to the management of foxes and other vertebrate pests involves establishing four key components. These are:

Defining the problem — The problem should be defined in terms of fox damage and the reduction in fox density required to reduce or prevent the damage.

Developing a management plan — Land managers must establish clear objectives in terms of the desired production or conservation outcome sought. Options for fox management include local eradication, strategic management, crisis management and no management. Eradication will rarely be a feasible objective. Where fox control is shown to be necessary, these guidelines strongly recommend sustained, strategic management as the principal management option.

Implementing the plan — A local or regional approach to fox management is usually most effective. This generally requires coordinated action by individual property managers and government and other agencies. Such action limits the extent of rapid recolonisation where only small-scale fox control is implemented.

Monitoring and evaluating the program — Monitoring has two aspects. Operational monitoring assesses the efficiency of the control operation. Performance monitoring involves gathering information to determine whether the strategy is meeting the desired long-term production or conservation goal.

The above approach has been adopted for developing these national guidelines, and the information in this report is designed to facilitate the development of strategies for managing foxes at the local and regional level.

Community attitudes

In Australia, as elsewhere, the fox is regarded as a killer, a pest, a rogue possessed of inordinate cunning, a commercial resource, a harmless or even beneficial component of the ecosystem, and finally, an honoured object of the chase.

The community generally has little knowledge of the biology and damage foxes cause in Australia. Those who speak on the need for fox control often call for eradication of foxes throughout Australia. This is clearly not achievable. Even with the possible success of present research into immunosterility, continuing control will be required.

Several of the techniques used to control foxes raise animal welfare concerns, most notably the use of steel-jawed traps. However, the use of steel-jawed traps has been wholly or partly banned in many states and territories but hunting with dogs, particularly den terriers, continues. Such hunting is not humane or effective, and often causes suffering to both hunted and hunter. A leg-snare device, developed recently in Victoria, offers a more humane alternative to steel-jawed traps, particularly in urban and semi-urban areas. However, humaneness of the device depends upon frequent inspection of the snares and the early removal of captured animals. Their acceptance will therefore depend on the development and enforcement of minimum inspection standards.

Poisoning with 1080 in buried meat baits is probably the most humane, efficient and selective method of fox control. Strychnine, still registered as a fox poison in some states and territories, is a much less humane poison. The humaneness of 1080 is a little unclear, but because foxes are highly susceptible to this poison, especially compared to most potential non-target animals, it should continue to be used until a more suitable alternative is found. Cyanide is a humane poison that kills rapidly. Unfortunately, the non-target impact of this poison is not well known and there are concerns about human safety. Further research is required on the possible use of cyanide for fox control.

The future

Current research aimed at immuno-sterilisation of foxes in Australia as an efficient form of biocontrol should be supported, although it must be recognised that this is high-risk, long-term research. Managers will need to rely on available techniques for the foreseeable future. The effect of fox predation on populations of a range of native species (including birds, reptiles and amphibians) in different ecosystems needs to be better quantified. At the moment, much of this work is concentrated in Western Australia and little data is available for the rest of the mainland. The relationship between fox densities and impact on prey populations in particular needs to be quantified.

The predator–prey relationship between foxes and rabbits requires closer study. Of particular importance is the effect of fluctuating rabbit numbers upon the prey range of foxes, especially any increased pressure upon endangered or vulnerable wildlife species as the result of a sudden drop in rabbit density.

Currently, relatively little is known of fox ecology in Australia and there is wide regional variation in habitat, behaviour and population dynamics. Studies are required, particularly on population densities and movement across different habitats, so that land managers can use this information to develop appropriate management strategies.

Recent evidence suggests that historical studies on lamb predation in Australia may have underestimated the economic losses due to foxes. Further studies are needed to better quantify the losses.

Commonwealth, state and territory governments must critically examine their present legislation and strategies relating to fox management. While more evidence is required about the extent of fox damage to wildlife in parts of Australia other than Western Australia, there is sufficient evidence that precautionary management of foxes is required in areas with uncommon native species susceptible to foxes. These include the smaller macropods. With the development of Landcare, and other similar community-based groups, it is possible to better coordinate fox management over large areas.

There is a need for improved coordination between agencies and government with interests and responsibilities for fox control.

INTRODUCTION

These guidelines for managing foxes are one in a series developed under the Vertebrate Pest Program (VPP) of the Bureau of Resource Sciences in cooperation with the Vertebrate Pests Committee of the Standing Committee on Agriculture and Resource Management (SCARM). Others include the feral horse, rabbit, feral goat, feral pig and rodents. The need for a new approach to vertebrate pest management is described in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993), which is a companion book which should be read together with these guidelines. Braysher (1993) explains why national guidelines for managing pest animals were developed, the development process, and the principles on which pest management should be based. The need to focus on damage caused by the pest and not the pest itself is stressed.

As stated in Braysher (1993), a set of guidelines for all vertebrate pests, taking account of the links between them and other aspects of land management, would have been more desirable than the single species approach adopted in the guidelines. This would have been consistent with the holistic approach to land management advocated under the Ecologically Sustainable Development strategy and Landcare. Although this has not been practicable, all the guidelines, including this one, consider interactions between species and other aspects of land management.

The guidelines are principally for state, territory and Commonwealth land management agencies, so that they can more effectively manage fox damage through better coordination, planning and implementation of regional and local management programs. The Commonwealth has a major interest in the management of vertebrate pests, as a manager of Commonwealth lands, through such initiatives as the Vertebrate Pest Program, the National Landcare Program and the National Strategy for the Conservation of Australia's Biological Diversity. Achieving the strategic approach to the management of foxes and other vertebrate pests involves establishing four key components as shown in Figure 1. Such an approach has been adopted for developing these national guidelines.

Defining the problem

Historically, the fox was considered a pest but not a significant predator of livestock in Australia. Recent studies by Lugton (1993) have again focused on this aspect of fox damage. However, the most important change has been the recognition that fox predation of wildlife is a major process threatening the survival of many native animals. Chapters 1 and 2 outline the history of the fox in Australia and trace the sources of wild populations. From this historical base, what is known about fox biology is then presented.

Chapter 3 reviews the evidence concerning the economic and environmental impact of foxes in Australia. These impacts are not well quantified, and further studies are needed to address these deficiencies.

Management plan

The primary aim of a land manager is to meet the desired conservation and/or production outcomes for the land, using practical, cost-effective methods without degrading the soil and other natural resources on which the long-term sustainability of the land depends. The environment in which land managers, including farmers, operate is highly variable. A number of factors influence the desired outcomes, such as fluctuating commodity prices, climatic variability including drought, plant and animal pests, grazing pressure, quality of stock and social factors such as the influence of animal welfare and conservation organisations.

The objective of the national guidelines is to encourage the adoption of 'best practice' fox management as distinct from reactive measures by individuals and agencies. 'Best practice' is based on cooperative action and adoption of a whole property planning approach to management, preferably linked to a regional or total catchment plan.

The guidelines will have met their purpose if the strategic approach they advocate is accepted and implemented by a significant number of agencies and individuals. This constitutes the criterion of performance.

Chapter 4 reviews management techniques for rabies.

A national strategy for managing foxes includes encouraging the group approach. Community attitudes strongly influence the management of foxes, and these issues are discussed in Chapter 5.

Chapter 6 reviews both past and current management and Chapter 7 reviews techniques for measuring and controlling fox impact and abundance. Various management options are discussed in Chapter 8. They include local eradication; strategic management (sustained, targeted or one-off); commercial harvesting and crisis management.

There are many ways of controlling foxes, but the integration of several techniques in a planned way, taking into account overall land management, fox biology, and other variables will improve their effectiveness. The way in which to develop an integrated fox management program is described in Chapter 8. This chapter also reviews the elements of fox management strategies at local and regional levels, including recommended management techniques and strategies for fox control for hypothetical agricultural and conservation systems.

Implementation

At the national level, 'best practice' requires that the various roles and responsibilities of

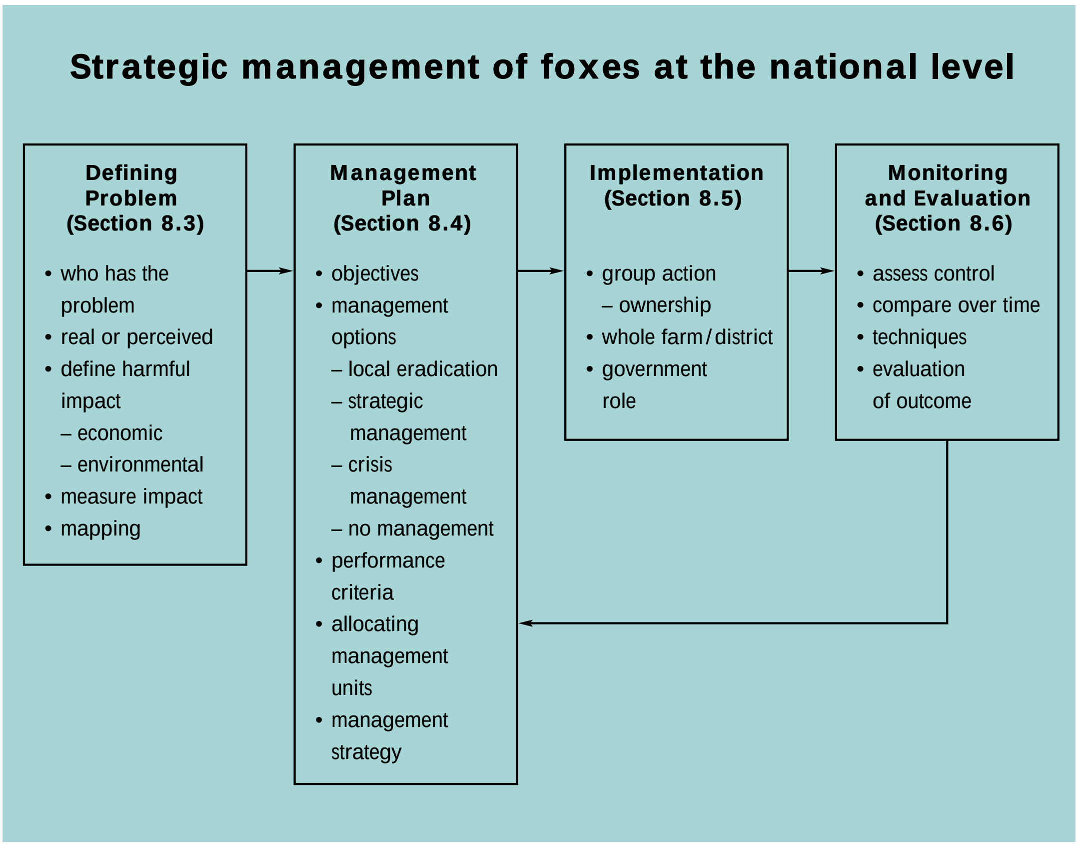


Figure 1: Strategic approach to managing fox damage.

governments, agencies, groups and individuals are taken into account and integrated. Chapter 9 reviews these issues, and describes how these factors are integrated into an overall management strategy.

Monitoring and evaluation

Monitoring is an essential part of fox management. Operational monitoring measures the efficiency of the control strategy, assessing the cost-effectiveness of control over time. Chapter 7 reviews monitoring requirements.

Performance monitoring seeks to evaluate the outcome of the management plan; that is, whether the conservation or agricultural production targets set initially are being met. This is reviewed in Chapter 8.

Both forms of monitoring enable managers to decide whether the management strategy needs to be modified.

Strategic management at the local and regional level

These guidelines set out best practice fox management at the national level based on current knowledge. They bring together the best available information on effective fox control, as a basis for better management of the damage due to this pest.

Vertebrate Pest Program

In the Environment Statement of December 1992, the Commonwealth Government provided increased resources to complete preparation of the guidelines for managing Australia's major vertebrate pest species and to establish key demonstration projects to facilitate adoption of best practice pest management. Projects will draw on the management strategies outlined in the relevant guidelines for each species. For most species, including foxes, it is anticipated that 'best practice' will evolve based on experience gained from undertaking strategic management. Using the management system to refine the pest management strategy is called learning by doing.

It is expected that community-based groups will become increasingly involved in the strategic management of vertebrate pests. The guidelines are designed to facilitate the ownership of the pest problem by such local groups, and the management strategy which might be developed and implemented based on them.

Note: All money values throughout the guidelines are in 1993-94 Australian dollars.

Throughout this document 'fox' refers to the European red fox (*Vulpes vulpes*).

1. History

Summary

Evolutionary origins of the European red fox (Vulpes vulpes) are uncertain. As a member of the Canidae, it may have evolved during the Eocene (30–50 million years ago), possibly in North America. The fox was first introduced to Australia in the 1860s and 1870s for hunting with horses and hounds. It occurs naturally only in the northern hemisphere and is found throughout most of the Palaearctic region. In Australia and elsewhere it has been a successful coloniser. Within 30 years of its initial release in southern Victoria in 1871, the fox attained the status of a pest in northern parts of the state. Colonisation was probably assisted by the spread of the rabbit in Australia at about the same time. By 1893 the fox was reported in New South Wales; in 1901 in South Australia; in 1907 in Queensland; and in 1912 in Western Australia. By the early 1930s, foxes were to be found in most habitats all over mainland Australia with the exception of the tropical north. There are no foxes in Tasmania.

1.1 Europe and America

Fossil records suggest that the family Canidae, to which foxes belong, evolved some 30–50 million years ago in the Eocene, probably in North America. The Canidae may come from two separate lines with foxes and jackals descending from *Cynodictis,* and dogs and wolves from *Amphicyon* (Lloyd 1980).

The evolution of the red fox as a distinct species is poorly documented. Bones of the animal are rare in all deposits which predate the Stone Age (Zeuner 1963). Three species of fox, including the red fox, occur in the Pleistocene (11 000 to 1 million years ago) fauna of Europe and, from the Middle Pleistocene, the red fox is known from the Thames deposits of Grays and Ilford in Essex (Zeuner 1963). In later Pleistocene times the three species (red, corsac and arctic fox) persisted and probably coexisted in Europe. As the ice receded to the Arctic at the end of the last glaciations, the arctic fox withdrew to higher latitudes and the corsac fox to the steppes of Russia, whilst the more adaptable red fox advanced widely (Lloyd 1980).

The history of the red fox in North America deserves comment. The native red fox of North America (*V. fulva*) is considered by Churcher (1959) to be the same species as *V. vulpes*. If so, then the former might be regarded as a race or subspecies of the latter. Certainly, European red foxes were introduced into Maryland in the middle of the eighteenth century and later to Long Island (Lloyd 1980). There is evidence that the early distribution of the native fox did not extend below 40 °N latitude and that the introduced red fox may have colonised the more southern areas as these were opened up by European settlers. The two subspecies may then have met and interbred resulting in a larger overall range for the species (Lloyd 1980).

1.2 Australia

Although newspapers reported the introduction of foxes as early as 1855, it is likely that the first successful releases took place in southern Victoria in 1871 (Rolls 1969). One of these took place near Geelong in Victoria, where rabbits had been released a few years earlier. This may be one of the few examples where a predator and its natural prey were introduced at about the same time. Two fox cubs were shipped from England to Adelaide in 1869, but their subsequent fate is unknown. Nonetheless, foxes were apparently common in the Coorong region of South Australia by 1888. By 1893 the shires of Euroa, Benalla and Shepparton (all in Victoria) had a bounty scheme on fox heads, indicating that the new arrivals quickly attained the status of pests. New South Wales quickly followed suit with the declaration of foxes as noxious animals at Armidale, and within a few years they were reported to be in southern Queensland.

Foxes were first reported to be in Western Australia, west of Eucla, in 1911–12 and 160 kilometres west of the South Australian border in 1915 (Long 1988). Their spread in the west was rapid, and some evidence suggests that they colonised the last of the forested areas of the lower south-west of Western Australia at the same time as the rabbit. Colonisation by foxes probably continued well into the 1950s, since Long (1988) records first sightings in the East Kimberley in 1968 and at Fitzroy Crossing in 1958.

Thus the fox's present distribution, which covers all of mainland Australia except the tropical north (Figure 2), was achieved in 100 years. However, the limits are not fixed. It is likely that the northernmost limit of foxes alters with seasonal conditions, expanding and contracting in response to a run of good seasons or a run of drought years. Similarly, Lloyd (1980) has indicated that in parts of Great Britain, the distribution and density of foxes seems to have waxed and waned considerably over the past century.

'Foxes occur throughout Australia except for the tropical north, Tasmania and some smaller islands.'

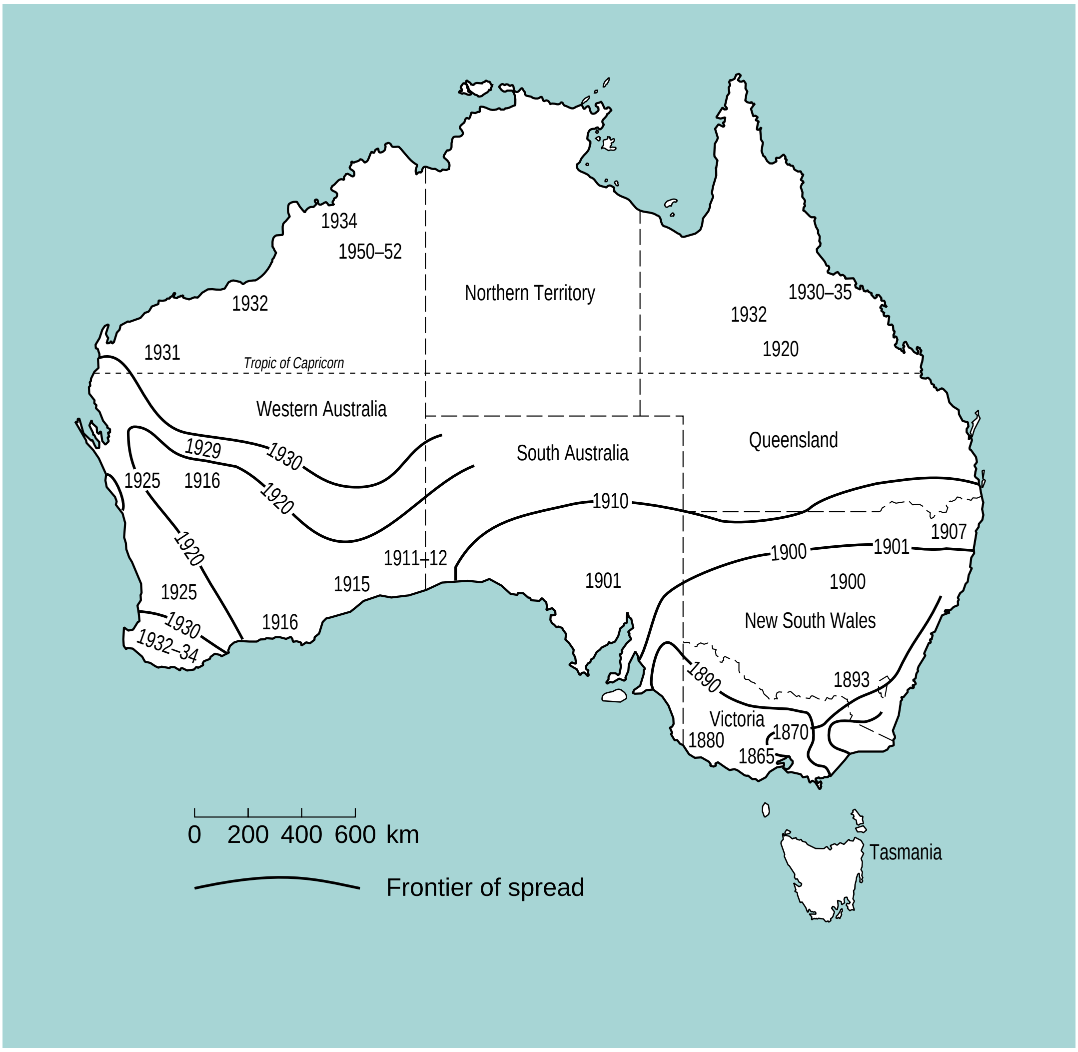


Figure 2: Spread of the red fox in Australia (after Jarman 1986).

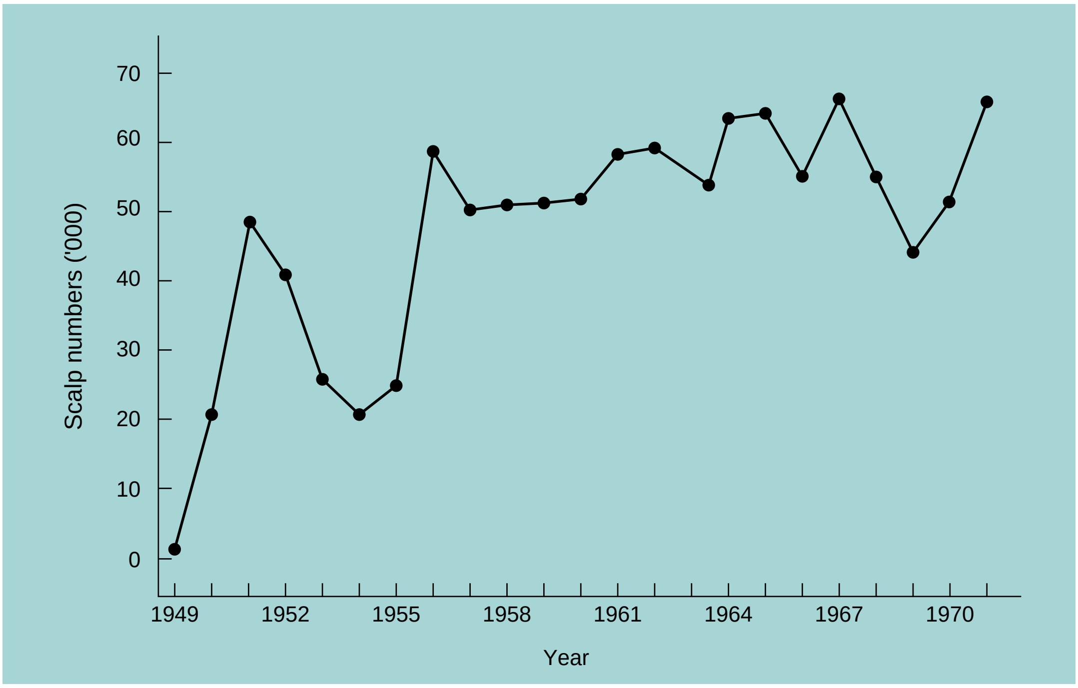


Figure 3: Interrelationship between fox and rabbit populations as demonstrated by decreased number of fox scalps returned for bounty payment in Victoria following the widespread outbreak of myxomatosis in 1951 (after Redhead et al. 1991).

Data from early bounty schemes in Australia suggest that the fox spread most rapidly across the inland saltbush and Mallee country, and more slowly in the forested ranges near the coast (Jarman 1986). However, in Western Australia, the early spread seems to have been along the southern coastline with a succession of sightings from Eucla in 1912 to Geraldton in 1925 (Long 1988) (Figure 2).

'The rapid spread of foxes in Australia was assisted by deliberate human introductions to new areas.'

If it is assumed that all Australian foxes originated from the early introductions to Victoria, then data from early sightings elsewhere on the continent suggest annual dispersal distances of up to 160 kilometres per year. This is unlikely, for although dispersal movements of this magnitude have been recorded, they are the exception rather than the rule. Recent data on cub dispersal in Victoria (Coman et al. 1991) indicates an annual dispersal distance of 11 kilometres with exceptional movements up to 30 kilometres, although this was based on a small sample size. While foxes dispersing into an area previously devoid of foxes may have dispersed more rapidly than more recent studies indicate, it is concluded that the early and rapid movement of foxes in Australia was assisted by deliberate human spread of the animal.

'In Australia the spread and establishment of foxes was closely linked to the spread of rabbits.'

The early history of fox introductions to Tasmania is poorly documented though several introductions have been recorded (Lever 1985; Statham and Mooney 1991). Fortunately, none were successful.

The early spread and establishment of fox populations was closely linked to the spread of rabbits. Australian studies on fox food habits (Section 2.2.7) highlight the

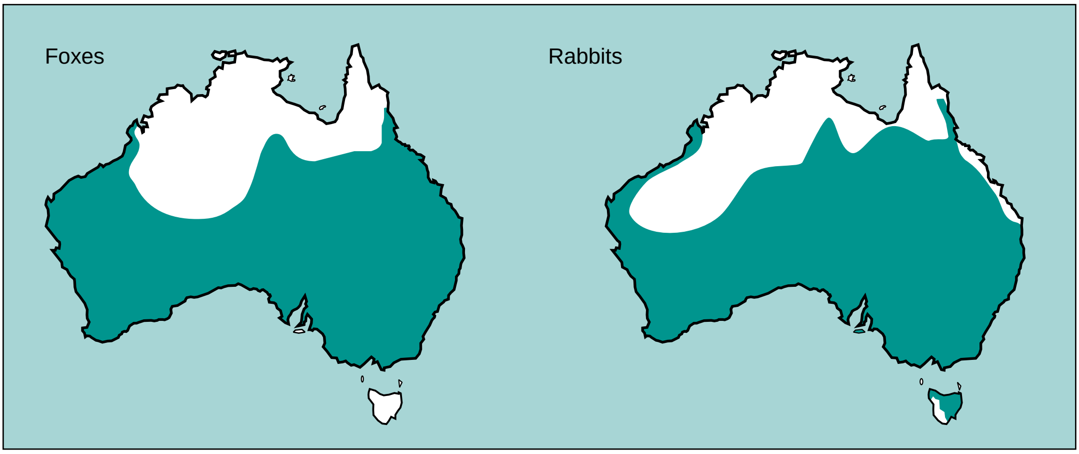


Figure 4: Relative distribution of foxes and rabbits in Australia (after V ertebrate Biocontrol Centre 1992).

importance of rabbit in their diet, and the data on early spr ead of foxes suggest that they spread more rapidly wher e rabbits were present. Long (1988) noted that in Western Australia, the fox appear ed to follow approximately the same invasion path as the rabbit, although several years later.

The interrelationship between foxes and rabbits is dramatically illustrated in Figur e3. In Victoria, a statewide bounty scheme for fox scalps began in 1949. Numbers r eturned for payment quickly r ose to a high level but then fell dramatically in 1952–53 when widespread myxomatosis outbr eaks reduced the rabbit population to a very low level. Significantly though, scalp numbers r ose again within a few years, possibly indicating the ability of foxes to switch to alter native food sources. Figure 4 shows the high degr ee of overlap between the distribution of rabbits and foxes.

2. Distribution and biology

Summary

The red fox is widely distributed throughout the southern half of mainland Australia and can survive in habitats ranging from arid through to alpine as well as urban. The only limitations on distribution appear to be the presence of dingoes, at least in some areas, and the tropical climate of northern Australia. In non-urban areas it appears to be most abundant in fragmented habitats typically found in agricultural landscapes. These offer a wide variety of cover, natural food and den sites. Density estimates in Australia, although few, range from 0.2 adults per square kilometre in coastal forest up to 12 adults per square kilometre in urban populations.

Females reproduce only once a year. Gestation lasts 51–53 days with most cubs born during August and September. Mean litter size is four up to a maximum of about ten. Both sexes become sexually mature from ten months of age. Although social groups of one male and several vixens do exist, most foxes are thought to have only one mate. Males may also leave their normal territory temporarily in search of other mating opportunities.

Overseas the disease most commonly associated with foxes is rabies, which is only endemic in Europe and North America. Many other infectious diseases occur in foxes, although little is known of their incidence in Australia, or their impact on population regulation. These include mange, canine distemper, parvovirus, toxoplasmosis, canine hepatitis, tularaemia, leptospirosis, staphylococcal infections and encephalitis. Like most carnivores that feed on a wide range of prey, foxes also carry a variety of endoparasites. The incidence of helminth parasites, in foxes in particular, has been intensively surveyed in south-eastern Australia because of their potential transmission to domestic animals. Other than the dingo, the fox has few natural predators, although cubs can be taken by birds of prey and dogs. Population turnover appears to be rapid, but its causes, particularly in Australia, are poorly understood. Mortality of foxes is thought to be due mainly to the impact of drought on their prey, principally rabbits, and that caused by humans. Mange and distemper may also be significant contributors.

Fox groups generally have well-defined home ranges with spatially stable borders. The size of a home range depends on the productivity of the environment, but varies from 1600 hectares in Canadian tundra to 30 hectares in urban areas. Foxes are mostly active from dusk to dawn and rarely travel more than ten kilometres per day within the home range. Dispersal is common, particularly in sub-adult males. It commences in late summer and continues through to the onset of breeding in winter. Exceptional dispersal distances of over 300 kilometres have been recorded with averages of between 2–40 kilometres.

Although predominantly carnivorous, the fox is an opportunistic predator and scavenger with no specialised food requirements. Diet studies conducted in Australia show sheep taken as carrion, rabbits and house mice to be the most common food items.

2.1 Distribution and abundance

2.1.1 Worldwide distribution of foxes

'Foxes are now found in several Australian cities.'

The red fox is the most common and widespread member of its genus, which includes 11 other species worldwide (Clutton-Brock et al. 1976). It occurs naturally in the northern hemisphere only, where it is distributed throughout most of the Palaearctic region (Lloyd 1980). Present-day distribution of the red fox is presented in Figure 5.

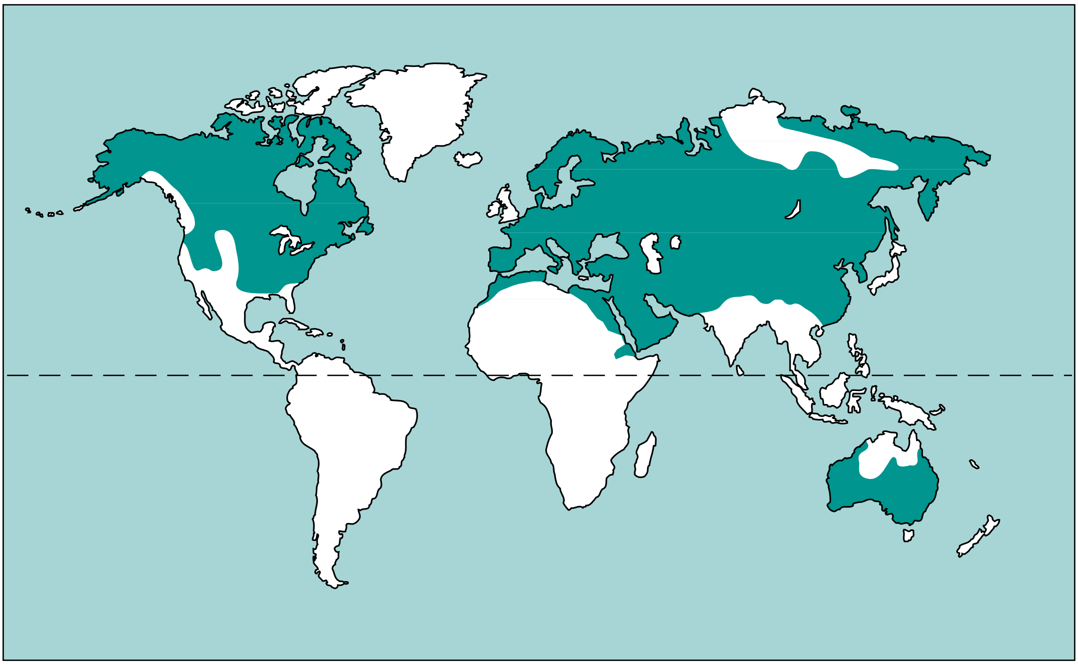


Figure 5: Present-day world distribution of the red fox (after Jarman 1986).

The success of the red fox in nearly all environments is attributable to a highly adaptable and unspecialised lifestyle with no specific habitat requirements (Corbet and Harris 1991). Historical evidence suggests that the red fox has expanded its natural range over the last 200 years (Lloyd 1980; Voigt 1987) possibly in part due to diminished competition with larger canids such as the wolf (*Canis lupus*). Since the mid-1940s, urban foxes have become common in British cities (Harris and Rayner 1986) and recently have occupied a number of Australian cities such as Adelaide, Brisbane, Canberra, Melbourne, Perth and Sydney (C. Marks, DNRE, Victoria, pers. comm. 1994).

2.1.2 Australian distribution

The red fox is found throughout the southern half of Australia with the exception of Tasmania and Kangaroo Island (Jarman 1986, Wilson et al. 1992). It occurs from the arid centre to the alps and is also found in urban Australia. In central Australia, its distribution is similar to that of the rabbit, but appears to be limited in some areas of eastern and western Australia by the presence of high densities of dingoes. Sharp boundaries in density along parts of the New South Wales border are probably due to the dingo fence and the displacement of foxes by dingoes. However, in areas of South Australia adjacent to the New South Wales border, foxes appear to be present even where there are high densities of dingoes. Here, dingoes probably influence fox density rather than distribution. Only isolated pockets occur in the far north, such as the Kimberley region of Western Australia (King and Smith 1985) and the Victoria River District and Barkly Tablelands of the Northern Territory (Wilson et al. 1992). Foxes appear to have reached the northern limit of their range as recently as the last 30 years (Jarman 1986). The northern limit of fox distribution in Australia may reflect climatic preference. The red fox does not occur in the humid tropical regions of North America and Asia although other *Vulpes* species do (Wilson et al. 1992).

2.1.3 Density estimates

The nocturnal and elusive nature of the red fox makes population density estimates

Table 1: Density estimates (foxes per square kilometre) of Australian fox populations.

Study	Habitat	Location	Fox density
Coman et al. 1991	Temperate grazing	Central Victoria	3.9
Thompson and Fleming 1994	Temperate grazing	Northern Tablelands, NSW	4.6–7.2
Newsome and Catling 1992	Dry sclerophyl forest	South Coast, NSW	0.2
Newsome and Catling 1992	Semi-arid grazing	Western NSW	2.0
Marlow 1992	Arid grazing	Western NSW	0.9
T. Bubela (Sydney University, pers. comm. 1994)	Sub-alpine	South-east NSW	1.8
D. Algar (CALM, WA) and P. Thomson (APB, WA) – pers. comm. 1993	Semi-arid grazing	South-west Western Australia	0.6–0.9
C. Marks (DNRE, Vic., pers. comm. 1994)	Urban	Melbourne	0–12

difficult to determine and often inaccurate. This is further complicated by the cyclical changes in fox densities associated with prey abundance. Their occurrence in such a wide variety of habitats also makes it difficult to apply a common census technique, making comparisons between different populations at best, tenuous. Details of population estimation techniques are presented in Chapter 7.

Estimates of fox densities vary from as high as 15 adults per square kilometre in urban areas of Britain (Harris and Rayner 1986; Harris and Smith 1987) to as low as 0.1 adults per square kilometre in tundra and boreal forest (Voigt 1987). Like all other species, population density depends very much on the productivity of the environment.

In Australia, fox density is perceived to be highest inside the dingo fence in semi-arid New South Wales where there is an abundance of rabbits and carrion, and lowest along the more heavily timbered coast and ranges (Wilson et al. 1992). The few density estimates which are available involve only a limited number of relatively small study sites. These are presented in Table 1. In conflict with the Wilson et al. observation, these figures suggest that higher densities are more common in the temperate grazing country of south-eastern Australia.

2.1.4 Habitat preferences

The worldwide distribution of the red fox, ranging from tundra to the desert as well as urban areas, suggests that it can survive in most environments. How an animal uses the specific habitats within the confines of its environment (specified by a territory or home range) is determined by a combination of factors including the distribution of food and water, shelter from predation and climate, breeding sites and the paths which link the various habitat patches. Identification of habitat requirements and how they are used are important in the design of effective strategies for managing fox damage.

'Worldwide fox distribution ranges from tundra to desert. Red foxes are not found in tropical climates.'

Habitat use by urban foxes has been studied in a number of British cities (Harris 1977; Macdonald and Newdick 1982; Kolb 1985; Harris and Rayner 1986). The most important urban habitat requirement appears to be that of cover (Harris 1977).

Exposed habitats such as front gardens, parkland and playing fields are avoided, with undisturbed habitats such as back gardens, rough ground and cemeteries preferred. There appears to be a temporal pattern, with foxes avoiding habitats at times when human activity is high. Roads are used for travel between habitat patches. This situation may change towards the suburban fringes or in urban areas interspersed with large tracts of rough ground or open space (Macdonald and Newdick 1982; Rosatte et al. 1991).

'Foxes are often abundant in agricultural areas as they offer a wide range of cover, food and den sites.'

These studies have been made easier in the urban areas because of the even and clearly defined distribution of habitats and the limited areas for travel. However, it is more difficult to make clear interpretations of habitat preferences in rural or wilderness areas. The fox is probably most abundant in fragmented environments typically found in agricultural landscapes because these offer a wide variety of cover, food and den sites. More uniform, open environments are less favoured as are heavily forested or mountainous areas. Foxes do not live entirely within closed canopy forests but can penetrate some distance into them in search of food (Jarman 1986). The red fox appears to be absent from areas with tropical climates, such as Asia, although the reasons for this are unclear. The fox's habitat preference within specific environments has not been studied in Australia.

2.2 Biology

The life history of the red fox has been extensively studied in the northern hemisphere (reviewed by Burrows 1968; Storm et al. 1976; Pils and Martin 1978; Lloyd 1980; Zimen 1980; Harris 1986; Henry 1986; Macdonald 1987; Voigt 1987). However, there have been few biological studies of foxes in Australia (Ryan 1976a; Coman 1988; Coman et al. 1991; Phillips and Catling 1991; Marlow 1992). Most of these studies have concentrated on the predatory relationship between foxes and the sheep industry, fox diet or fox endoparasites. The biological information presented here is therefore based mainly on observations from the northern hemisphere. The extent to which this information applies to foxes in Australia is unclear, emphasising the need to better understand the biology of the fox in Australia, especially those aspects essential for developing control strategies.

The European red fox adapted well to Australian habitats.

Source: CSIRO

Foxes use dens for the birth and early caring of cubs.
Source: CSIRO

2.2.1 General description and classification

The red fox is a member of the family Canidae which includes wolves, jackals and coyotes. Males are slightly larger than females. Both males and females, but particularly females, have seasonal variations in body weight. Adults have a head and body length of 570–740 mm, a tail length of 360–450 mm and weigh between 4.5–8.3 kilograms (Coman 1983).

Behavioural traits, which are common to many other canids, include the use of dens (commonly enlarged rabbit burrows) for the birth and early caring of cubs; surplus killing of prey and caching of food for later consumption; predominantly nocturnal and crepuscular activity; and territorial family groups with juvenile dispersal common. Numerous scent glands, particularly anal sacs, are used to mark territories. They have a wide range of vocalisations, most commonly heard during the mating season.

2.2.2 Reproduction

The red fox is monoestrus, vixens coming on heat only once during the breeding season and then for only two to three days. Females are reproductively active from July to October with a peak during August in south-eastern Australia (McIntosh 1963a; Ryan 1976a), although there may be latitudinal variations as found in the northern hemisphere (Lloyd and Englund 1973; Storm et al. 1976). Ryan (1976a) found sperm or spermatids present in males in every month except January, with peak production occurring from June to August. Gestation lasts 51–53 days with most cubs born during August and September.

'Vixens come on heat once a year. Cubs are mostly born in August and September.'

Mean litter size is four up to a maximum of around ten. Cubs are suckled until four weeks, then progressively weaned onto solids. Both sexes become sexually mature from ten months of age. The number of non-breeding vixens in any population is highly variable, being most common where populations are subject to low levels of control and least common where mortality rates are high (Corbet and Harris 1991). This may be due to the social suppression of reproduction in large groups. In these cases some non-breeding females may act as 'helpers', which are so defined because of their supportive role in raising cubs (Macdonald 1979). The mechanisms for this behaviour remain unclear. Foxes are thought to be largely monogamous. However, polygamous social groups of one male and several vixens do exist, the vixens invariably being closely related (Macdonald and Bacon 1982). Males are also known to leave their territory in search of other mating opportunities, but this occurs during the breeding season and has minimal management implications.

'The average litter is four cubs; maximum litter is about ten cubs.'

2.2.3 Diseases and parasites

The disease most commonly associated with the fox, and one to which the species is particularly susceptible, is rabies (Wandeler et al. 1974; Macdonald 1980). It is a major public health concern throughout Europe and North America where the disease is endemic, and also in Australia where every effort is taken to prevent its introduction (Chapter 4). Many other infectious diseases occur in foxes, although little is known of their incidence in Australia or impact on population regulation. These include mange, canine distemper, parvovirus, toxoplasmosis, canine hepatitis, tularaemia, leptospirosis, staphylococcal infections and encephalitis viruses (Voigt 1987).

Foxes carry a variety of endoparasites (Lloyd 1980). The incidence of helminth parasites in foxes in particular has been intensively surveyed in south-eastern Australia because of their potential transmission to domestic animals (Pullar 1946; Coman 1973a; Ryan 1976b). Most prevalent are *Taenia pisiformis, T. serialis, Spirometra erinacei, Dipylidium caninum, Toxocara canis, Uncinaria stenocephala* and *Ancylostoma caninum.*

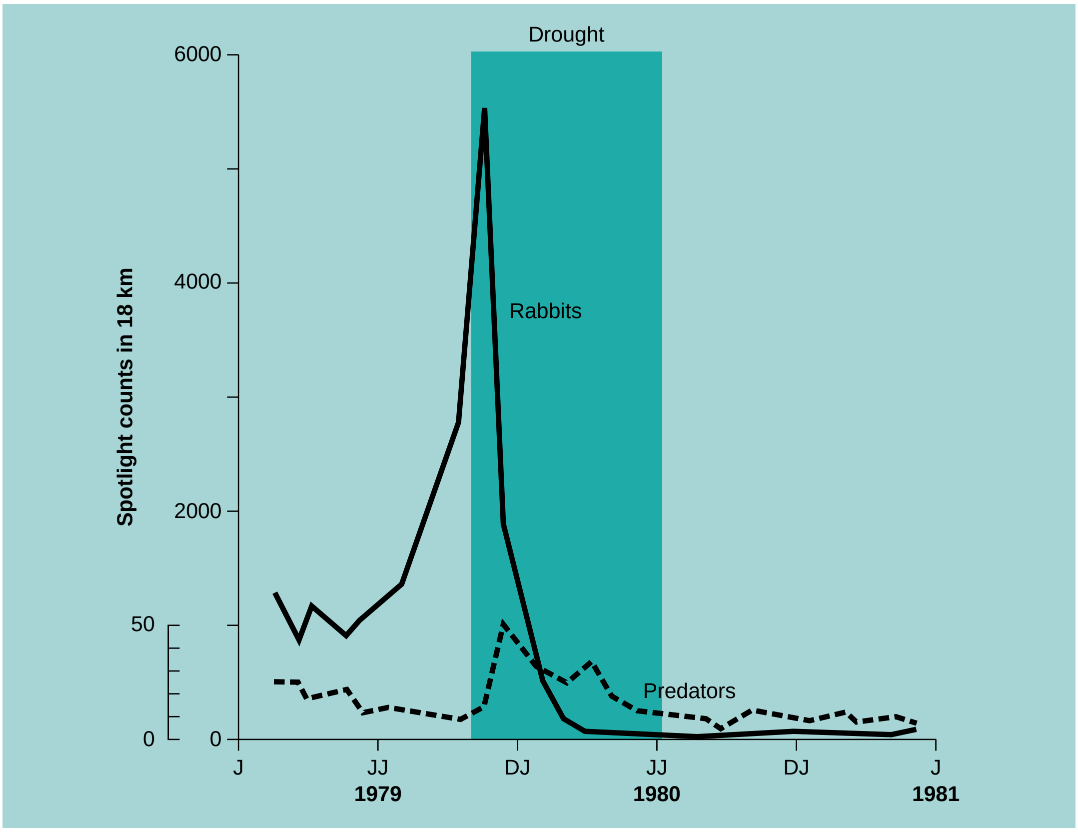


Figure 6: Variations with time of rabbit and predator (cat and fox) numbers at Yathong Nature Reserve in central-western New South Wales (after Newsome et al. 1989)

'Foxes can carry rabies and other diseases, although fox rabies has so far been kept out of Australia.'

In some parts of the world foxes are an important end host for the hydatid tapeworm (*Echinococcus granulosus*). Although thousands of foxes have been examined for signs of this parasite in Australia, it has only been found in a few animals, and then at low levels. Consequently, it is assumed that foxes do not play an important role in the life cycle of *Echinococcus* in rural Australia despite their susceptibility to this parasite. The situation is less clear in urban areas where it appears that even a few infected foxes are a risk to human health (Jenkins and Craig 1992).

Ectoparasites known to occur in Australia, and which are found on foxes in the northern hemisphere (Corbet and Harris 1991), include fleas (*Spilopsyllus cuniculi, Pulex irritans, Ctenocephalides canis*), ticks (*Ixodes ricinus*) and mites (*Sarcoptes scabiei, Demodex folliculorum, Notoedres* spp., *Otodectes cyanotis* and *Linguatula serrata*). Ringworm (*Microsporum*) is also recorded occasionally. In a recent study, Phillips and Catling (1991) suggested that the observed low fox density in rainforests of southern coastal New South Wales may be due to mortality resulting from the high incidence of dog ticks (*Ioxodes holocyclus*). This suggestion warrants further study.

2.2.4 Mortality factors

The red fox has few natural predators, although cubs can be taken by birds of prey and dogs (Corbet and Harris 1991) and there is circumstantial evidence that dingoes may influence the distribution of foxes (Section 2.1.2). In Australia, dingoes are known to kill and eat adult foxes (P. Bird, APCC, SA pers. comm. 1993). Population turnover appears to be rapid, but causes, particularly in Australia, are poorly understood (Coman 1983). In a sample of 317 foxes killed by hunters in south-eastern Australia, it was found that 54% of animals were less than one year old and 71% less than two years old with few (4%) animals surviving beyond four years (Coman 1988).

'Most foxes are killed by people or the effects of drought.'

Most deaths are believed to be due to human intervention and the impact of drought on their main prey, rabbits. Storm et al. (1976), in a North American study, reported that more than 80% of tagged foxes died as a result of shooting, trapping or road kills. Harris (1978), in a survey of British urban fox mortality found that 61% of adults died from road accidents, 18% were delib-

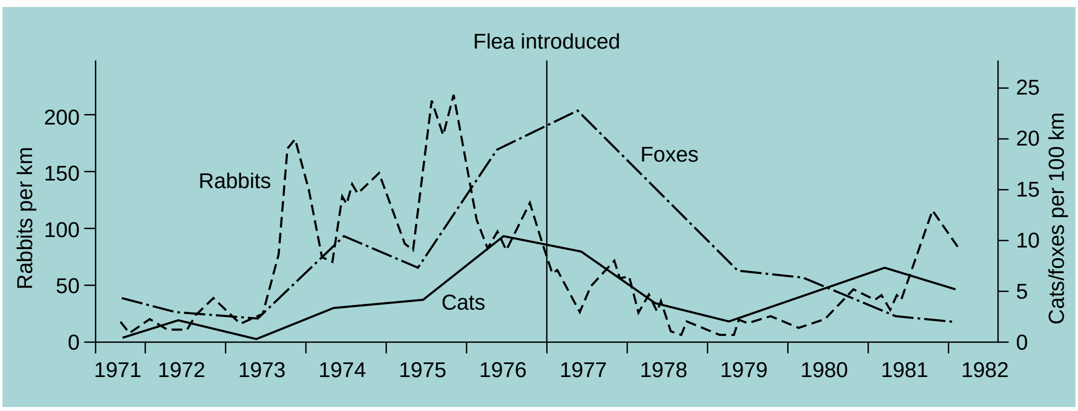


Figure 7: Variation in fox and feral cat numbers in relation to changes in rabbit numbers in south-western Western Australia (after King and Wheeler 1985). There was an increased incidence of myxomatosis following the introduction of the European rabbit flea.

2

Table 2: Comparison of mean home range estimates (minimum convex polygons) for foxes in different habitats.

Habitat	Home range (ha)	Reference
Tundra (British Columbia)	1611	Jones and Theberge 1982
Farmland (Ontario)	900	Voigt and Tinline 1980
Farmland (Victoria)	610	Coman et al. 1991
Alpine (New South Wales)	550	Bubela 1993
Forest (New South Wales)	416	Phillips and Catling 1991
Farmland/woodland (Western Australia)	340	D. Algar (CALM, WA) and P. Thomson (APB, WA) – pers. comm. 1993
Forest/urban (West Germany)	133	Zimen 1984
Urban (England)	30	Saunders et al. 1993

erately killed by man, 10% died from disease, 3% from fights, less than 1% from parturition deaths and the remainder (7%) from misadventure or unknown causes. Sarcoptic mange is a significant mortality factor (Trainer and Hale 1969; Pils and Martin 1978; Tullar and Berchielli 1982), as of course is rabies where it is endemic (Macdonald 1980). Secondary poisoning as a result of pest control programs, principally 1080 control of rabbits, is not uncommon (McIlroy 1981) as is primary poisoning from baits intended for larger carnivores such as dingoes (McIlroy 1986). The number of baits distributed intentionally for fox control in Australia has risen dramatically in recent years. This is possibly due to decreased hunting pressure as a result of the collapse in the fur trade and increasing concern for the damage they cause to native wildlife populations and agricultural production (Chapter 3).

'Rabbits are the main prey of foxes in the southern pastoral areas of Australia.'

In the southern pastoral zones of Australia, rabbits are the principal prey of foxes and feral cats. When rabbit populations crash, either due to drought (Figure 6) or outbreaks of myxomatosis (Figure 7), fox and feral cat populations also collapse after a lag period (Brooker 1977; Myers and Parker 1975a, b; Newsome et al. 1989; King and Wheeler 1985; Redhead et al. 1991). During the lag time, foxes are believed to prey heavily on the remaining rabbits and on native fauna. The role foxes play in regulating rabbit density, and the implications of managing or not managing foxes for native wildlife during rabbit management programs, is unclear and needs further investigation.

'We need to know more about how foxes affect rabbit and wildlife populations.'

2.2.5 Movements and home range

Red fox family groups generally occupy well-defined home ranges with non-overlapping, adjoining and stable borders (Storm 1965; Ables 1969; Sargeant 1972; Pils and Martin 1978; Voigt and Macdonald 1984). Overlapping home ranges reported in some studies are thought to be due to inadequate data collection and analysis or to the study animals being closely related (Voigt 1987). However, Doncaster and Macdonald (1991) observed continually drifting territories in an urban fox population. The combined evidence from studies of scent marking, social encounters and movement patterns suggests that home ranges are the same as territories (Henry 1979; Macdonald 1979).

'Fox family groups usually occupy well-defined home ranges.'

A home range is generally proportional in area to the amount of resources it contains. Foxes in habitats with abundant food sources have smaller home ranges (Harestad and Bunnell 1979; Lindstedt et al. 1986). The variation in fox home range size as implied by resource productivity in different environments is shown in Table 2. Voigt and Macdonald (1984) proposed that the pattern of mortality and the extent of seasonal climatic variation also contributed to home range size, and concluded that red foxes are so variable in their behaviour that any extrapolations to an area based on studies from another should be viewed with caution. This means that fox management, especially in terms of baiting intensity and the size of fox-controlled buffer zones needed for the protection of a specific area, needs careful consideration (Section 7.5).

The extent to which foxes can patrol and hence maintain a territory is influenced by the size of the territory. An urban fox with a home range of 30 hectares is able to visit all boundaries two to three times in a night (Saunders et al. 1993). In contrast, Sargeant (1972) found that rural foxes with home ranges of 250–750 hectares required two weeks to cover the entire territory. These differences may result in varying levels of encroachment between neighbours as well as the extent of social contacts. Apart from this, the most common incidences of foxes disregarding territorial boundaries occur as a result of dispersal behaviour or adult males searching for mating opportunities. Daily travelling distances by resident adults within their territories rarely exceed ten kilometres, with most activity between dusk and dawn (Voigt 1987; Saunders et al. 1993).

'Adult foxes rarely travel more than ten kilometres per day.'

2.2.6 Dispersal

Dispersal by the red fox has been studied extensively in Europe and North America

2

Table 3: Percentage occurrence and percentage volume of major food items identified in the stomachs of foxes by Coman (1973b) (first figure) and Croft and Hone (1978) (second figure).

Food item	% Occurrence	% Volume
Sheep	31, 29	20, 19
Rabbit	39, 25	35, 20
House mouse	26, 15	14, 10
Macropod species	3, 1	2, 1
Possum species	7, 1	5, 1
Pig	1, 5	1, 5
Fox	3, 1	1, 1
Cattle	1, 2	1, 1
Domestic poultry	1, 4	1, 3
Bird species	19, 9	5, 5
Insects	36, 37	8, 12
Other invertebrates	7, 11	1, 4
Cold-blooded vertebrates	3, 5	1, 2
Plant material	57, 38	3, 12

because of the importance of this behaviour to the spread of rabies (Phillips et al. 1972; Steck and Wandeler 1980). The majority of dispersal occurs in sub-adult foxes, particularly males, commencing in late summer and continuing through to the onset of breeding in winter.

'The greatest movement of foxes occurs when young males disperse.'

A variety of dispersal patterns have been revealed in radio-tracking studies. These suggest two distinct phases: sudden, quick and mainly straight line travel followed by slower, less directed movements that persist until the animal establishes the boundaries of its new territory (Zimen 1984). A series of exploratory trips prior to the main dispersal event are also common. All of these phases occur over a relatively short period. Longer dispersal distances are associated with less productive environments. Exceptional movements of over 300 kilometres have been recorded in North America and 100 kilometres in Europe (Corbet and Harris 1991). Mean dispersal distances are much smaller than this, ranging from 2.8–43.5 kilometres for males and 1.8–38.6 kilometres for females (Trewhella et al. 1988). In Australia, Coman et al. (1991) in central Victoria, observed a mean dispersal distance of 11 kilometres based on a study of 13 dispersing animals. Marlow (1992) monitored the dispersal of five female foxes which dispersed a mean distance of 3.5 kilometres. In a recent study in south western Australia, Marlow and Thomson (WA CALM and APB, pers. comm. 1995) observed mean juvenile dispersal in males of 43 km (n=7, range 9–170 km) and females of 15 km (n=6, range 6–22 km).

2.2.7 Diet

Although predominantly carnivorous, the red fox is an opportunistic predator and scavenger with no specialised food requirements. There have been several studies on the diet of the fox in Australia mainly because of concern about its role as a predator of sheep and native fauna (McIntosh 1963b; Martensz 1971; Ryan and Croft 1974; Brunner et al. 1975; Seebeck 1978; Bayly 1978; Green and Osborne 1981; Triggs et al. 1984; Brunner and Wallis 1986; Baker and Degabriele 1987; Wallis and Brunner 1987; Catling 1988; Brown and Triggs 1990; Lunney et al. 1990; McKay 1994). Two of the most comprehensive in terms of areas covered were those of Coman (1973b); and Croft and Hone (1978). These involved the examination of over 2000 fox stomachs from throughout Victoria and New South Wales. The most common items are presented in Table 3, although there were numerous regional and seasonal variations within and between studies. Assuming energy intake is best reflected by percentage volume, sheep (believed to be mostly taken as carrion), rabbit and the house mouse are the most important food items to the fox on a statewide scale. Similar observations have been reported from fox populations in the northern hemisphere (Sequeira 1980). Foxes also have some distaste for food items such as insectivore and carnivore meat, although cannibalism of litter mates or predation by vixens on other litters is not uncommon (Macdonald 1977).

''Foxes are opportunistic predators and scavengers with no specialised food requirements.'

Sargeant (1978) quantified the prey demands of captive foxes. Cubs began to eat prey four weeks after birth. Thereafter, prey consumption averaged 197 and 271grams per cub per day for weeks 5–8 and 9–12 respectively, and 363 grams per cub per day for the post-denning period. Feeding by adults averaged 321 grams per adult per day. Free water was not needed by either cubs or adults. Saunders et al. (1993) constructed a generalised model to estimate the daily energy expenditure, excluding direct costs of reproduction, for urban foxes. Based on yearly averages for this study, an adult male required 2001 kilojoules per day which was the equivalent of 372 grams of wild mammal or 524 grams of scavenged meat. The implications of these food requirements, particularly during the post-denning period, to prey biomass within the family group territory are substantial. Sargeant (1978) estimated this to be equivalent to 18.5 kilograms per square kilometre (two adults and five cubs).

'Sheep taken as carrion, rabbits and house mice are the main food of foxes.'

While diet studies indicate the range of prey consumed by foxes, diet studies alone are not a reliable indication of the extent of damage caused by foxes. Some endangered native species may occur only rarely in the diet, but foxes may be having a significant impact on their populations. Conversely, other species that occur consistently in the fox diet may be in sufficient numbers that they can tolerate long-term fox predation without any resulting decline in population densities. The damage that fox predation causes to native fauna can only be quantified by scientifically designed and replicated studies where fox predation is reduced and the response of the prey is monitored. The results of such studies are outlined in Section 3.1.

'Fox predation does not necessarily have a significant effect on the populations of prey species.'

2.2.8 Social organisation

A combination of aggressive and non-aggressive encounters, scent marking and vocalisations are used to maintain fox territories (Sargeant 1972; Niewold 1980; Voigt and Macdonald 1984). Most encounters are due to dispersal or adult males trespassing on neighbouring territories in search of receptive females. To a lesser extent, females can return to their territory of birth and some foxes will explore neighbouring territories perhaps in search of food (Niewold 1980; Voigt and Macdonald 1984; Mulder 1985).

The composition of family groups varies with habitat. Large territories in the American Midwest (Sargeant 1972; Storm et al. 1976) and Ontario, Canada (Voigt and Macdonald 1984) were found to be typically occupied by only one adult pair of foxes along with their litter of cubs which eventually dispersed. Although not well documented, most observations suggest that this is also the predominant family group composition throughout Australia. Macdonald (1979, 1981), von Schantz (1981) and Mulder (1985) found that in areas with more food and other resources, family groups tended to be larger, consisting of one adult male and up to several vixens. Within these groups, vixens were usually related and only the dominant female produced a litter. Subordinate females are recognised as 'helpers' which may feed, guard, groom and play with the cubs of the breeding vixen (Macdonald 1979). Where more than one vixen breeds within the one family group, communal denning and care of young may occur (Tullar et al. 1976). The presence of only a few solitary males in these more productive areas suggests higher male mortality (Voigt 1987). Von Schantz (1981) also concludes that it is in the best interest of the dominant pair to first expel male offspring as they have the least to contribute to the raising of subsequent litters.

2.2.9 Conclusion

'Relatively little is known about the ecology of foxes in Australia.'

Red foxes are highly adaptable and occupy a wide range of habitats. Likewise, they show considerable variation in their behaviour, population density, reproductive potential and diet between these habitats. Macdonald (1981) argued that these differences arose largely from the effects of two group variables: the pattern of resource availability, such as the abundance and dispersion of available food or the distribution of cover or dens; and the intensity and pattern of mortality. Voigt (1987) suggested that the extent of seasonal climatic variation also contributed to these variations. This is particularly likely to be the case in Australia where the fox can be found from desert to alps (Figure 2). Because of these variations, accurate prediction of the behaviour of a fox population, particularly without baseline information, is difficult if not impossible. Relatively little is known of fox ecology in Australia. Studies are required, particularly on population densities and movement across different habitats, so that land managers can make soundly based decisions on appropriate management strategies.

3. Economic and environmental impacts

Summary

The fox has long been recognised as a serious threat to Australian native fauna, but until recently, this has been based mainly on anecdotal and circumstantial evidence. For example, foxes have been identified as a factor limiting the success of seven out of ten mainland reintroductions of native fauna.

The best evidence of the primary role foxes play in population regulation of some native fauna comes from Western Australia. Fox control resulted not only in substantial increases in the populations of some marsupials, but also in wider habitat use. However, for some native species, other factors beside predation may be operating. For example, it has been shown that factors which affect food for malleefowl chicks may also need to be addressed in addition to predation.

There is debate about the extent to which foxes are a useful biocontrol agent for rabbits, and whether there is a need to manage foxes when rabbit populations are reduced, in order to prevent increased fox predation on native fauna. Foxes undoubtedly exert some control over rabbits, but not when conditions are favourable for growth of rabbit populations. In areas where native wildlife are at significant risk from fox predation, fox management should be considered as part of rabbit control.

The economic impact of foxes in Australia has been poorly studied but the principal losses almost certainly involve newborn lambs. Earlier studies on the causes of lamb loss generally dismiss predation as being insignificant on a state or national level. More recent evidence suggests that foxes may take from 10–30% of lambs in some areas.

Positive economic impacts of the fox relate entirely to the value of fox pelts. In the recent past, high export prices for fox pelts provided significant income for Australia, but the market fluctuates widely and current pelt sales are low. The impact of commercial harvesting upon fox numbers and fox damage during the years of high pelt prices is unknown, but some anecdotal evidence suggests that numbers have risen since the high-level harvesting ceased.

One important social aspect of fox predation in Australia is its potential impact

Phascogale species are believed to be at risk from fox predation.

Source: Applied Biotechnologies

on ecotourism. Many of Australia's wildlife species that are vulnerable to fox predation are unique and constitute an important tourism asset.

3.1 Environmental impact

The fox has long been recognised as a serious threat to populations of native wildlife. Finlayson (1961) for example described how, over a 25 year period, regions in central Australia were being stripped of its smaller wildlife species by increasing populations of foxes. Similarly, the decline of species such as the brush-tailed rock-wallaby (*Petrogale penicillata*) on mainland Australia is frequently attributed to predation by foxes (Le Souef and Burrell 1926; Wakefield 1954 as cited in Short and Milkovits 1990). Such observations were, however, mostly based on anecdotal and circumstantial evidence. It was not until 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.

'Foxes can pose a serious threat to populations of native animals.'

Because Australian native fauna did not co-evolve with the fox, susceptible prey species may have few strategies to avoid predation by this animal. Further more, the impact of the fox on wildlife has probably been exacerbated by habitat fragmentation and modification since European settlement (Mansergh and Marks 1993).

'Because they did not co-evolve with the fox, Australian native animals may have few strategies to avoid fox predation.'

Compared to other continents, the damage to Australian wildlife since European settlement has been catastrophic and unparalleled other than for some island faunas. At least 20 species of Australian mammals have become extinct. This represents about one-half of the world's mammal extinctions in the last 200 years; a further 43 species are judged to be either endangered or vulnerable (Commonwealth Endangered Species Advisory Committee (ESAC) Report 1992).

'The impact of foxes on wildlife has probably been exacerbated by habitat modification and fragmentation.'

Undoubtedly the causes are complex. The ESAC (1992) report discusses a suite of threatening processes including habitat loss; habitat change and degradation; impact of introduced animals and plants; disease; exploitation; and climatic change. A threatening process which has recently come to light is the impact of predation by foxes on native marsupials and on the malleefowl (*Leipoa ocellata*). Except for some detailed studies of fox predation on a limited range of Western Australian native mammals and some work by Priddel (1991) on malleefowl, there is little quantitative information on the damage foxes cause to native fauna (Pech et al. 1995). However, there is a considerable number of anecdotal and observational reports. Consequently, the examples in these guidelines are heavily biased toward Western Australia although it is likely that the fox is having a similar impact in other parts of Australia.

3.1.1 Fox removal studies in Western Australia

In Western Australia, the impact of fox predation on some marsupials has been examined in a series of predator removal experiments (Kinnear et al. 1988 and unpublished works; Friend 1990; Morris 1992). Such experiments have yielded substantial and consistent population increases by a variety of marsupial species. The results suggest that not only has there been substantial population increases, but also a wider use of the habitat when the predation pressure is lowered. Some results from these predator removal experiments are described below.

Rock-wallabies (Petrogale lateralis)

Rock-wallabies were once common throughout south-west Western Australia. By 1979 only six isolated colonies existed and these were in decline (Kinnear et al. 1988). In a pr edator removal experiment, foxes wer e controlled using 1080 baits in two colonies; and three colonies served as experimental controls (no fox contr ol). All populations wer e periodically assessed befor e and after fox control.

After eight years, the populations subject to fox contr ol increased four to fivefold (Figure

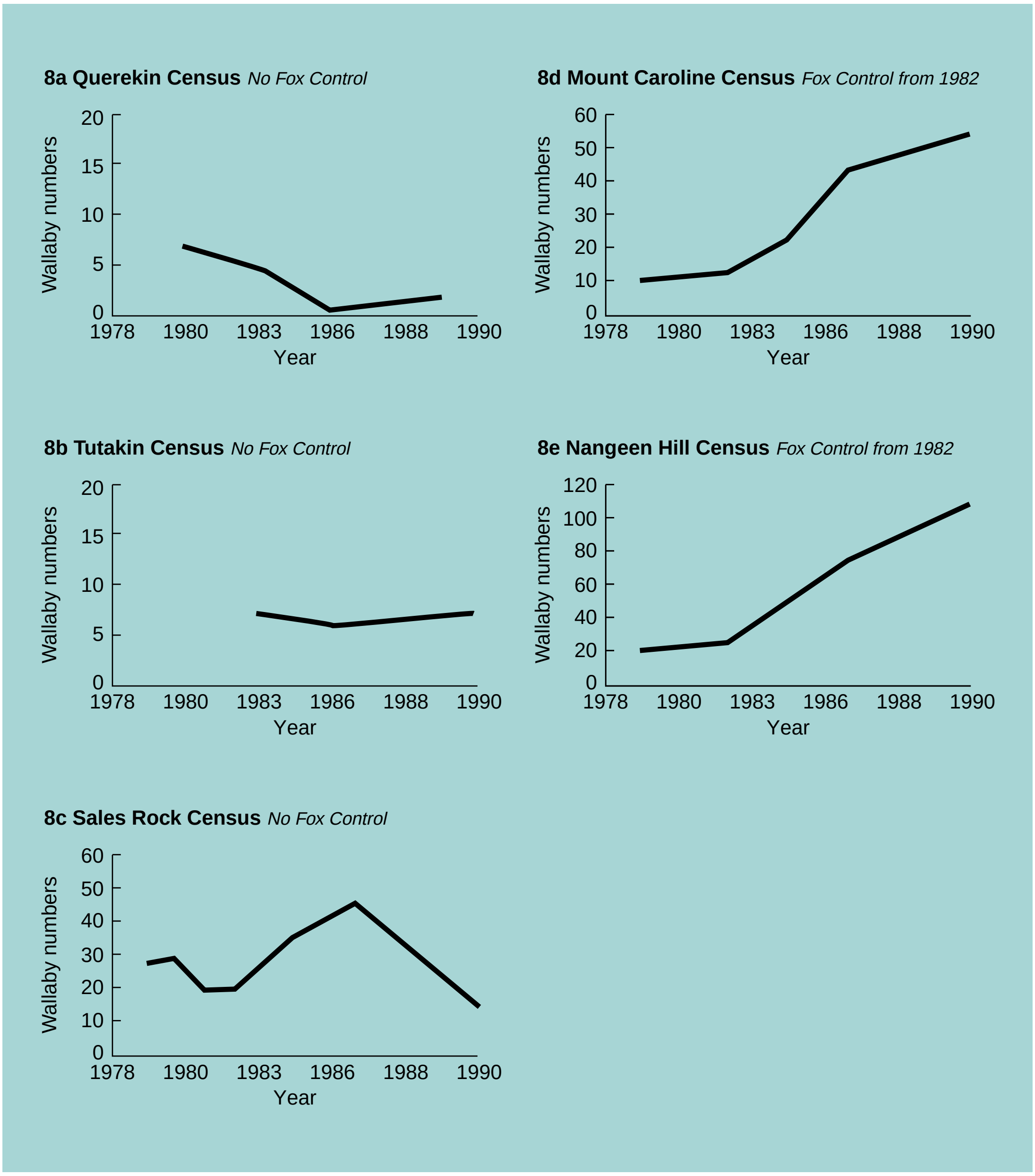


Figure 8: Predator removal experiment conducted over eight years in W estern Australia for five colonies of r ock-wallabies (*Petrogale lateralis*). Thr ee colonies r eceived no tr eatment (Figure 8a,b,c), while foxes wer e controlled in two other colonies (Figur e 8 d,e) (after Kinnear et al. 1988). *Note: Variable y-axis scales used for wallaby numbers at different sites.*

8d,e). Those not subject to fox control remained the same, or fluctuated and then declined (Figure 8a,b,c). A third population in an area having no fox control was reduced to a single, barren female. Rock-wallabies have since been reintroduced into one site (Querekin) in association with fox control, and their numbers have increased.

Rothschild's rock-wallabies (Petrogale rothschildi)

Another fox removal experiment was conducted to determine the impact of foxes on Rothschild's rock-wallabies in the Dampier Archipelago (J. Kinnear, unpub.). This wallaby is endemic to Western Australia and is restricted to the Pilbara and Gascoyne regions. Foxes have invaded Dolphin Island (which carries *P. rothschildi*) by crossing a narrow passage that separates the island from the mainland (the Burrup Peninsula). Enderby Island has rock-wallabies but is fox free.

Abundance indices derived from standard spotlight traverses showed a marked difference in rock-wallaby abundance between Dolphin Island and fox-free Enderby Island. For every three hours of spotlighting

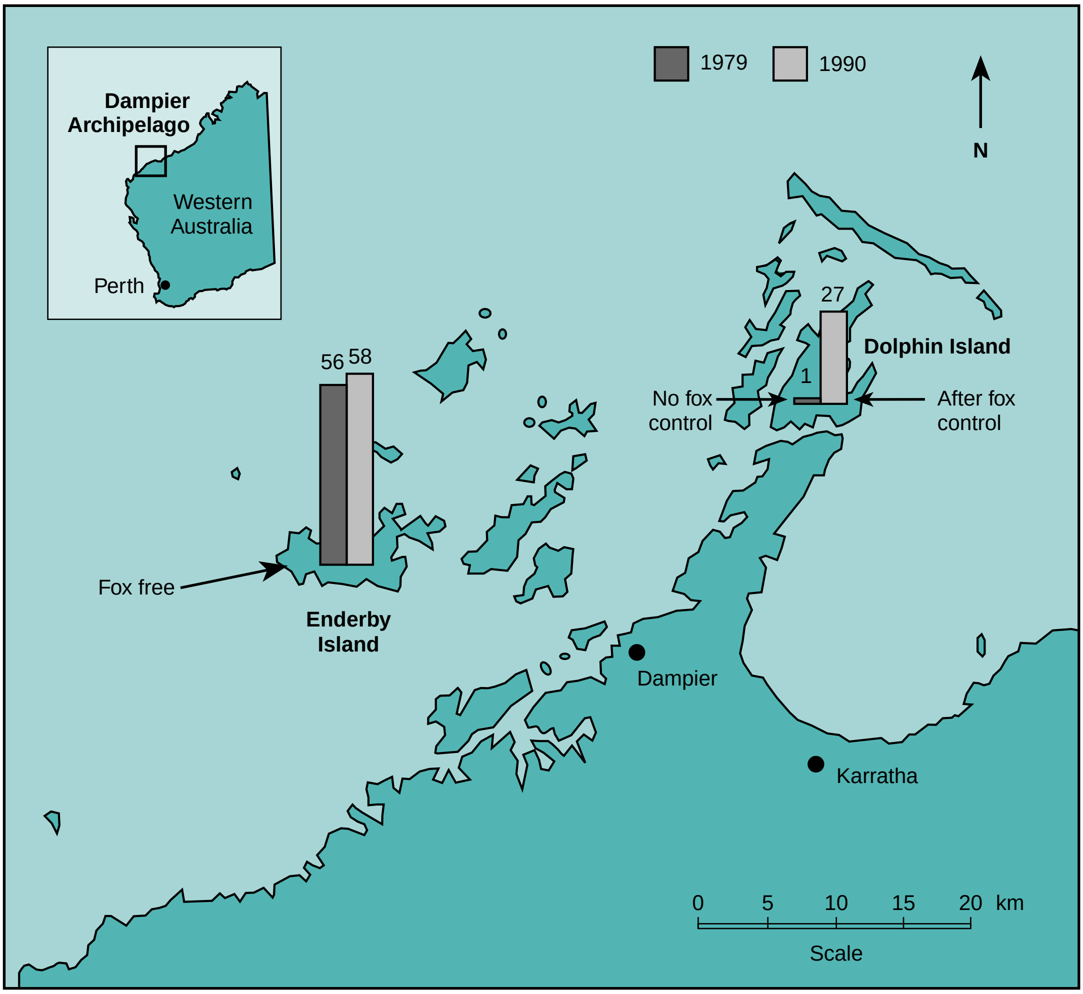


Figure 9: The relative abundance of Rothschild's rock-wallaby (*Petrogale rothschildi*), before and after fox control in the Dampier Archipelago. Enderby Island is fox free while foxes had invaded Dolphin Island by crossing the narrow passage that separates it from the mainland (J. Kinnear, unpub.).

Although foxes have been implicated in the demise of the malleefowl, other factors are thought to be involved including habitat modification.

Source: D. Priddel, NSW NPWS

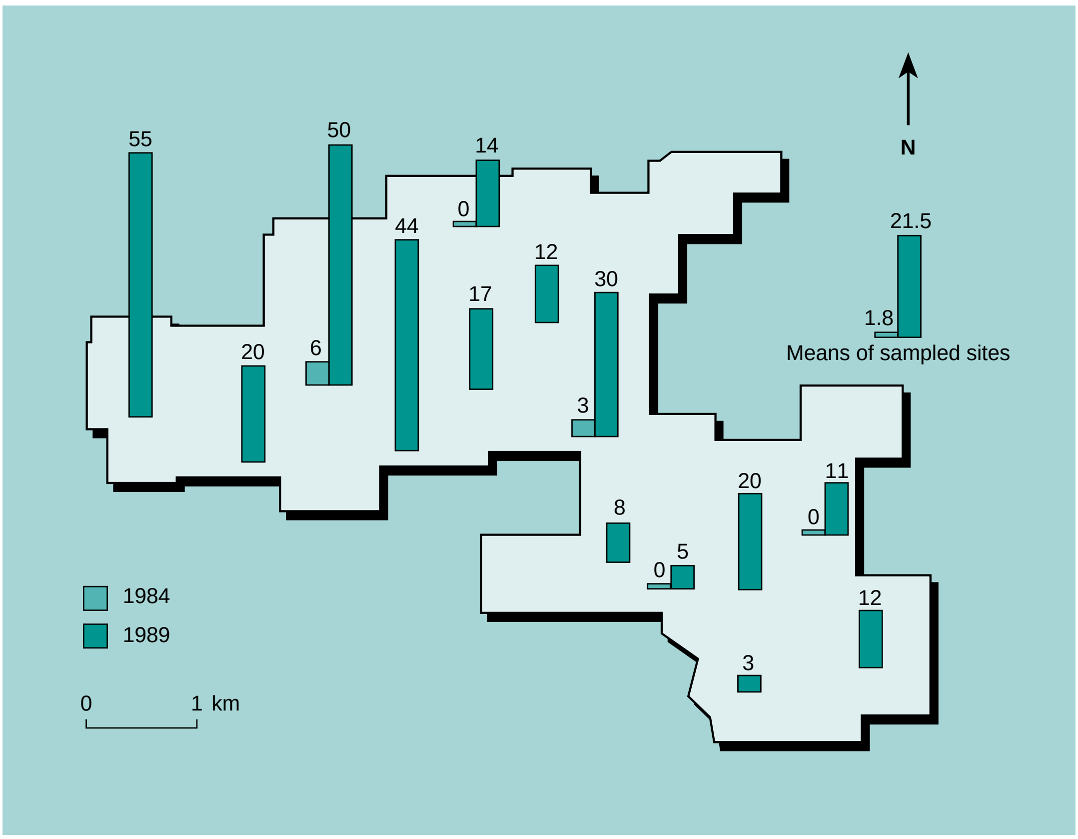


Figure 10: Percentage capture rate of bettongs (*Bettongia penicillata*) after five years of fox control in Tutanning Nature Reserve. Light green columns show the capture rate prior to fox control; dark green columns show the capture rate following five years of fox control in the reserve (J. Kinnear, unpub.).

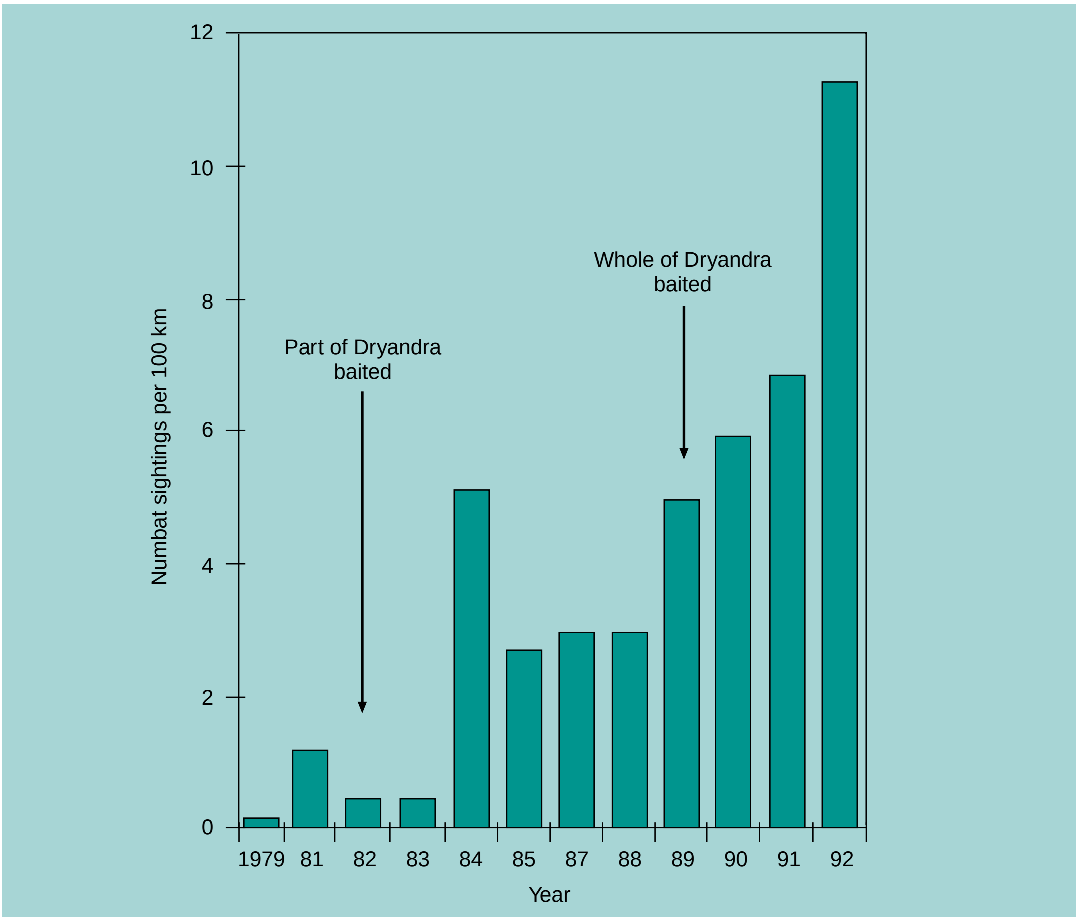


Figure 11: Numbat (*Myrmecobius fasciatus*) sightings in Dryandra State For est between 1979 and 1992. Fox contr ol program implemented in 1982 (J.A. Friend, CALM, W A, pers. comm. 1992).

on fox-free Enderby, appr oximately 60 r ock-wallabies were sighted, while on Dolphin Island (with foxes) only one r ock-wallaby was sighted.

The spotlight traverses wer e repeated after a period of fox contr ol using 1080 baiting on Dolphin Island. Following fox contr ol on this island, the sightings incr eased by nearly thirty-fold (Figure 9). Thus, r emoval of foxes fr om Dolphin Island r esulted in a marked incr ease of rock-wallabies on the island.

Bettong (Bettongia penicillata)

Tutanning Nature Reserve (2200 hectar es) is a natural bush r emnant in the wheatbelt of Western Australia, about 150 kilometr es south-east of Perth. The r eserve lost thr ee species of marsupials, a numbat, a possum and a bandicoot, between 1971 and 1975. T ammars (*Macropus eugenii*), bettong and brushtail possums (*Trichosurus vulpecula*) declined to very low numbers. The bettong, which was formerly abundant in the r egion, but thought to be extinct because none wer e reported during a ten-year period, was located but found to be in very low numbers. In 1984, the r eserve was trapped for bettongs and seven were captured and r eleased. Captures were successful only at two sites characterised by dense cover (Figur e 10).

'Fox control resulted in increased numbers and distribution of bettongs in a Western Australian reserve.'

A baiting pr ogram for foxes was implemented and maintained for five years.

In 1989, the reserve was trapped again and 63 bettongs were caught for approximately the same trapping effort. Prior to fox control there were no captures on some trap lines. After fox control the capture rate of bettongs increased and was as high as 55% of traps set in some areas. To summarise, not only did fox control result in a population increase, it also enabled the bettong to occupy and reproduce successfully in a larger proportion of the reserve (Figure 10). Tammar wallaby and brushtail possum numbers also increased.

Numbats (Mymecobius fasciatus)

Dryandra State Forest (more than 10 000 hectares) is a pocket of remnant bushland in the wheatbelt near Narrogin, about 175 kilometres south-east of Perth. It is a highly significant conservation site because of the persistence of the numbat within its boundaries. During the 1970s, the numbat population declined to a low level (Friend 1990). Similarly, tammar wallabies, bettong and brushtail possum were also uncommon. During monthly trapping and spotlight surveys over two years (1969–70) there were few records of these species and the trapping success was less than 2% (A. Burbidge, CALM, WA, pers. comm. 1992). Additional efforts to trap bettongs in 1975 were unsuccessful.

'Numbats and other native animals increased in Dryandra State Forest after foxes were baited.'

A fox removal program was implemented in 1982 in a selected portion of Dryandra State Forest. The 1080 baiting was undertaken monthly, over five years. Numbats increased significantly within the baited area, but not outside the baited area (Friend 1990). In 1989 the whole of Dryandra was treated with 1080 meat baits. Since then numbats have increased substantially (Figure 11).

Following fox control, bettongs appeared to increase in numbers within the baited area, and after three years of regular 1080 baiting of the whole Dryandra State Forest area, numbats, bettongs and brushtail possums appeared to have increased. Tammar wallabies, once thought to be extinct, are now commonly seen in some areas.

3.1.2 Evidence from south-east Australia

In New South Wales, fox removal has been shown to increase malleefowl survival. Priddel (1991, page 3) states: *'Populations in New South Wales are in drastic decline and imminent danger of extinction ... The most significant threat to the survival of the malleefowl in New South Wales is the introduced fox (Priddel 1989)... the threat posed by the fox can be reduced by a campaign of intensive baiting'.*

'Fox removal has been shown to increase malleefowl survival in New South Wales.'

In a further study and from earlier reports, Priddel and Wheeler (1990) concluded that feral cats and foxes were a major factor influencing the survival of this species. However, it was shown that control of predators alone was not sufficient to ensure survival of malleefowl chicks (Priddel 1991). He states: *'Other factors are implicated in the demise of malleefowl, namely stock, goats, rabbits and fire'.*

Fire opens the canopy and increases the vulnerability of malleefowl to avian predators (Priddel and Wheeler 1990). Food is a limiting factor (Priddel 1991) on Yathong Nature Reserve, New South Wales. The study showed that newly hatched chicks, which were released into mallee where foxes have been controlled, starved unless given supplementary food.

Phillips and Catling (1991) studied the home range and activities of foxes in a wilderness area of coastal south-eastern Australia. Small and medium-sized mammals were abundant and comprised 52% of the diet of foxes. Such high prey densities are in contrast to the Western Australian situation, but fox densities (and presumably predation pressure) were judged to be low.

During studies of the distribution and abundance of fauna in two forested regions, one in the north, and the other in the south of eastern New South Wales (P.C. Catling, in preparation), foxes were found to be abundant in all 13 study sites of the southern region. At the same time small wallabies were not found, quolls were present in only one area, and bandicoots in six areas, both at very low abundance. In contrast, of the ten northern study sites, foxes were only found in four, at approximately half the abundance found in the south. Small wallabies and quolls were present in nine areas, bandicoots in seven areas, and all were mostly at high abundance.

Norman (1970) studied fox predation in short-tailed shearwater (*Puffinus tenuirostris*) colonies in Victoria. He found predation rates to be generally low (less than 2%) but could not identify unconfirmed kills nor the extent to which viable individuals were being removed from the colony. Hornsby (1981) observed one instance of fox predation on a juvenile euro (*Macropus robustus*) as well as several attempted kills of yellow-footed rock-wallabies in the Flinders Ranges of South Australia.

Regular inspection of tortoise nesting sites along the Murray River in South Australia showed that 93% of eggs were taken by foxes (Thompson 1983). It was also found in this study that the age structure of tortoise species in the Murray contained a disproportionately large number of old individuals, which was attributed to egg losses. As older individuals die and with juvenile recruitment restricted by fox predation, tortoise populations along the Murray will continue to decline.

A list of native species believed to be at risk from fox predation is presented at Appendix A.

3.1.3 Impact of fox removal on other predators

In Western Australian, numbats have increased from low densities during fox baiting programs (Section 3.1.1), and numbats have been successfully reintroduced into wheatbelt reserves in concert with 1080 baiting programs. In another area of Western Australia, subsequent research (Friend 1990) recently identified a second limiting factor apart from fox predation. A numbat reintroduction experiment into a nature reserve in Western Australia had not been as successful as previous wheatbelt introductions despite fox control. There is evidence that predation by feral cats became the limiting factor. It is not known why cat predation is a significant mortality factor in this semi-desert setting. Feral cats in this area seem less inclined than foxes to take baits. It is subjective observation which also suggests that cats may increase in density following the removal of foxes.

Recent studies in the Gibson Desert of Western Australia appear to confirm these observations (Christensen and Burrows, in press). Feral cat numbers increased fourfold when fox control was initiated whilst there was no change in cat numbers in a neighbouring site where no fox control was undertaken.

'Feral cat numbers may increase when foxes are removed.'

The impact on native fauna of a fox management program which eliminates foxes but favours other predators, such as feral cats, requires more study. It needs to be carefully considered in the development of a fox management strategy.

3.1.4 Evidence from areas lacking foxes

Manipulative predator removal experiments, such as those discussed above, provide strong evidence that fox predation is a major threatening process for Australian native fauna. In addition, there is considerable circumstantial evidence that is consistent with these experimental findings. In the absence of the fox, areas such as the wet tropics (Torresian Biogeographic Region), Tasmania, Kangaroo Island and numerous smaller islands, appear to carry intact and abundant faunas (Johnson et al. 1989). This is despite the presence of feral cats and other impacts such as significant habitat loss. Conversely, in the presence of the fox, there is a history of extinction and major changes in the distribution of surviving mammal species over wide areas of the Australian continent. Other factors, however, such as the absence of rabbits in some areas, could also account for the current abundance of native fauna in some areas free from foxes.

'Predator removal studies provide strong evidence that fox predation is a major threatening process for Australian native fauna.'

3.1.5 Impact of foxes on reintroductions of native fauna

In a review of attempts to reintroduce macropod species in Australia (Short et al. 1992), foxes were identified as a factor limiting the success of seven out of ten mainland reintroductions. They also found that reintroductions to islands and mainland sites which had predators such as foxes and cats, had a success rate of only 8%. In stark contrast, the success rate of reintroductions to island sites which had no predators was 82%. Perhaps the most convincing example of fox predation presented by these authors involved the reintroduction of Parma wallabies (*Macropus parma*) to a site at Robertson in eastern New South Wales. A total of 45 animals were released (12 fitted with radio transmitter collars). Three weeks after translocation the heads and thoraxes of two wallabies, which had been buried by foxes, were found one to two kilometres from the point of release. Of the 26 carcasses eventually recovered, 24 were buried (typical caching behaviour of foxes). Within two months, no collared animals remained alive, and within three months all 45 wallabies are believed to have been taken by foxes.

Sharp (1992) identified several factors affecting attempts to re-establish rufous hare-wallabies (*Lagorchestes hirsutus*) in the arid zone. Foxes were implicated in the failure to establish one colony, and feral cats were implicated in another colony. Fire caused the loss of another population.

3.1.6 Impact on traditional lands

In the desert regions, traditional Aboriginal living patterns persisted well into the twentieth century. Burbidge and McKenzie (1989) have shown that in the Western Australian desert regions, mammal extinctions have been common and widespread. The disappearance of many mammals coincided with the time that Aborigines left the desert region. Burbidge and Mackenzie (1989) reported that foxes did not become established in many areas until after the mammals had gone. They suggested that the subsequent change in the fire regime as evidenced by an increased incidence of wide-scale wildfires was a major cause of the decline in those species. They suggest that in the absence of traditional Aboriginal burning practices, which in the past generated habitat mosaics and a system of fire breaks, the fauna was not only deprived of essential habitat but also made more vulnerable to predators.

Attempts to re-establish rufous hare-wallabies into the desert regions have been thwarted principally by high levels of predation, foxes in one case, and feral cats in another (Sharp 1992). Reintroductions of some semi-arid fauna are doomed to fail without fox and feral cat management, although other factors such as appropriate cover, food and other essential resources no doubt are also important. However, there is no effective method for wide-scale predator control in the semi-arid region. Sustained poisoning of foxes in strategic areas is currently the only method that is known to be effective.

3.1.7 Fox competition with native fauna

Although the role of the fox as a predator of wildlife is well recognised, there is little known about its impacts as a competitor.

Either competition or predation by foxes could threaten the viability of wildlife populations reduced by habitat loss and modification. Morris (1992) suggests foxes may compete with the chuditch or western quoll (*Dasyurus geoffroii*) for food in jarrah forest in Western Australia. Foxes can also prey on young chuditch. A preliminary unreplicated test suggested that poisoning foxes with 1080 may allow chuditch to increase.

3.1.8 Environmental consequences of potential range expansion

The fox has the potential to expand its range to include Tasmania, Kangaroo Island and other islands with suitable habitat. Were this to occur it would probably have major detrimental impacts on the native fauna of these islands, particularly in Tasmania where probable consequences of fox predation are obvious for such prey species as the eastern quoll, bandicoots, bettong and ground parrot. Other consequences, such as competition between foxes and other species, are less certain, but the fox could be a strong threat to the Tasmanian devil.

'If foxes were introduced to Tasmania, Kangaroo Island or other smaller islands they could cause considerable damage.'

There have been several unsuccessful attempts to introduce the fox into Tasmania (Statham and Mooney 1991). The origin of a fox killed near Launceston in 1972 is still unknown. It would be relatively easy for people to make further attempts. All larger Australian islands have regular sea and air traffic, making irresponsible, deliberate efforts at introduction almost inevitable in the long term. Early detection would be unlikely in isolated locations.

Whether foxes could spread further north is uncertain. There are records of foxes in the Kimberley region of Western Australia (King and Smith 1985) and an isolated population exists on Killarney station in the Victoria River district of the Northern Territory (Wilson et al. 1992). The consequences for native fauna of these or other populations of foxes spreading more widely are unknown, but could be significant.

3.1.9 The fox as a predator of rabbits

Parer (1977), Wood (1980) and Newsome et al. (1989) conclude that the fox, in conjunction with other predators, can restrict rabbit populations under certain circumstances. Pech et al. (1992) defined these as being: *'at low rabbit densities, foxes are capable of regulating rabbits, while at high rabbit densities, rabbits escape from predator regulation and foxes would not have a significant impact on rabbit numbers'.*

'Foxes are not effective at controlling rabbit numbers in good seasons.'

This prediction fits the historical pattern. Foxes have been present in Australia for more than a hundred years and during this period rabbit plagues were commonplace.

If this model is correct, the fox may be viewed as beneficial by reducing the frequency of rabbit outbreaks, or by extending the interval between outbreaks by restraining rabbit population growth rates. In essence, when rabbit densities are low, fox predation may under certain circumstances limit rabbit population growth.

It may be concluded on the basis of this model that the fox is capable of exercising a measure of biological control on the rabbit populations. However, the fox is not an effective biocontrol agent, because it cannot prevent the build up of rabbit numbers as a result of favourable conditions, and it has minimal impact at high rabbit densities. The important question is whether the role that foxes play in rabbit control outweighs the damage foxes cause to native wildlife. The answer is likely to vary depending on region and circumstances. For example, in broadacre cropping land and other areas where there are few native wildlife species susceptible to fox predation, it may be advantageous to maintain fox predatory pressure on rabbits by not using 1080 poisoning to manage rabbits. It has been clearly demonstrated that foxes are highly susceptible to secondary poisoning from eating 1080-poisoned rabbits (Birchfield 1979; Christensen 1980; King et al. 1981; McIlroy and Gifford 1991). It would be necessary to determine that susceptible native wildlife are not likely to be present.

'Foxes are highly susceptible to secondary poisoning from eating 1080-poisoned rabbits.'

Where native wildlife is at significant risk from fox predation, use of 1080 on rabbits to cause secondary poisoning of foxes may be warranted, though its efficacy is uncertain. Christensen (1980) linked rabbit control with 1080 to an increased abundance in native marsupials in Western Australia. Conversely, when the use of 1080 was reduced following the introduction of the European rabbit flea in Western Australia, populations of native marsupials such as bettongs, wallabies and numbats declined. A better understanding of the relationship between rabbits, foxes and feral cats and impact on native wildlife from controlling rabbits with and without fox management is required.

3.2 Economic impact

3.2.1 Harmful economic impacts

Within a few decades of their introduction, foxes were regarded as an agricultural pest as is evidenced by the numerous bounty schemes in place around the turn of the century. Although records are lacking, it was certainly predation upon newborn lambs which quickly earned the fox a bad reputation. Sheep, and especially lambs, being of relatively small size and lacking aggression, are more prone to predator attack than many other livestock species. Further, sheep management often involves unsupervised grazing in large holdings. Under these conditions, it is not surprising that high losses of lambs to predators are often claimed. Even so, the role of the fox as a predator of otherwise viable lambs is subject to much controversy and further conclusive studies are required.

'Soon after it was introduced, the fox was regarded as an agricultural pest.'

Fox predation on lambs may be significant on some properties.

Source: R. Knox, APB

Curiously, one of the first reports of fox damage in Australia related not to the animal itself but to the rather cavalier attitude of some early hunt clubs who, in the course of pursuing their quarry, damaged the fences and walls of early settlers (Rolls 1969).

In published studies the fox has historically been perceived as an insignificant predator of livestock (Fennessy 1966; Hone et al. 1981) and hence there has been little development of appropriate management strategies. This situation is beginning to change, partly as a result of the fox's current high profile as a predator of endangered native species, but also due to a new emphasis on intensive management and the protection of stud flocks, plus the sudden withdrawal of commercial fox harvesting operations. Added to this is a promoted awareness of risks associated with fox involvement in the potential spread of rabies. This elevated status of the fox as a threat to the agricultural community has occurred in the continuing absence of conclusive data on fox damage and the cost and benefits of management.

'Ultrasound studies suggest that fox predation on lambs may be more important than was previously believed.'

While there have been few published studies which show foxes as significant predators of lambs, general causes of lamb mortality have been well studied (for example Rowley 1970). These past surveys indicated that the biggest single factor in lamb losses appeared to be associated with the birth process or as a result of poor maternal care, with primary predation causing the death of an otherwise healthy lamb being only of 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 (1965b) 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 a maximum of 9.7% actually died because of predator attack. A proportion of the latter would have been weak or moribund lambs so that only 2% of the total lamb crop was assessed as having been killed by predators.

'Rogue foxes can cause high losses of otherwise viable lambs.'

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 which exhibit poor mothering ability, and the proximity of optimal fox habitat. There is evidence that individual killer foxes become habituated to the killing of 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 livestock 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 live lamb was recorded. Ewes were generally undisturbed by the presence of the foxes. These findings were supported by the study of Mann (1968) where the exclusion of 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.

'Foxes can account for up to 30% of lamb deaths in some areas.'

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. For example, a recent study at the Rutherglen Research Institute, Victoria (J. Reeves, Rutherglen Research Institute, Victoria, pers. comm. 1993) indicated that foxes took 7% of all lambs previously recorded as foetuses present in a flock of 896 ewes. Importantly, many of the lambs taken were completely removed from the paddock immediately after birth, and therefore would not have been recorded using conventional methods for estimating lamb loss. While losses of this magnitude may be insignificant to some graziers, they are obviously important to breeders of valuable stud stock. While the losses may be insignificant at a regional or national level, the operation of rogue foxes on individual properties can sometimes cause very high losses of otherwise viable lambs.

In a recent study of fox predation on lambs in western New South Wales, Lugton (1993) presents data indicating a high loss 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 (1965a) and others, an estimate can be made of the damage caused by foxes in the sheep industry. However, the techniques rely on the recovery of all lambs killed by foxes and, as explained above, this is not always possible.

Although no quantitative studies have been undertaken, recent observations also suggest the fox is a predator of cattle (K. Smith, RLPB, Moss Vale, NSW, pers. comm. 1994). Reported instances are sporadic and mostly restricted to small rural subdivisions on semi-urban fringes. When it occurs, however, the effect of fox predation is substantial — calves dying as a direct result of predation or cows having to be put down as a result of fox attacks during calving.

'The fox is a legendary poultry thief, but poultry in intensive farms are well protected from foxes.'

Losses of other farm livestock to foxes are probably not of economic significance, although the prowess of the fox as a poultry thief is legendary. Today, most commercial poultry farming operations use intensive or battery farming and the animals are generally well protected. Usually it is the small backyard poultry flock which suffers, but while of major concern to the individual operator, these losses are not of serious economic significance. Foxes are also a significant problem for some commercial emu and ostrich farms. Fox predation on newborn goat kids is common but the level of loss is not considered significant at a national level. For high-value

3

commercial cashmere herds, however, losses to individual enterprises due to fox predation on kids can be high.

Foxes can be a major nuisance to landholders, especially 'hobby' or 'weekend' farmers through loss of household or hobby stock. Loss of a few ducklings or a newborn goat kid can cause genuine distress to owners. There has been increasing demand on vertebrate pest control agencies to supply poison baits for fox control to prevent these losses.

In summary, the role of the fox as a predator of livestock is not well understood, despite a number of studies of lamb mortality. The importance of fox predation on lambs as a cause of significant economic losses will vary from district to district and from time to time. While the more recent studies indicate that foxes may be more important as a livestock predator than first thought, the losses are probably lower than those caused by a combination of natural factors including starvation, mismothering, dystocia and adverse weather.

Further studies are required to assess the importance of predation by foxes to lamb losses. Emphasis in these studies needs to be on examining possible links between predation levels and a range of factors including local density of foxes, role of other predators, the importance of killer foxes, proximity of flocks to heavy cover, flock size and duration of lambing, breed of ewes, incidences of twinning, possible seasonal differences in predation pressure, and lambing shelter. Projects funded under the Vertebrate Pest Program (see Introduction) will provide substantial information on the impact of foxes on livestock production.

There are no comprehensive data available on the costs of fox control in Australia. The major costs would be the preparation and field delivery of poison baits (Section 7.5.2).

3.2.2 Ecotourism

An emerging issue associated with the management of fox damage in Australia is the potential impact of fox predation upon the aesthetic quality of fauna parks, wilderness areas and reserves. Because of the uniqueness of much of Australia's fauna, those reserves, parks or wilderness areas in which tourists are able to view uncommon or distinctive wildlife are a valuable resource, both in economic and aesthetic terms.

There is no practical method for assessing the economic impact of foxes on wildlife although it may be considerable, particularly for ecotourism. The interest shown by international tourists towards Australia's fauna such as kangaroos, koalas and penguins, both in zoos and wildlife parks as well as in the wild, are an indication of the potential of this industry.

'Where foxes are controlled in Dryandra State Forest, spotlight tours to view native mammals are becoming popular.'

In South Australia, the Warrawong Sanctuary, run by Dr John Wamsley, has demonstrated that native fauna — such as wallabies, potoroos, bettongs and bandicoots — protected by fox-proof enclosures can be shown to the public by 'display feeding'. Foxes and cats have been eliminated from within the park and a fox and cat-proof fence erected and supplementary feeding provided. Guided groups of visitors can view a range of smaller native mammals in a semi-natural setting, which in other circumstances would rarely if ever be seen.

With fox management, there is potential to display native mammals in the wild to a receptive public. For example, in Dryandra State Forest spotlight tours of the forest are becoming popular since the population recoveries of the numbat (a diurnal species now seen frequently), the bettong and the brushtail possum. Thirty bettongs per hour are commonly seen. In Dryandra village, a rustic collection of woodcutter dwellings now used as tourist lodgings, as many as 30 wild bettongs can be seen near dusk congregating at the feeding site. It is possible for a person to sit quietly amongst a group of bettongs and watch them busily and noisily foraging for scattered wheat grains.

Persistent control has greatly reduced the number of foxes on Phillip Island and their likely impact on little penguin (*Eudyptula minor*) populations. For the period 1987–92, 202 foxes were destroyed while in the same period 499 penguins were identified as having been killed by foxes (M. Hayes, DCNR, Victoria, pers. comm. 1993). Although other factors such as pollution are probably more important, the risk foxes pose to an estimated annual $50 million tourist industry is significant.

These examples demonstrate the potential for wildlife to attract tourists. National parks provide an ideal venue for the tourist industry to exploit a worldwide interest in Australia's unique wildlife. In selected areas, fox management may allow reconstruction of some of the mammal fauna that formerly existed, provided other population-limiting factors are not operating.

Ecotourism ventures may be an effective element of an integrated approach to managing Australia's endangered or vulnerable wildlife. By combining wildlife rehabilitation programs with economically viable ecotourism ventures, income earned can be used to maintain or increase the protected areas.

3.3 Resource value and use

In the past, Australia has been one of the world's most important exporters of fox pelts. Tables 4 and 5 show that the sale of fox pelts can generate significant export income.

'There is no evidence that harvesting foxes for pelts had a significant impact on reducing the damage they cause.'

Unfortunately overseas demand fluctuates widely, and although the industry flourished in the first half of the last decade, prices have since dropped considerably. This decline is due to a number of factors including the vagaries of fashion, increased supplies from other countries and campaigns by the anti-fur lobby. The figures in Table 5 represent only saleable pelts. The total harvest of foxes in any one year would be higher. As an example, in some years 10–20% of foxes can have severe mange (B. Coman unpublished data). These pelts and an unknown percentage of pelts badly damaged by bullets would not be sent to markets.

'Low export prices for fox pelts has discouraged commercial harvesting.'

The commercial harvest for fox pelts in Australia occurs during autumn and winter in the south-east of the continent. The fur industry estimates that about 60% of fox pelts supplied to the trade comes from New

Table 4: Quantity and value of wild red fox pelts supplied during 1982–83 from the major exporting countries involved (after Ramsay 1994).

Country	Unit value ($A) of pelts	Number ($A)	Value
Australia	23.20	350 981	8 152 000
Canada	57.03	88 800	5 063 000
USA	57.03	445 630	25 414 000

Note: Australian figures refer to exports only; figures for other countries include internal use. North American figures include pelts from farmed foxes.

Table 5: Number and value of raw fox pelts exported from Australia (after Ramsay 1994).

Calendar year	Number of pelts auctioned	Unit value ($A)	Percentage used locally
1986	109 271	22.23	18.4
1987	105 654	21.40	20.6
1988	101 982	9.80	17.8
1989	44 145	10.46	19.0
1990	56 427	8.39	9.6

3

South Wales, 30% from Victoria and the remainder from South Australia. Most foxes are killed at night using high-powered rifles in conjunction with powerful spotlights. A smaller percentage is taken via fox drives or the use of den dogs. The use of steel-jawed traps for commercial hunting is uncommon.

The annual harvest of fox pelts varies widely and usually reflects the export price. This is shown in Table 5 where the total number of fox pelts auctioned at the Melbourne market varied from 109 000 in 1986 to 44 000 in 1989.

4. Rabies and foxes

Summary

Rabies is a major threat to Australia, particularly if it becomes established in wild foxes. At present the two main foci of sylvatic rabies are in Western Europe and North America, both characterised by a high incidence of the disease in fox populations (up to 85% of diagnosed cases). In these areas it is considered that in the absence of foxes, sylvatic rabies could not be maintained by other wild species. This is due to the high susceptibility of foxes to rabies, and the behaviour and structure of fox populations which ensure the disease is readily spread and maintained. The two approaches presently employed to control fox rabies are population reduction and vaccination. In areas where rabies is endemic, elimination of the disease through vaccination may be the more economically, socially and scientifically acceptable. However, in Australia, assuming initial distribution of the disease is limited as is the number of vectors involved, population reduction is seen as the better alternative. If rabies became established in foxes, the distribution and abundance of the species in Australia would make control operations a daunting if not impossible task. Other wild host populations including dingoes and bats could also become involved, perhaps further complicated by the as yet unknown susceptibility of other native species. The implications of this scenario are that in the first instance, efforts should concentrate on preventing the entry of rabies into Australia and secondly, if it does, strategies should be in place to rapidly eliminate the disease at its point of introduction.

4.1 The disease

'Rabies occurs on all continents except Australia and Antarctica.'

Rabies occurs on all the continental land masses with the exception of Australia and Antarctica (MacInnes 1987; Blancou 1988). The only reported instance of rabies in Australia was in Tasmania in 1867, a small outbreak which was quickly eradicated (Pullar and McIntosh 1954). Rabies is one of the most feared of human infectious diseases due to the distressing clinical symptoms, the inevitability of death once symptoms appear and the severity of past treatments. The number of people dying from rabies worldwide is estimated at between 20 000 and 75 000 per year, while the number of people treated because of exposure to rabid animals is between 500000 and three million (MacInnes 1987; Fenner et al. 1987; Wandeler et al. 1988).

'The only reported instance of rabies in Australia was a small outbreak in Tasmania in 1867 which was quickly eradicated.'

4

4.1.1 Description

The rabies virus belongs to a group known as the lyssaviruses within the family Rhabdoviridae. The disease, which principally affects the central nervous system, is thought to infect all species of mammal and is nearly always fatal (Kaplan et al. 1986). The most common route for rabies transmission is by a bite from a rabid animal. Rabies virus, like all other viruses, needs living host cells in order to replicate and survive. The tissues of an animal that has died from rabies lose their infectivity at a rate that varies with the initial virus content and the environmental influence (Wandeler 1980).

'Rabies transmission is usually by a bite from a rabid animal.'

There are two main epidemiological cycles of rabies: urban, with the domestic dog as primary host; and sylvatic with one or more wildlife vectors involved. Cases of human rabies are relatively rare in developed countries where the urban cycle has virtually been eliminated.

4.1.2 Present worldwide status

Many rabies epidemics have been recorded, with the dog acting as the main host and primary transmitter of the infection to man (Kaplan 1985). In developed countries, the advent of cheap and effective rabies vaccines (Sikes 1975) which allowed for large-scale vaccination campaigns, coupled with the control of stray dogs, have effectively eliminated the dog as a vector of rabies between 1945 and 1960 (Tierkel 1975). Urban rabies now occurs principally in parts of Africa, the Indian subcontinent, South-East Asia, and Central and South America where there are communities associated with large numbers of unvaccinated or stray dogs (Geering 1992).

Without the fox, it is doubtful that sylvatic rabies would occur over most of the geographical range of the disease with the possible exception of South-East Asia. A number of wildlife vectors are involved, although it is usually only one species which is responsible for perpetuating the disease in a particular region (Geering 1992).

4.1.3 Fox rabies

At present the two main foci of sylvatic rabies are in Western Europe and North America. The disease is both characterised by a high incidence of rabies in fox populations, with up to 85% of diagnosed cases in all species (Wandeler et al. 1974), and by the cyclic nature of the disease. The latter is related to seasonal peaks in fox reproduction (Müller 1971). Without the fox, it is doubtful whether sylvatic rabies could be maintained by other wild species either singly or collectively (Lloyd 1980). The westward spread of rabies in Europe has been at approximately 25–60 kilometres per year (Moegle et al. 1974).

The fox rabies virus has several unique characteristics including high rates of infection and viral excretion and a low frequency of post-infection immunity. The incubation period in various laboratory trials has ranged between 4–181 days (Wandeler 1980). An infected fox may not show symptoms until a period of high stress such as dispersal, mating or birth which also happen to be the periods of greatest contact between foxes (Tinline 1988). Following incubation there is a symptomatic period, typically of 3–5 days, throughout which the virus is usually secreted (Sikes 1962). Despite a limited amount of evidence it appears that the number of foxes encountered by a rabid fox would be the same as if it were healthy, and that the rate at which these contacts are made would be increased by the heightened activity of rabid foxes (Macdonald and Bacon 1982).

While the characteristics of rabies within the fox ensure that it is perhaps the most susceptible wild animal, the behaviour and structure of fox populations also ensure that the disease is readily spread and maintained. In particular, dispersal by subadult foxes is believed to be responsible for the autumn peak in the cases of fox rabies and for the long distance progression of the disease (Toma and Andral 1977; Artois and Andral 1980). During the mating season (winter), males may also stray from their own territories in search of breeding opportunities. Territories vacated by the death or movement of a previous occupant can be incorporated into adjacent, higher density territories (Macdonald 1980). At other times of the year there is limited between-territory contact (Macdonald and Bacon 1982). This in turn limits spread and slows down the progression of rabies (Wandeler 1980). The high reproductive capacity of foxes coupled with the continual turnover of territories means that areas affected by rabies will be repopulated in a relatively short time, thus creating a new population of susceptible animals for the next wave of the disease (Tinline 1988).

Comprehensive reviews of the nature and mode of action of rabies and the role of wildlife in its transmission can be found in Baer (1991), Wandeler et al. (1974), Kaplan et al. (1986), Steck and Wandeler (1980), Zimen (1980), Macdonald (1980), Bacon

(1985), MacInnes (1987), Campbell and Charlton (1988) and O'Brien and Berry (1992).

4.2 Management techniques for rabies control

The primary aim of rabies control programs is to protect humans from infection and from economic loss (Wandeler 1988). This can be attained by a drastic reduction in the fox population or by mass immunisation of the host species, principally foxes. In both cases the aim is to reduce the number of susceptible foxes to below the threshold density of animals which is necessary to maintain rabies in the wild (Anderson et al. 1981). Epidemiological evidence from Europe suggests that the threshold density lies in the range of 0.2–1.0 foxes per square kilometre (Müller 1971; Bogel et al. 1976 and 1981; Steck and Wandeler 1980; Macdonald 1980) with 1.0 being the most frequently quoted value (Anderson et al. 1981).

4.2.1 Rabies control in endemic areas

The current practice in Europe and North America of treating fox rabies epidemics by oral vaccination is relatively recent (Black and Lawson 1970; Baer et al. 1971). Prior to this, reducing fox density was considered the only option. This was based on the following premises (Wandeler 1988):

- rabies always disappeared from areas where the disease itself and control efforts had reduced the fox population density to a low level;
- rabies did not penetrate into regions which had a tradition of small game hunting where foxes were considered a pest and systematically destroyed; and
- areas with low carrying capacities for foxes such as marshland and alps were barriers to rabies.

Traditional methods for reducing fox populations for rabies control are trapping, shooting, gassing of dens and poisoning. Their usefulness for stopping or slowing the spread of rabies has been controversial. Zimen (1980) points out that the fluctuations in the incidence of rabies during disease outbreaks may equally be due to the normal fluctuations in the incidence of fox rabies rather than the efforts to reduce population density. He concluded that mortality of foxes caused by rabies far outweighed all effects of human induced fox mortality. Despite substantial efforts in France, Germany, Poland and other parts of Europe, as well as North America, traditional control methods have failed to halt the spread of fox rabies (Linhart 1960; Johnston and Beauregard 1969; Wandeler et al. 1974; Toma and Andral 1977; Macdonald 1980). Wandeler (1988) suggests that for the fox, human control has long been the most important mortality factor and that foxes adapted well to this situation. This resilience to human control, coupled with the high reproductive potential and carrying capacity of foxes in rural and urban environments, are the probable causes for the failure of fox population reduction efforts in halting the spread of rabies. Bacon and Macdonald (1980) also argue that the killing of foxes can be counterproductive to rabies control because the disruption to fox social systems results in a greater degree of movement into new territories and an increase in aggressive contacts between foxes.

4.2.2 Vaccination

The first field evaluation of oral vaccination of foxes using attenuated (weak) vaccines was carried out in Switzerland with chicken heads as bait (Steck et al. 1982). The trial was considered successful with two subsequent rabies outbreaks halted and no evidence that the vaccine strain had become established in wild or domestic animals. Similar campaigns quickly followed in Belgium (Brochier et al. 1988), Germany (Wachendörfer et al. 1985; Schneider et al. 1985), France (Artois et al. 1987), Italy, Luxembourg and Austria (Schneider et al. 1988) and in Canada (MacInnes et al. 1988; Johnston et al. 1988).

Recent advances in cloning and gene expression have led to the development of a new generation of rabies vaccines, the recombinant virus vaccines. The duration of immunity conferred by this recombinant virus (a minimum of 12 months) corresponds to the length of protection required for fox vaccination in the field (Schneider and Cox 1988). More importantly, and unlike the attenuated strains, there is no evidence of residual rabies in a variety of non-target animals (Rupprecht and Kieny 1988; Wiktor et al. 1984). The first field applications of recombinant vaccine baits took place in Belgium (Pastoret et al. 1988; Brochier et al. 1991). Following the final distribution of bait, vaccine-induced immunity was evident in 81% of the foxes sampled.

In south-eastern Ontario, rabies has historically shown peaks of incidence over a 3.5 year cycle. The last such peak was in the first quarter of 1986 (Tinline 1988). However, since the aerial vaccine baiting of foxes, the incidence of rabies in foxes has declined to its lowest level in 30 years. Most of the cases which do occur are across the Ottawa River from Quebec, which is experiencing a major rabies epizootic (R. Rosatte, Ontario Ministry of Natural Resources Rabies Unit, pers. comm. 1994).

These trials indicate that the eventual eradication of sylvatic rabies in endemic areas is possible, although the results still need to be treated with caution. Anderson (1991) points out that in these latter trials (and similarly in nearly all previous evaluations of wildlife vaccination campaigns) the experimental design failed to include comparable non-treatment areas in which baits were not distributed. This does not allow for the cyclical nature of rabies in fox populations to be fully taken into account in the trial results. Voigt (1987) also raised this problem but acknowledges that in the control of rabies a non-treatment area is generally not possible. There is also a need to improve upon the low level of immunisation achieved in juvenile animals. In the second baiting period of the trials reported by Brochier et al. (1991) which was prior to dispersal, bait uptake by juvenile foxes was only 49%. Anderson (1991) also concludes that an overall immunisation of 81% may be sufficient to prevent the spread of rabies in low to moderate density fox populations (such as the two per square kilometre in these trials) but for higher densities in the order of four per square kilometre, a 90% coverage would be necessary to block transmission.

4.2.3 Baiting systems

Whichever strategy is applied, a bait incorporating either a vaccine or a toxin needs to be delivered to fox populations for the purpose of rabies control. Baits such as horse meat, tallow and chicken heads have long been used in fox control, mostly in association with poisons such as 1080 (sodium monofluoroacetate) and strychnine. Oleyar and McGinnes (1974) and Allen (1982) also used ground beef and pork coated in granulated sugar to deliver chemosterilants to wild foxes. In Great Britain the present Ministry of Agriculture, Fisheries and Food (MAFF) recommendations for population reduction in urban foxes in the event of a rabies outbreak is for the distribution of day-old chicks injected with a gelatine solution of strychnine (C. Cheeseman, MAFF, Great Britain, pers. comm. 1993). With the relatively recent advent of orally administered rabies vaccines, the development of baits specifically for this purpose has received a great deal of attention.

4.3 Implications for Australia

The risk of fox rabies ever being introduced to Australia is low. Rabies could only be brought into the country via an infected animal, and with strict quarantine controls over legal imports, the major risk is obviously from smuggling or illegal landings (Garner 1992). Such imports may not be rare, although the likelihood of a smuggled animal becoming rabid is probably low and with limited opportunities for it to be a threat to other animals (Forman 1993). This however does not preclude the possible introduction of sylvatic rabies to Australia.

The uncertainty of the origins of existing epizootics in Europe with the suggestion that it was the result of adaptation of the canine virus to foxes (Blancou 1985) also shows that the behaviour of a disease such as rabies is not predictable. Finally there is the even less likely event that rabies could be deliberately released as was threatened by terrorists in the United Kingdom in 1989 (Wilson 1992).

'The risk of fox rabies ever being introduced into Australia is low.'

Circumstances will determine which approach to rabies control is selected. In areas where rabies is already endemic, elimination of the disease through vaccination may be more economically, socially and scientifically acceptable. However, population reduction is seen to be the better alternative where the disease is presently absent such as in Australia and Great Britain, assuming, of course, that detection of its introduction is rapid so that distribution is restricted, as are the number of carriers of the disease involved. Furthermore, should rabies be introduced to Australia the use of vaccines would be prohibited until such time that evidence was available of their safety in the Australian environment (AUSVETPLAN Disease Strategy for Rabies 1991). Existing contingency plans for the control of fox rabies in Australia therefore rely on population reduction techniques (AUSVETPLAN Emergency Operations Manual, Wild Canid and Felid Control 1991). These involve the aerial and ground distribution of poison baits (1080, strychnine and cyanide) supported by trapping, den fumigation, shooting, exclusion fencing and harbour destruction. Coman (1992) attempted to implement these techniques in simulated rabies outbreaks in Victoria with limited success. This was partly due to a lack of resources which would not be the case in the real event. However, there were still obvious deficiencies in techniques which require further development. The failure of a policy of population reduction in endemic rabies areas similarly cannot be disregarded.

If rabies became established in foxes, the distribution and abundance of the species in Australia would make control operations a daunting if not impossible task. Other wild host populations including dingoes and bats could also become involved, perhaps further complicated by the as yet unknown susceptibility of other native species. The implications of this scenario are that in the first instance, rabies should not be allowed to enter Australia and secondly, if it does, strategies should be in place to rapidly eliminate the disease at its point of introduction.

Through the use of simulation models of sylvatic rabies, Pech and Hone (1992) also highlight the need for efficient disease surveillance systems to be in place. Assuming rabies was first detected in foxes and the reporting rate of rabid foxes was the same as that for Great Britain, Bacon (1981) estimated that 100–200 foxes might contract rabies before authorities could be 95% certain of being informed. Pech and Hone (1992) suggest that this may take 4–7 months from the time of introduction which might allow rabies to spread between 5–35 kilometres from the initial point of infection. The further the disease spreads before it was detected the less likely that existing fox control methods would prevent rabies from becoming endemic.

4.4 Implications for fox management

It is inappropriate to initiate large-scale fox management programs on the basis of exotic disease risk alone. However, land managers should be aware of the role that the fox can play in the spread and maintenance of rabies if the disease was introduced to this country. In terms of understanding the likely behaviour of fox rabies in Australia which is essential for contingency planning, the greatest information gap remains the accurate assessment of fox distribution and abundance. Similarly, we also know very little about achievable rates of population reduction by poison baiting, preferred baits for different environments or appropriate bait application techniques.

5. Community attitudes affecting fox management

Summary

Perceptions of the fox as a pest depend very much on individual backgrounds and upon deep-seated historical perceptions of the fox as a ruthless and cunning exploiter. These perceptions can hinder development of a rational approach to managing this animal.

Historically, the fox has been important for hunting, a tradition that remains in Australia today with many hunt clubs and other, less formal methods for hunting foxes. It is unlikely that recreational hunting can effectively control fox damage, although recreational hunters may assist individual landholders by removing problem animals.

There has been little attention to the animal welfare aspects of fox management in Australia. However, there can be no doubt that some current control techniques cause pain and suffering to the animal. The ethics of hunting foxes with hounds or other dogs is beyond the scope of this strategy since the technique is not recognised as a method of damage control. Of the poisons used for fox control in Australia, cyanide (currently used only experimentally) is probably the most humane and strychnine the least humane. Information on the humaneness of 1080 in members of the Canidae is equivocal but, because of the very high sensitivity of foxes to this poison, it has an advantage over the other two poisons used because of its relative target-specificity. Shooting with high-powered rifles is a humane method of fox control, but the use of rim-fire rifles and shotguns increases the risk of maiming and slow death.

5.1 Perceptions of the fox

Attitudes and policies towards foxes and their management are, almost certainly, coloured by historical perceptions of the animal. At different times in our history it has been variously regarded as a killer, a pest, a rogue possessed of inordinate cunning, a harmless or even beneficial component of the fauna and an honoured object of the chase.

The idea of endowing animals with the characteristics, particularly the failings, of humans, and having them enact imaginary dramas which ridicule the faults of man has been popular with writers as early as Aesop and as late as Walt Disney. Even in the bible, the fox is cast as being deceitful, *'Oh Israel, thy prophets are like the foxes of the desert'* (Ezekiel 13:4). This trend can be traced through history, perhaps reaching its zenith in Medieval times when Reynard the fox became a popular story character.

Unfortunately, much of the myth associated with such tales has become installed in what might be termed contemporary popular ecology in Australia, where foxes are seen as cunning and ruthless exploiters of wildlife and smaller domestic livestock species. As a result, it is often difficult to separate fact from opinion and opinion from myth. It has only been in the last decade that scientific evidence relating to the effects of fox predation on Australian wildlife has been collected (Chapter 3).

'The fox is variously regarded as a killer, a pest, a cunning rogue, a harmless component of the fauna, or an honoured object of the chase.'

There are a wide range of perceptions about the economic impact of foxes. It is important that accurate information on the impact of foxes is obtained and communicated to the general public and to land managers in particular, so that they can make informed decisions concerning the need for fox management.

5.2 Sport hunting

5.2.1 Traditional hunting

The tradition of riding with hounds is one which early English colonists transferred to Australia and, in fact, is the main reason for the introduction of the fox to this country (Chapter 1).

The first true hunt clubs were established in the 1850s although the Adelaide Hunt dates back to 1842. It is doubtful whether these early clubs hunted foxes, the more likely quarry being native species (Rolls 1969). Currently there are 23 listed Hunt Clubs in Australia (Cameron-Kennedy 1991) but the sport appears to be expanding. All states except Queensland and the Northern Territory have established Hunt Clubs. This includes Tasmania which is fox free. The existence of hunt clubs in fox-free areas indicates that the hunt is essentially a social institution and the presence of the quarry is of secondary importance.

Traditional fox hunting probably contributes little to the management of fox damage. Clubs see themselves primarily as sporting and social organisations.

Unlike other forms of recreational fox hunting (see below), hunting with horses and hounds is highly organised and includes a Hunt Committee, Master of Hounds and Field Master. Clubs usually have strict rules and guidelines. The Hunt Clubs Association of Victoria, for example, has a detailed code of rules for fox hunting (HCAV 1988).

5.2.2 Other forms of recreational hunting

Battues or fox drives are still common in some rural communities. Here, groups of individuals meet, generally on an informal basis, and use unarmed beaters (often with dogs) to drive foxes into a waiting line of guns. Usually it is only small areas of prime fox cover that are treated.

'Shooting of foxes, usually at night with high-powered rifles, is a common sport in southern Australia.'

Another common technique of fox hunting is the use of small terrier dogs to flush foxes from dens. Animals thus dislodged are either killed with shotguns or coursed with large lurcher dogs.

Finally, the sport shooting of foxes, usually at night with high-powered rifles, is a common recreational sport in many parts of southern Australia. Such shooting is also the main method employed in the harvesting of wild fox pelts, but many shooters will take foxes by this technique without any expectation of commercial gain from the sale of fox pelts.

In many districts, recreational shooters with high-powered rifles are invited onto farms just prior to or during the lambing season. The resultant localised reduction in fox numbers may give some temporary respite to lamb predation losses.

Recreational fox hunting often requires specialised firearms and ammunition. In addition, hunters undoubtedly contribute in other ways to local and regional economies although the extent of this has not been estimated.

5

5.3 Animal welfare

5.3.1 General

Animal welfare groups aim to protect animals from cruelty and improper exploitation, encourage the considerate treatment of animals, and denounce practices perceived as causing animals unnecessary stress. The Australian and New Zealand Federation of Animal Societies (ANZFAS) accepts that from time to time some feral animals may cause agricultural or environmental damage, and that in these situations there is a case for pest control (ANZFAS 1990). However, their view is that only humane methods conducted under the supervision of relevant government authorities, and within sound long-term population reduction programs, are acceptable.

The cruelty related to the use of various fox control techniques relies essentially on subjective assessments. In fact, a clear definition of humaneness is difficult. The authors have used the definition used in Section 3.3 of the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes — *'Pain and distress cannot be evaluated easily in animals, and therefore investigators must assume that animals experience pain in a manner similar to humans'.*

Generally speaking, the humaneness of techniques associated with the management of introduced pest species in Australia has received little attention, with most emphasis being placed upon the methods used to cull native species such as kangaroos and wallabies. The Sub-committee on Animal Welfare of the Standing Committee on Agriculture and Resource Management has produced Codes of Practice for some feral animals but not for predators (Sub-committee on Animal Welfare 1991). Sometimes in the case of the introduced predators, there is a tendency to justify relatively inhumane control techniques on the basis that the predators themselves inflict pain and suffering on their prey. This argument is commonly, but in the author's opinion, wrongly used by some graziers to justify the setting of steel-jawed traps for wild dog control.

Both the RSPCA Australia and ANZFAS are strongly opposed to the hunting of animals for sport. In the case of vertebrate pests like the fox, they recognise the need for management measures but oppose the use of non-specific baiting or the use of toxins which may cause suffering (RSPCA 1985).

5.3.2 Riding with hounds and other forms of dog hunting

Since the use of dogs (with or without hounds) cannot be regarded as a method of broadacre fox control, it requires little comment in these guidelines. A detailed defence of fox hunting has been prepared by the Hunt Clubs Association of Victoria (HCAV 1988).

'Hunting foxes with dogs is more of a sport than a control method.'

The use of small terriers as den dogs and larger lurcher dogs for coursing foxes is, likewise, more of a sport rather than a control tool. In the case of den dogs, the terriers as well as the foxes often receive severe bite wounds. Fighting between fox and terrier can often be prolonged, and not all foxes bolt immediately from the den and into the waiting guns. Similarly the use of larger dogs for coursing foxes is questionable on animal welfare grounds. Death of the downed fox can often take several minutes, and again, the dogs themselves can receive serious bite wounds.

5.3.3 Sport and commercial shooting

The humaneness of shooting as a control technique for foxes depends almost entirely on the skill and judgement of the shooter. High-powered rifles of calibres from .17 up to .243 are commonly used. Generally, shooting with high-powered rifles is a humane technique for fox destruction. These rifles are generally fitted with powerful telescopic sights and are used for a stationary target only. Under these conditions, rapid death from head shots or chest shots is usual. In those few cases where the animals are wounded rather than killed outright, the massive wounds caused by these high-velocity projectiles usually result in death within a few minutes.

'Skilled shooting with a high-powered rifle is generally a humane technique for fox destruction.'

The less powerful .22 calibre, rim-fire rifles should not be used for fox control because of the greater risk of non-lethal wounding.

The humaneness of shooting foxes with shotguns rather than rifles is more difficult to judge. Here, the weapons are most commonly used upon a running target, and the opportunity for non-lethal wounding is much greater. Factors that affect the humaneness of the technique include the size of shot used and the gauge of the shotgun, distance over which shot travels, skill of the operator, and presence or absence of thick cover. In general terms, only 12-gauge weapons utilising heavy shot (No.2 or BB size) should be used at distances of up to 35 metres — sufficiently close to allow deep penetration of the shot into the critical lethal areas (brain, chest cavity).

5.3.4 Den fumigation

Although not widely used, the introduction of lethal gas into fox dens is sometimes used as a control technique. Most commonly, the technique is used to destroy young pups in breeding dens. In Australia only two fumigants are used, chloropicrin (trichloronitromethane) or phosphine gas generated from aluminium phosphide, although carbon monoxide cartridges are being considered for use as a more humane fumigant for den fumigation in Victoria (C. Marks, DCNR, Victoria, pers. comm. 1994).

Chloropicrin

This is a non-flammable and colourless liquid which vaporises slowly at room temperature (sea level) (Sexton 1983). It is a strong sensory irritant which causes profuse watering of the eyes, nasal passages and intense irritation of the respiratory tract (Chapman and Johnson 1925; TeSlaa et al. 1986). Chloropicrin was widely used during the First World War as a chemical warfare agent (Timm 1983).

Measurement of sensory irritation has been attempted in mice (*Mus domesticus*) by measuring the decrease in respiration rate upon exposure to a sensory irritant (Alarie 1981). A commonly used measurement is the concentration of an irritant which produces a 50% decrease in an animal's respiration rate (RD_{50}) and this has been suggested as the level of irritation which may result in respiratory injury following repeated or extensive exposure (Kane et al. 1979).

The RD_{50} for mice when exposed to chloropicrin was found to be 7.98 ppm. Chronic exposure at this level for six hours per day over five days produced ulceration and permanent damage to the respiratory system (Buckley et al. 1984). Toxicity of chloropicrin is primarily influenced by the effects on the small and medium bronchi of the lung, with death resulting from respiratory failure (Clayton and Clayton 1981). The speed at which this will occur depends upon the concentration of the gas and the exposure time.

'Chloropicrin causes extended suffering and is not a humane control agent.'

Although no work has been published on the efficacy of chloropicrin as a fox den fumigant, some parallels might be expected with the use of this chemical in rabbit warrens. Oliver and Blackshaw (1979) observed that chloropicrin was unevenly distributed in a rabbit warren when it was introduced without a power fumigator, at particular points in the warren. The gas, being heavier than air, will sink and collect at low spots in the warren. Concentrations in these areas have been shown to build up to levels of 5 ppm in a few hours, causing the rabbits to move to areas in the warren containing higher and more immediately lethal concentrations of the gas.

Gleeson and Maguire (1957) suggested that chloropicrin has a delayed effect on rabbits which have been exposed to sub-lethal but acute doses. This was typically observed in rabbits which escaped from fumigated warrens. These were sometimes found to have died, apparently from the effects of the gas, some weeks after initial exposure. Similar results are likely in foxes.

In summary, chloropicrin is not a humane agent for fox control. The symptoms seen in live animals of other species and the pathological changes seen in autopsied animals suggest that some suffering occurs over periods of several hours or, in the case of animals escaping from dens, possibly days. Power fumigators, which quickly force the gas through all parts of the den, might decrease the time to death, and therefore the duration of suffering.

Phosphine (Hydrogen phosphide)

This is a colourless gas, about 20% heavier than air, which is produced by the action of water on aluminium or magnesium phosphide. Because hydrogen phosphide is a highly flammable gas it is prepared as a solid tablet with ammonium carbamate which will, upon generation of the phosphine, produce carbon dioxide and ammonia and thus reduce the risk of gaseous combustion of the phosphine (Sexton 1983).

In humans, the gas does not appear to cause sensory irritation and is characterised by a slight garlic-like odour. It is a systemic poison which depresses the central nervous system and respiratory function (Sexton 1983). Inhibition of vital cell enzymes is probably caused by the action of phosphine upon bone marrow and organ tissues (Klimmer 1969).

In a concentration of 2000 ppm, the gas is rapidly lethal to humans in less than one minute (Sexton 1983). At 400 ppm it is lethal to rabbits in 30 minutes (Jokote 1904, quoted in Oliver and Blackshaw 1979). Unlike chloropicrin, chronic exposure at low levels (1–2.5 ppm for over three weeks) gives no evidence of subacute or chronic poisoning (Klimmer 1969).

Oliver and Blackshaw (1979) found that rabbits could remain immobile during lethal exposures, indicating that the chemical is not a sensory irritant to them. The actual pain and suffering caused in rabbits is not known, but in humans the symptoms often include nausea, abdominal pain, headache and convulsions with ensuing coma (World Health Organisation, undated).

Oliver and Blackshaw (1979) measured phosphine gas concentrations in rabbit warrens following the administration of aluminium phosphide tablets. Their results suggest that the time taken to achieve maximum gas concentration in the warren can be many hours and that it is largely governed by the availability of moisture.

In summary, it is concluded that phosphine is more humane than chloropicrin. Again, the length of suffering or discomfort depends upon gas concentrations in the dens and, under moist conditions with ample tablets used, the time to death may be short.

5.3.5 Trapping — steel-jawed and snare

Steel-jawed trapping is now used infrequently for fox control in Australia. Very often, where foxes are caught in steel-jawed traps, they are set for other species, especially wild dogs and rabbits. The method is clearly inhumane and it is of little value as a control technique, being time consuming and relatively non-specific. It is desirable that steel-jawed traps for fox control be either banned or restricted in those states and territories where such trapping is still allowed.

Although there is a diverse range of mechanical trapping devices used to replace the standard leg-hold, steel-jawed trap, none of these has been specifically designed for foxes. As an example, six designs of spring traps have been approved by the Ministry of Agriculture, Fisheries and Food in the United Kingdom for use on specified mammals but none of these are suitable for the taking of foxes (Bateman 1982). A soft catch trap (Victor Oneida, USA) has been extensively investigated, used and recommended in the USA, where it is regarded as both effective and humane.

'Steel-jawed traps are inhumane and are not effective for fox control.'

The soft catch trap has been used extensively in New South Wales as part of a major research program on fox ecology and the effects of imposed sterility (McIlroy et al. 1994). In one continuous period of seven months, a total of approximately 14000 trap nights produced a trapping success of one fox per 150 trap nights (Kay et al. 1995). Soft catch traps have also been used with some success to catch dingoes in Queensland.

In Victoria, a leg-hold snare trap initially designed to replace the earlier gin trap for wild dog control, is effective for capture of foxes. The device uses a snare thrower which tightens a thick but pliable wire noose around the animal's leg. While this device causes less bone and tissue damage than the steel-jawed trap, some stress is involved and frequent inspection of snare lines is required to prevent suffering in captured animals. The trap is regarded by the RSPCA, Victoria as a more humane alternative to the steel-jawed trap (P. Barber, RSPCA, Victoria, pers. comm. 1992) and is perhaps the only technique currently available for the selective removal of foxes in urban areas. However, setting of these snares is time consuming and a relatively inefficient method for large-scale control. It is recommended for use only in localised, semi-urban and urban situations where other conventional means of control, such as shooting and poisoning, cannot be used. Their humane use depends on frequent inspection and clearance, and until standards for this are established and enforced, they are likely to be unacceptable on animal welfare grounds.

5.3.6 Poisoning

Sodium mono-fluoroacetate (1080)

Sodium mono-fluoroacetate (1080) inhibits citrate and succinate metabolism in the tricarboxylic acid cycle by the formation of fluorocitrate. The inhibition by fluorocitrate is thought to be primarily responsible for the toxicity of 1080 (Atzert 1971). However, Kun (1982) has conducted experiments which suggest that 1080 has other modes of action in the mitochondria.

Irrespective of the exact mode of action, the end result is a loss of energy, an accumulation of fluorocitrate in body cells and a disturbance of central nervous system activity and heart function. Death results from progressive depression of the central nervous system, ending with either cardiac failure or convulsive respiratory arrest as the terminal event.

The toxicity of 1080 varies markedly in different animal classes and even between and within genera. Generally, cold-blooded vertebrates are more tolerant than warm-blooded ones, herbivores more tolerant than carnivores, and birds less affected than mammals. The LD_{50} for mammals varies between 0.1 milligrams per kilogram and 10milligrams per kilogram, with foxes being amongst the most susceptible.

'1080 is relatively target-specific with foxes being highly susceptible to the poison.'

There is no detailed study of 1080 poisoning of foxes, but general observations suggest that the symptoms exhibited are similar to those seen in dogs (L. Staples, Applied Biotechnologies, Victoria, pers. comm. 1992). In this species, Chenowith and Gilman (1946) describe a latent period of one to two hours during which the animal is apparently normal. The onset of central nervous system stimulation is shown by sudden appearance of hyper-excitability, the animal running about and vocalising vigorously. Within a few minutes, hyper-excitability gives way to convulsions. Barking and panting persist during the convulsive period which may last for up to two hours and end in respiratory failure. It is significant that anaesthetised animals still show evidence of extreme central nervous system stimulation so that the behaviour of the animal does not necessarily indicate extreme pain or suffering. On this basis, it is difficult to draw any conclusions regarding the degree of suffering experienced by foxes poisoned with 1080.

ANZFAS is opposed to the use of 1080, particularly for carnivores and omnivores, preferring that cyanide be used if research finds it to be suitable. However, there is a strong view that 1080 is the most suitable poison presently available for widespread fox management. It is relatively target-specific with foxes being highly susceptible to the poison. It is especially useful in Western Australia and other regions where native fauna are relatively tolerant to it due to the natural occurrence of 1080 in the environment. Studies have also shown that it rapidly degrades in water and soil. It also shows no significant, long-term accumulation in body tissues (Eason 1992).

Strychnine

Strychnine is an indole alkaloid derived from the seeds of the South-East Asian plant *Strychnos nux vomica*. The LD_{50} for strychnine in tested species varies from 0.5–3 milligrams per kilogram, with members of the Canidae family being among the more susceptible species. Strychnine acts upon the central nervous system and essentially prevents normal functioning of muscle tissue. The earliest signs of poisoning are nervousness, tenseness and progressively developing stiffness. Violent tetanic spasms may occur spontaneously or be initiated by various stimuli such as touch, sound or sudden bright light. The animal finds it impossible to stand, and falls rigidly to its side with legs stiff and outstretched, neck and back arched, ears erect and the lips pulled back from the teeth. Initially the spasms are intermittent, but they soon become more frequent. Spasms become continuous and death results from spasms of the diaphragm and asphyxia, usually within an hour of the start of clinical signs (Seawright 1989). In July 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 inhibits oxidative enzyme systems and causes death from anoxia. Acute cyanide intoxication is characterised by rapid, deep breathing; irregular, weak pulse; salivation; muscular twitching and spasms; staggering gait; coma; and death (Seawright 1989). The cyanides are particularly rapid in their action and death usually occurs from a few minutes to an hour after the onset of clinical signs. The clinical course will occupy only a few minutes in the most acute cases (Jubb et al. 1985). Even with subacute doses, the course of intoxication rarely exceeds 45 minutes and most animals that live for two hours after the onset of signs will recover.

Cyanide has been used experimentally in Australia for fox control and has the advantage of producing rapid death so that fox carcasses can be retrieved for inspection. Either potassium or sodium cyanide can be used and the chemical is normally encapsulated in wax to prevent premature decomposition in baits (Section 7.5.2).

Because of its rapid action cyanide can be considered as a humane poison. Its use for routine fox baiting requires further investigation, particularly in the methods of presentation and the likely impact on non-target fauna. Because cyanide salts decompose rapidly in the presence of moisture to produce hydrogen cyanide, there are problems of user safety which will require careful investigation.

5.4 Implications of fox harvesting for damage control

Despite a considerable harvest rate in some years, there is no evidence that this rate of removal had a significant impact upon the level of damage caused by foxes. This contrasts with the view of many landholders and hunters that since the decline in fox pelt prices, the density of foxes has risen sharply as has the damage they cause. The perception of increased risk of fox damage since the decline in pelt prices is supported by the figures for the amount of 1080 poison used for fox control in some areas. As an example, Figure 12 shows the dramatic increase in use of fox baits in New South Wales during the second half of the last decade (J. Thompson, Department of Lands, Queensland, pers. comm. 1994). However, this might also reflect, in part, an increase in livestock commodity prices, an increase in the numbers of livestock vulnerable to attack, and changes to regulations governing the use of fox baits (Thompson et al. 1991). The recent concerns about fox predation on wildlife (Section 3.1) may also have contributed.

There was no decline in the high take of foxes in the mid-1980s as might have been expected if the harvest was having a significant impact on fox density (Table 5).

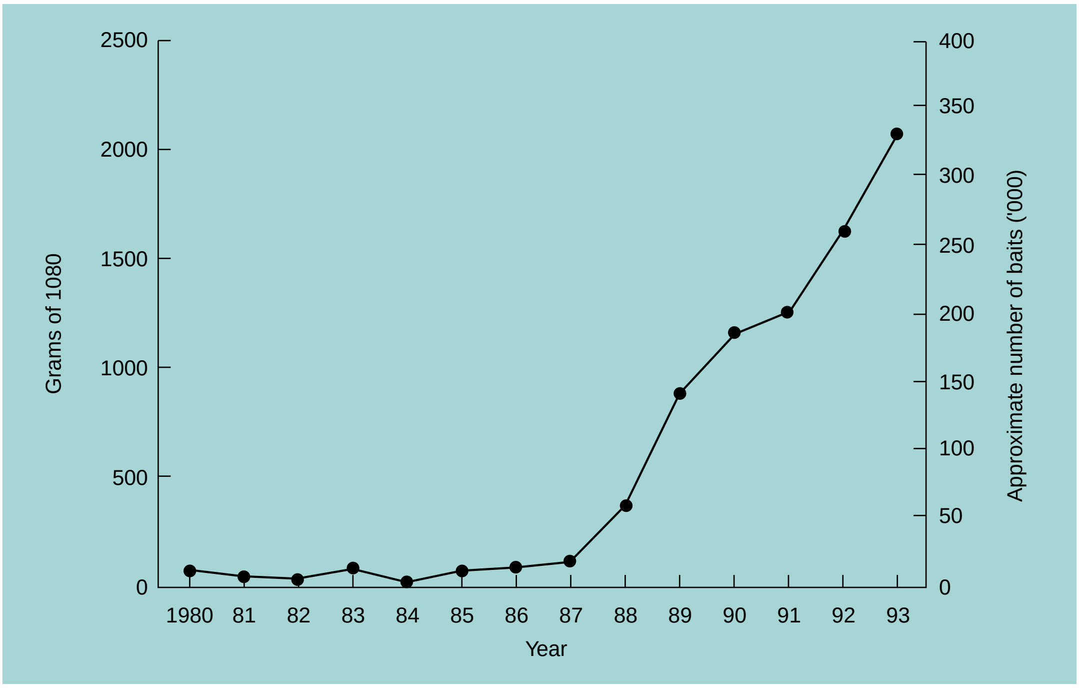


Figure 12: The quantity of 1080 and the number of baits used for fox control in New South Wales between 1980 and 1993 (updated from Thompson et al. 1991).

However, it is not clear whether the harvesting during this time represented a constant catch-effort each year or whether the areas of land hunted for foxes varied from year to year.

At best, commercial harvesting provides only sporadic relief from fox damage since the level of hunting activity reflects the highly variable return from pelt sales.

6. Past and current management

Summary

Historically, management of fox damage in Australia has relied on the payment of bounties, coupled with a range of control techniques including shooting, poisoning and trapping. The fox is widely regarded as an agricultural pest although less emphasis is placed on its management compared with other pests such as the rabbit and feral pig. In most states and territories, legislative provisions require the control of foxes by landholders; these are rarely if ever enforced.

Although there is a growing awareness by conservation authorities of the environmental impact of foxes, without the active participation of the agricultural community, effective fox management over large areas will not be possible. At present, most fox control programs are either initiated to protect enterprises at critical times of the year such as at lambing, or to enhance survival of native species through reduced fox predation rates. Government agencies mostly recommend the use of poisons (strychnine or 1080) to reduce fox populations with other options including shooting, trapping, fumigation or adjustments to farming practices. Coordinated management programs involving several properties, and where applicable a range of land uses, is uncommon despite receiving a higher profile in recent times. No systematic evaluation of these programs or of individual control operations has been undertaken except in Western Australia.

6.1 History

Historically, a range of management techniques has been used to try and manage fox damage. These include hunting; shooting; poisoning with strychnine, cyanide and 1080; and fox drives. These techniques are outlined in Chapter 7. During the 1980s, foxes were extensively hunted for their pelts, but as discussed in Section 3.3, evidence suggests that this was merely a harvest and did little to reduce overall fox density. However in its defence, many landholders believe that there has been an increase in fox damage associated with the decline of the commercial fox take. There is no quantifiable assessment of the extent of damage.

6.1.1 Bounty systems

The payment of a bounty or bonus upon presenting proof of the destruction of a pest animal has been frequently used against foxes (Rolls 1969; Lloyd 1980; Whitehouse 1977). Bounties were first offered in 1893, some 20 years after foxes were first introduced to Australia (Rolls 1969). In Western Australia, bounties were paid during 1928–56 (Gooding 1955). Figure 13 presents the data from the scheme as a plot of the number of fox scalps submitted for payment against time (years). From the upward trend in the number of scalps it can be implied that the bounty scheme had little impact on fox numbers. Indeed, conventional bounty systems have been shown to be an ineffective form of predator control. The reasons for this are numerous (Smith 1990) and include fraudulent practices, failure to provide long-term relief from pest impact, high costs, and selective removal of surplus animals. Often bounty hunters target the area where pests are in greatest density and most easily caught. This is usually not the area where control is most needed (Whitehouse 1977).

'Bounties have been ineffective for controlling foxes.'

Fairley (1968 quoted in Whitehouse 1977) comprehensively reviewed bounties as a means for managing foxes in Northern Ireland. He concluded that bounties were ineffective. Many of the foxes killed by people would have died of natural causes. Animals taken under bounty schemes are usually the young inexperienced animals which are yet to breed. For example, half the dingoes caught are less than one year

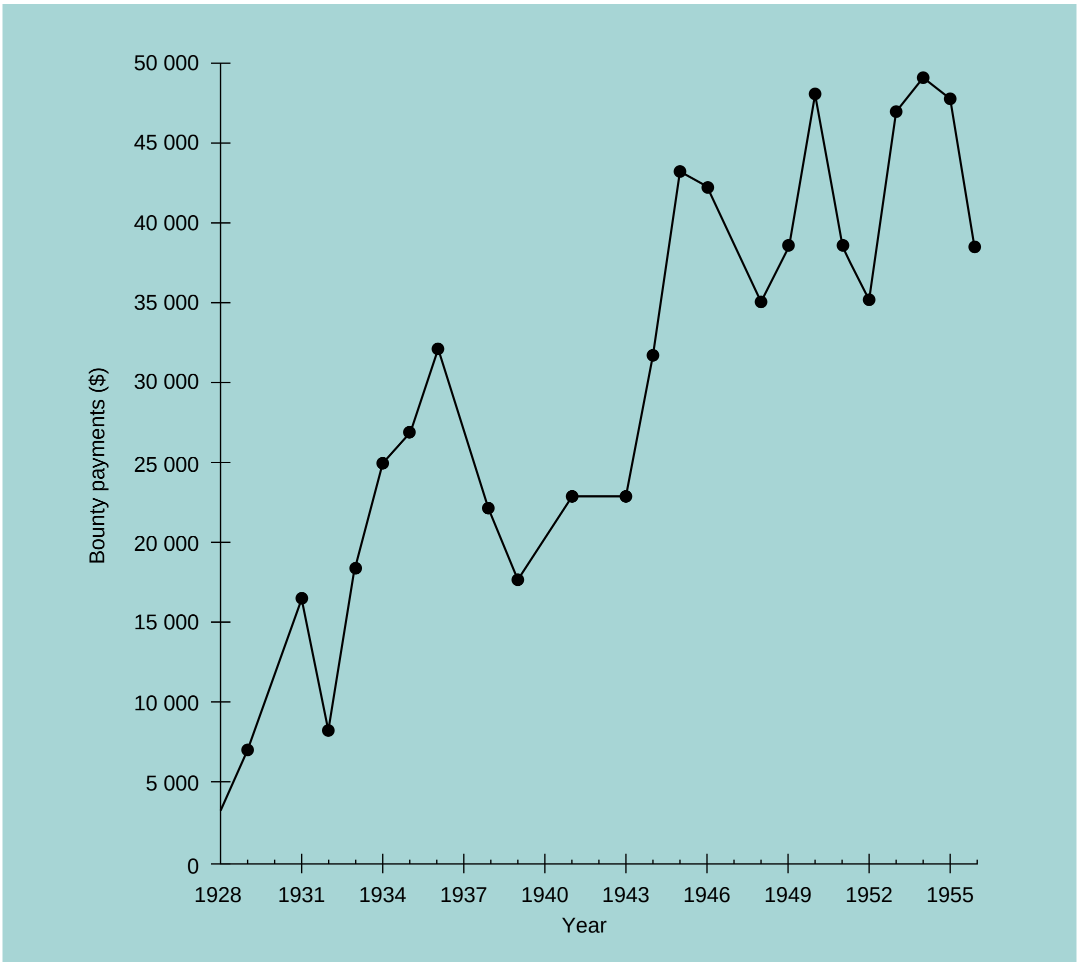


Figure 13: Bounty payments in Western Australia. The upward trend in payments demonstrates that bounties are not an effective method of fox control. If the system were effective a decline in payments would be evident (modified from Gooding 1955).

old and 78% less than two years old (Whitehouse 1977). Just because large numbers of pests are killed does not mean that the pest population declines.

6.2 Legislation and coordination of management programs

Although the fox is regarded as a pest species in all states and territories, there is less emphasis placed on its management compared to some other vertebrate pests such as the rabbit and feral pig. This may in part be due to the perception that foxes have little impact on agricultural production; a usual prerequisite of an enforceable and widespread management policy. There is a growing awareness by conservation authorities of the environmental impact of foxes, and Western Australia in particular has made a significant investment in fox control to protect threatened mammals in several key areas. Other states are investigating similar action. For example, South Australia is studying the effectiveness of fox management to protect yellow-footed rock-wallabies in the North Flinders Ranges.

The value of fox pelts until recent times was also sufficiently high that commercial harvesting was seen as a cost-effective management strategy which in many areas absolved the largest group of affected landholders, the lamb producers, from the need to undertake their own control. Although there are legislative provisions in most states and territories to require the management of foxes by landholders, these are rarely if ever enforced. Despite this, government agencies actively encourage fox management through advisory, training and research services. In practice, fox management is mostly reactionary either to protect enterprises at critical times of the year such as lambing or kidding, or to enhance the survival of native species through reduced predation rates. At the time of writing, the only systematic evaluation of the effectiveness of fox management has been in Western Australia.

'Fox control is the responsibility of the landholder — whether private or government.'

The following is a summary of the present legislative status and management policy for the fox throughout Australia. This includes prescribed methods of control which in most cases involves the use of poisons. Because of their toxicity and potential for misuse both to the detriment of humans and non-target fauna, the use of poisons is normally regulated under state and territory legislation. In all states and territories, landholders and government agencies also have the option of using other management techniques such as shooting, trapping, exclusion fencing, fumigation, or adjustments to farming practices. While most state authorities issue advisory notes on these techniques, their use is governed by other less specific legislation such as firearm or animal welfare acts.

'Because of their toxicity and potential for misuse, the use of poisons is regulated by legislation.'

6.2.1 Commonwealth Government (Australian Nature Conservation Agency)

The Commonwealth Government is involved in the management of feral animals directly through its responsibilities as a manager of Commonwealth lands, and indirectly through its responsibilities under the *Endangered Species Protection Act 1992*. Under this Act, administered by the Australian Nature Conservation Agency (ANCA), foxes have been listed as a key threatening process. Accordingly, there is a responsibility to prepare a Threat Abatement Plan for the impact of foxes on endangered or vulnerable species, and to ensure its implementation within areas of Commonwealth responsibility.

6.2.2 Northern Territory (Conservation Commission of the Northern Territory)

The fox is classed as a pest under the *Territory Parks and Wildlife Conservation Act 1988*. Unless a pest control area is declared for the fox, there is no obligation on a landholder to take action. At present, foxes are only managed in areas where endangered species release programs are being conducted. In most of these cases, conventional 1080 baiting is used (Section 7.5.2). There is virtually no direct landholder involvement in fox control although some foxes are poisoned as a result of dingo baiting operations.

6.2.3 Western Australia (Agriculture Protection Board)

The fox is a declared animal under the *Agriculture and Related Resources Protection Act 1976*. They can only be imported or kept under high-security conditions, and their numbers in the wild are required to be controlled. The Agriculture Protection Board (APB) provides advice to landholders for fox control in response to requests and will help coordinate district campaigns and supply baits. Despite the fox being a declared animal under legislation, a management policy is not actively enforced.

Baits made from beef crackle and containing either 1080 or strychnine may be purchased from the APB by landholders for use in fox control. Alternatively, manufactured dried meat baits containing 1080 can be purchased with the authority of the APB, or landholders can make their own baits with strychnine tablets or powder. For coordinated campaigns, APB District Officers will inject fresh meat baits with 1080 or insert a one-shot oat into a bait. Regulations specify provisions relating to the manufacture, handling, storage, transport and authority for the use of 1080. Landholders are required to notify the occupier of every adjacent property of the intention to lay baits and the period and location of baiting prior to laying the baits. Recommendations govern the use of these baits on private land and include erection of signs, distance restrictions for the laying of baits (such as in relation to urban areas or water storages), and tethering or burying of baits. Other recommended management techniques are exclusion fencing, modification to animal husbandry such as shed lambing of valuable stock, trapping (steel-jaw and snare), fumigation and den destruction, and shooting.

The APB encourages and assists groups of neighbouring landholders to participate in coordinated management campaigns. They also undertake a limited amount of contract poisoning on behalf of landholders. A more recent development has seen district groups of landholders organising fox shooting drives. The Western Australian Department of Conservation and Land Management carries out fox control programs on selected areas of land under its management. To date this work has been primarily for research purposes, targeting specific areas and fauna species known or thought to be at risk from fox predation. The 1080 meat baits used are manufactured and supplied by the APB. Results from research have recently led to the production of operational guidelines for fox control. The guidelines detail recommended procedures for identifying the need for fox control and planning, preparation and implementation of 1080 baiting programs. In 1990–91, 56 000 baits were supplied for this purpose. From very crude estimates, the cost to APB of field involvement with foxes in 1991–92 was approximately $250000 (M. Sexton, APB, WA, pers. comm. 1992).

6.2.4 Australian Capital Territory (ACT Parks and Conservation Service)

Foxes are an unprotected animal under the *Nature Conservation Act 1980*. Foxes can be taken or killed without a permit. However, a permit is required to keep, sell, import or export foxes. Routine fox management is conducted within Tidbinbilla Nature Reserve to protect captive populations of waterbirds and small macropods. Fox control on agricultural land is undertaken by the landholder, primarily by shooting although more recently Foxoff baits have been used.

6.2.5 Queensland (Department of Lands, Land Protection Branch)

The fox is a declared animal under the *Rural Lands Protection Act 1985,* and as such it is the duty of owners and occupiers of land to destroy it. However, the legislation is not enforced for foxes. Department of Lands field officers provide advice and formal direction for the control of foxes throughout Queensland. They also issue 1080 baits for fox control. Authorised control officers may use strychnine baits to control foxes, but these baits cannot be issued to landholders. The use of strychnine is discouraged in favour of 1080. Meat baits are generally used. Landholders can purchase strychnine from pharmacists following the issue of a permit from the Health Department. Use of 1080 baits is regulated on private lands and the user must abide by conditions of use relating to notifying neighbours, distance restrictions and erection of signs.

It is illegal to introduce, keep or sell foxes except where permits are issued for scientific or educational purposes. The fox is recognised as a threat to agriculture and management programs operate throughout the state, particularly in coastal or sheep producing areas. In national parks bordering the Queensland coast, foxes are believed to have a significant impact on coastal nesting turtles, and annual control campaigns are conducted. Some fox control may be carried out as part of wild dog control, particularly in the southern part of the state.

Foxes are recognised as an increasing problem in urban areas and a significant effort has been made to publicise the detrimental impact of the species on domestic and native animals. In addition to poisoning, trapping (using cage traps in urban areas) and shooting are also recommended as control techniques. Coordinated management campaigns are not common and fox control is usually in response to individual requests for assistance.

6.2.6 Victoria (Department of Conservation and Natural Resources)

Foxes are declared vermin under the *Catchment and Land Protection Act 1994*, which establishes responsibility for their control with owners and occupiers of land. Despite this, no notice has ever been issued compelling a landholder to control foxes. Under the Act it is also an offence for any person or institution to keep live foxes in Victoria without a permit.

Where foxes are identified as being a problem, the Department of Conservation and Natural Resources (DCNR) will issue 1080 meat baits, preferably the manufactured Foxoff bait or alternatively cooked liver or similar. These must be used in accordance with established regulations including use of prescribed baits, burying the bait, distance restrictions for the laying of baits such as in relation to urban areas or water storages, notification of neighbours, and erection of signs. Other approved control techniques are trapping (cage or treadle snare) and shooting. In the past, there was no coordination of fox management on private lands. However, this is changing in conjunction with the development of mass produced, long shelf-life 1080 baits. DCNR is about to implement a series of coordinated control campaigns using these baits. These will be supported by advice on how best to undertake fox management. Main emphasis is placed on the integration of control techniques into a preventative management program before the fox becomes a problem. For the year 1991–92, DCNR allocated approximately $450 000 for fox control on public land (R. Waters, DCNR, Victoria, pers. comm. 1992).

Recently DCNR initiated ‘Foxlotto’ which is open to farmers, professional shooters and shooting clubs. This scheme is a variation of the bounty system. Upon presenting a fox scalp or entire pelt, shooters receive a lottery ticket and enter a draw for a range of monthly and annual prizes. In 1992, over 15 000 scalps were presented under this scheme, a quantity which appears relatively small compared to the 35 000 pelts taken from Victoria in 1986 (30% of the 110000 total for Australia). Nevertheless, this scheme has potential to develop awareness about fox damage and what can be done to alleviate it.

On public land, coordinated management campaigns are carried out to protect a variety of indigenous species from fox predation. These include little terns (Bairnsdale), penguins (Phillip Island and Port Campbell), eastern barred bandicoots (Hamilton and Gellibrand Hill) and lyrebirds (Sherbrooke). Fox predation on native wildlife is listed as a potentially threatening process under the provisions of the *Flora and Fauna Guarantee Act 1988*. This requires the development of an Action Plan which sets out effective management techniques to prevent or overcome damage due to this threatening process.

6.2.7 South Australia (Animal and Plant Control Commission)

The fox is a proclaimed animal under class 5a of the *Animal and Plant Control Act 1986*. The Act prohibits the keeping, movement, sale and release of foxes. Other provisions require a landholder to control foxes, although this provision is not presently enforced.

The Animal and Plant Control Commission (APCC) is required to develop, implement and advise on coordinated programs for the control of proclaimed animals. The fox is recognised as a threat to both agriculture and native wildlife, but until recently was given low priority in comparison to other pest animals.

Prior to 1993, strychnine was the only poison available for baiting foxes in South Australia but has since been phased out in favour of 1080. The number of approvals given to landholders for the purchase of strychnine to control foxes and the associated number of baits prepared by them between 1985 and 1991 are presented in Table 6. The estimated yearly expenditure on fox control with strychnine by landholders and government agencies in 1992 was $250 000 (M. Williams, APCC, SA, pers. comm. 1992).

The amount of fox baiting carried out in South Australia has increased dramatically since the introduction of 1080. This is undoubtedly due in part to perceptions that foxes may be having a more important effect on domestic stock and wildlife than previously recognised, but is also a result of a greater emphasis on a group approach to fox baiting. Group participation through existing networks such as Landcare has encouraged many landholders to take part in large baiting campaigns. Bait materials commonly used include injected meat, liver, fish, fowl heads and eggs, and Foxoff manufactured baits.

Table 6: Number of 35 milligram strychnine baits prepared for fox control in South Australia in 1984–85 to 1990–91.

Year	Number of Baits (35 mg / bait)
1984–85	23 771
1985–86	91 629
1986–87	79 400
1987–88	185 829
1988–89	88 286
1989–90	90 486
1990–91	43 857

6.2.8 New South Wales (NSW Agriculture)

The fox is not a declared noxious animal under the *Rural Lands Protection Act 1989* having been deleted from the list in 1977. This was in recognition of the difficulty in enforcing a legislative requirement to control foxes. Under proposed legislation (Non-Indigenous Animals Act), the fox will be placed in category 5 which includes all animals which are recognised as widespread pests. There is no restriction on the keeping, transport or sale of foxes in New South Wales.

Despite this, the fox is considered a significant agricultural and environmental pest. In recognition of this, NSW Agriculture and Rural Lands Protection Boards actively participate in services aimed at assisting landholders and other government agencies to control fox populations. Coordinated fox control programs are encouraged, principally to better regulate the use of toxic baits and to reduce the threat to non-target animals. Because of this concern, there have been recent amendments to the *National Parks and Wildlife Act 1974*, which requires a Fauna Impact Statement to resolve conflicts between pest animal control programs and the potential impact of these on endangered fauna (Korn et al. 1992).

Rural Lands Protection Boards issue 1080 baits consisting of either manufactured baits, fowl heads, and 100 gram pieces of fresh meat or offal for fox control. Recently there has been a consistent increase in the amount of 1080 used for fox control in New South Wales, rising from 57 grams in 1980 to 2000 grams in 1993. This is equivalent to an increase in the number of baits from approximately 2050 to 330 000 (Figure 12).

Use of 1080 baits is regulated and users are required to abide by certain requirements including distance restrictions in relation to human habitation, notification to the public about use of poison, and erection of signs. No other poison is registered for fox control although there is believed to be significant illegal use of various lethal chemicals such as phosdrin. The only other recommended control techniques are exclusion fencing, flock management and shooting.

6.2.9 Tasmania (Department of Environment and Land Management and Department of Primary Industry and Fisheries)

The fox is a prescribed creature under the *National Parks and Wildlife Act 1970* and vermin under the *Vermin Destruction Act 1950*. Under these Acts it is an offence to bring a fox into the state, keep one in captivity or allow one to go at large in the state. Also the Vermin Destruction Act requires land occupiers to suppress and destroy vermin. All reported sightings are investigated by the Parks and Wildlife Service and/or Department of Primary Industry and Fisheries, initially by interview, and then if justified by field surveys. The last fox known to have been killed in the wild was a young vixen in 1973 which was of unknown origin.

7. Techniques to measure and control fox impact and abundance

Summary

Damage and abundance *— A large range of native fauna are susceptible to fox predation. Fox gut analysis provides an indication of species at potential risk, but not the extent of predation pressure. Survey techniques to identify the distribution and abundance of vulnerable species before and after fox removal is the most reliable method for land managers to assess damage. It is important to be aware that factors other than fox predation may affect prey abundance. Techniques for monitoring prey density include pitfall and small mammal traps, spotlight and animal track counts.*

The major agricultural damage due to foxes is lamb loss. However many other factors cause lamb loss including difficult birth, poor mothering, cold exposure and predation by other pests such as feral pigs. A guide is presented to help to distinguish between the various factors causing lamb loss.

The primary aim of fox management is to protect native fauna or increase lamb production. The success of fox management should be guided by direct measure of these parameters. Sometimes, such as for scientific research, fox density needs to be estimated. Techniques include breeding den counts in early summer, scent stations, track and spotlight counts.

Maps, from simple hand-drawn charts, to sophisticated geographic information systems, are useful for recording the distribution and relative density of foxes and vulnerable prey in an area, and for planning control.

Control techniques *— Techniques include trapping, shooting, poisoning, den fumigation, exclusion fencing and changed farming practices. Poisoning using 1080 is the most suitable lethal technique. It can be made target-specific to foxes through choice of bait, strict control of 1080 content and bait placement, for example by burying it. In Western Australia, dried 1080 meat baits have been shown to be very effective for fox control and are likely to be in other parts of Australia. However before they are extensively used elsewhere, the applicability, especially in relation to non-target kills, needs to be assessed.*

Research to develop an effective biocontrol agent to manage foxes offers some promise. However, it is breaking new ground and has to address difficult scientific, technical and biological problems. Consequently, the research must be considered high-risk and long-term.

7.1 Introduction

'The aim of fox management should be to reduce to an acceptable level the agricultural and environmental damage foxes cause.'

Techniques are described in this chapter for assessing fox impact as well as for planning, implementing and then monitoring the effectiveness of management programs. Details are provided separately for environmental and agricultural situations where differences in objectives and procedures exist. Many of the techniques described in this chapter have been developed and tested only in Western Australia where considerable efforts have been placed on fox control in recent years. In some cases this will result in strategies which are geographically specific, and this needs to be taken into account until similar work is conducted in other parts of Australia. Land managers should carefully assess the applicability of Western Australian techniques to other areas.

The principal objective of fox management, where the need for control is identified, is to remove or reduce to an acceptable level the damage foxes cause to production and conservation values.

7

7.2 Assessing impact

7.2.1 Introduction

Effective fox management requires the extent of fox damage to be quantified either as lost agricultural production, or for conservation, the degree to which the population of native animals is suppressed. For some pest species such as the feral pig, where the relationship between pest density and damage is known for some forms of damage, indicators of abundance can be a useful correlate of impact. This correlation is not known for foxes. In addition there is no simple, reliable technique for estimating fox density for a range of habitat types and prey density. Consequently, this makes changes in population parameters of the potential prey species in response to predator control the only reliable method for estimating the extent of fox damage.

'Accurate assessment of fox damage allows management strategies to be targeted more effectively.'

7.2.2 Environmental impact assessment

In Section 3.1 it is concluded that foxes are major pests of wildlife over much of Australia. However, the extent of this impact has not been widely quantified. The few studies which exist are from restricted geographic regions and with only a few native species. Unfortunately, it may take many years to accurately quantify the extent of fox damage to wildlife in which time more species may be driven towards extinction. In the absence of any clear evidence, the land manager must assume adverse impact where foxes are known to interact with populations of significant or endangered native species, including a range of small to medium-sized animals such as ground-nesting birds, dasyurids, bandicoots, possums, smaller wallabies and rodents (Appendix A).

Initially, an indication of fox predation can be identified by direct observation of fox and prey interactions or by indirect surveys of fox food habits such as scat or stomach content analysis. These, however, are not always an accurate indication of predation pressure on threatened species. More important would be to monitor the distribution and abundance of native species using established survey techniques suitable to Australian conditions. Cooperrider et al. (1986) provides details of a wide range of techniques. Other techniques include those relating to soil plots and small mammal trapping (Newsome and Catling 1979), bird counts (Braithwaite et al. 1989), and in Environmental Impact Statements prepared by CSIRO Division of Wildlife and Ecology (for example Shodde et al. 1992), although the latter, while excellent information, are not readily available.

'Diet studies do not necessarily reflect the impact of foxes on prey populations.'

Survey techniques suited to different faunal groups are as follows:

- Amphibians and reptiles
  - timed, random or set transect counts (species can be identified by sight or call)
  - terrestrial pitfall or aquatic cage traps
- Mammals
  - grid trapping with spring-set box traps or pitfall traps (small mammals)
  - wire cage traps (medium size mammals)
  - track counts on raked plots (medium to large mammals)
  - set transect surveys, either walked, or covered by vehicle or helicopter; using spotlights or nightscopes at night (large mammals and arboreal mammals)
- Birds
  - mist nets
  - set transect surveys (species identified by sight or call)
  - spotlight counts (nocturnal species)

If native animal populations are declining or restricted to marginal habitats, based on real or assumed prior information, all factors which might be responsible need to be considered. Causes other than fox predation might include habitat fragmentation and degradation, changes to fire regime, competition with introduced species, disease or hunting. While this information is being gathered, an indication of the extent of fox impact may be gained through changes in the distribution and abundance of prey species following the removal of foxes. Preliminary information may be obtained by pilot control studies, with suitable controls, which monitor the responses of selected prey species. The results of such pilot studies would provide an indication as to whether fox control is a valid management strategy for the threatened species.

7.2.3 Agricultural impact assessment

Introduction

The major agricultural impact due to foxes is predation of lambs (Section 3.2.1). Because the fox hunts mostly at night, direct observations of them killing lambs are rare. There are also a number of other predators which can be involved, including dingoes, wild dogs and feral pigs. Before commencing a fox management program, it is necessary to establish that the fox is implicated and is causing significant economic losses.

'The major agricultural impact of foxes is predation on newborn lambs.'

Lamb losses attributable to predation by foxes

To determine the extent of fox predation on lambs, it is necessary in the first instance to determine the principal causes of lamb loss. The following constraints on lamb survival can be identified (Alexander 1984):

- dystocia or difficult birth which is related to birth weight and pelvic size of the ewe. Lambs lost to this cause generally show evidence of haemorrhage in the central nervous system;
- cold exposure which becomes apparent when large numbers of lambs die coincident with periods of adverse weather;
- starvation/mismothering due to factors such as failure of the ewe to bond with her lambs, accidental separations after bonding, udder defects and competition with litter mates. These can only be assessed by direct observation;
- extremely high or low birth weights which predispose lambs to death from birth injury, cold exposure or starvation; and
- predation based on circumstantial evidence such as unexplained low lamb marking, presence of predators and carcasses showing mutilation.

A decision tree can be used to determine the causes of lamb deaths (Figure 14a). If predation is suspected of being the major factor, and various potential predators are present, the impact of each species needs to be determined. The following signs are useful (Figure 14b; Rowley 1970; Anon 1991):

- *Was the lamb alive when attacked?* Attacks on live animals result in bleeding at the wound site, with subsequent clotting forming dark haemorrhagic areas. Dead animals do not bleed. A lamb born alive shows a distinct blood clot at the exposed end of the umbilical artery and a lamb born dead shows no clot. Whether the lamb had walked or not is indicated by whether hoof cover is worn on the soles of the feet (Figure 14b **[5]**);
- *If alive, was the lamb sick or healthy?* Examination of the lungs will show a clear difference between successful breathing, light pink and healthy; compared to lungs which have not been properly aerated being dark and liverish in colour (Figure 14b **[4]**). Lambs are born with protective, soft membranes covering the sole of the hooves (Figure 14b **[5]**). These are rapidly lost when they begin to walk. In normal lambs the fat around the heart and kidneys is firm, white and lacking in obvious blood vessels. When a lamb fails to feed these fat reserves become soft, gelatinous and dark plum red in colour.

(a) Decision tree

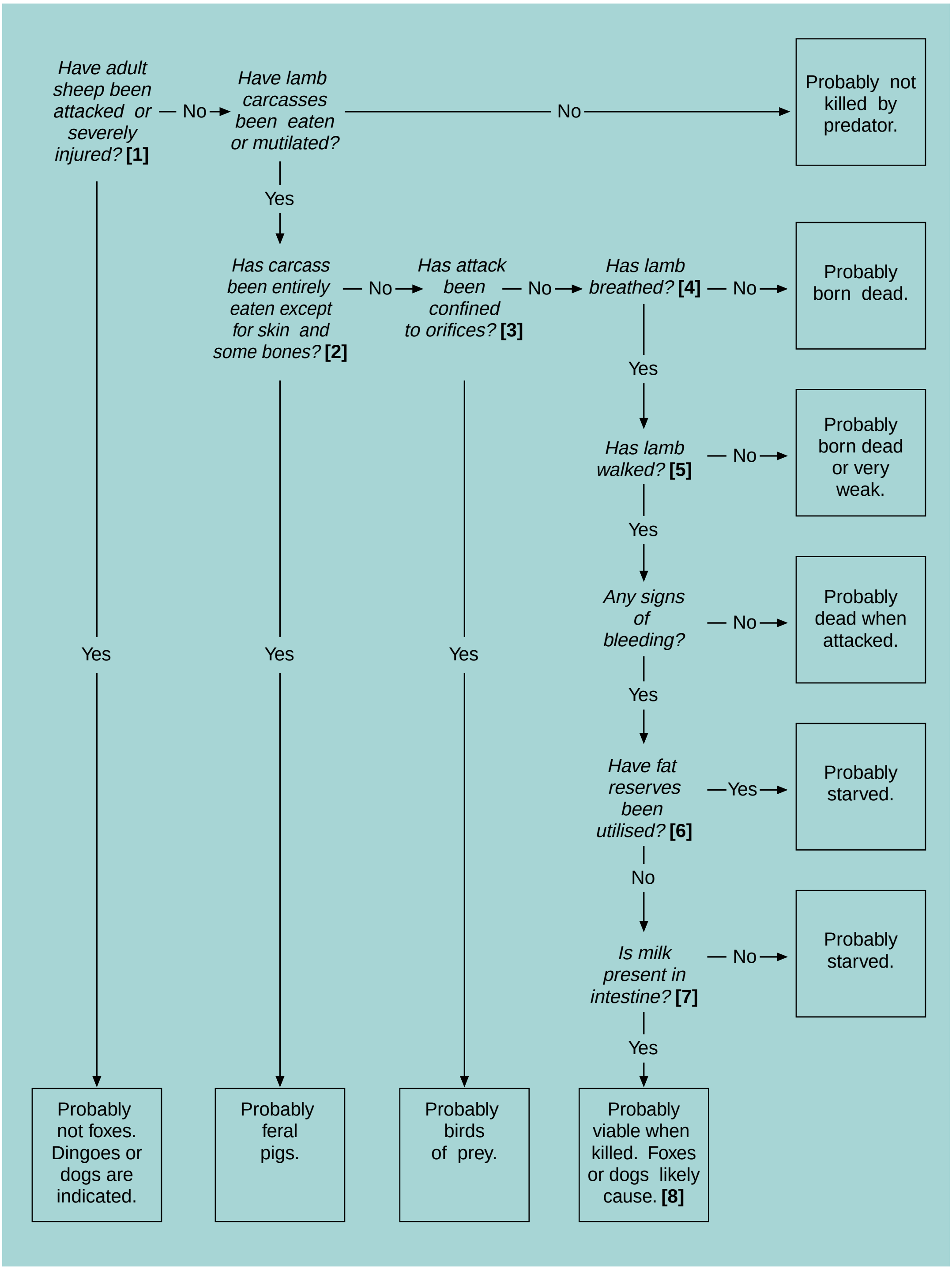


Figure 14: (a) Decision tree for determining the cause of lamb death (after Agriculture Protection Board, Western Australia 1990); **(b) Observable indicators** which can be used to help determine the cause of lamb death.

(b) Observable indicators

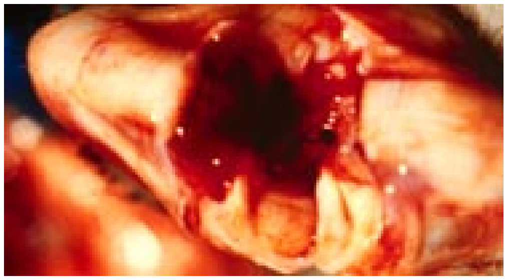
[1] *Severe neck wounds on adult sheep indicating dingo or wild dog attack.*
Source: NSW Agriculture

[2] *Extensive mutilation and consumption of lamb carcass indicating the possibility of feral pig predation.* *Source: Queensland RLPB*

[3] *Lamb with eye picked out by birds post–mortem.* *Source: J. Plant, NSW Agriculture*

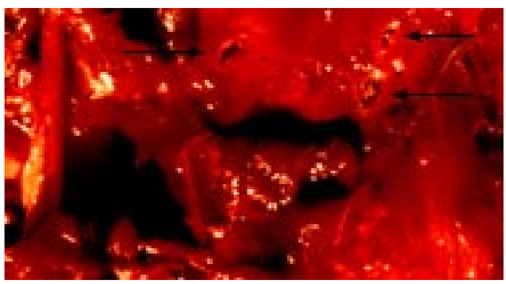
[4] *Unexpanded, heavy, dark-red lung of a still-born lamb.*
Source: J. Plant, NSW Agriculture

[5] *Foot of a still-born lamb with intact sole membrane (left) and foot from lamb that has walked (right).* *Source: J. Plant, NSW Agriculture*



[6] *Stifle (knee) joint showing breakdown of body fat (i.e. lamb has starved).*
Source: J. Plant, NSW Agriculture

[7] *Milk in small intestine of lamb that has suckled (right); empty intestine of still-born or weak lamb (left).* *Source: J. Plant, NSW Agriculture*



[8] *Fine puncture marks in skin indicating possible fox predation.*
Source: J. Plant, NSW Agriculture

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Similarly, successful feeding is demonstrated by milk in the stomach and gut (Figure 14b **[7]**); and

- *What species of animal was responsible for the predation?* Wounding by mammals involves biting often with matching punctures on opposite sides of the limb or trunk. The carcass is usually moved from the site of death. Feeding by birds of prey is characteristically on the upper side only, at the site where the lamb died and usually involves attacks to the eyes, mouth, navel, nose and anus (Figure 14b **[3]**). Attacks by foxes (and dogs) are often characterised by a large number of lambs killed or mutilated in the one night. When this occurs the majority of carcasses are usually left in the paddock. Depending on what part of the body is first attacked, typically the neck area is crushed with evidence of canine puncture marks on the inside of the lamb skin or the muzzle of the lamb is mutilated or bitten off. Puncture marks can be used to differentiate wild dog or dingo attacks from fox as the latter has a very slender jaw (Figure 14b **[8]**). The distance separating the canine teeth on foxes (25–32 mm) is considerably less than in most dogs (Lloyd 1980). Although the haemorrhage resulting from a broken neck will be obvious in post-mortem examination, the lesions resulting from bites in other areas of the body may not show externally or internally by ventral inspection. For confirmation of fox or dog predation the carcass needs to be fully skinned.

Assessing the extent of fox predation

As indicated above, diagnosis of fox predation is possible by examination of carcasses. In some situations where foxes are active in lambing paddocks few carcasses can be found despite significant predation (Lugton 1987). It is difficult to accurately determine the full extent of fox predation. Ultrasound foetal counts to establish the maximum reproductive potential of the flock combined with an assessment of all causes of lamb loss including disease and mismothering is necessary. This would be beyond the resources and expertise of most land managers, making it difficult to decide whether or not it is economically justified to undertake fox management.

A rigorously designed experimental assessment of the full impact of the fox on agricultural production is necessary. It should include the costs and benefits of fox control (Section 10.2.1).

Land managers must make their own best assessment of lamb predation by foxes based on examination of carcasses and consideration of all causes of lamb loss. Comparison of production figures with similar areas where there is no known predation may also provide a guide, although the influence of other factors such as weather and ram fertility also need to be taken into account.

As is the case for threatened native fauna (Section 7.2.2), it may be feasible to conduct pilot studies to test the impact of foxes on livestock by appropriately designed regional experiments. Fox control and non-treatment sites would be necessary, and the resultant lambing success would need to be measured.

7.3 Measuring fox abundance

7.3.1 Introduction

Abundance can be measured in three ways: as the number of animals in a population, as the number of animals per unit of area (absolute density), and as the density of one population relative to that of another (relative density) (Caughley 1977). For an elusive animal such as the red fox, population size or absolute estimates of abundance are difficult to obtain and usually inaccurate. In most situations, estimates of relative abundance will be sufficient for an initial census of the fox population and to then evaluate the success or otherwise of management programs. Numerous census techniques are available, the most useful being discussed below. Technique selection depends on the habitat and available resources. Cyclical changes in fox densities associated with prey abundance or disease can further complicate estimates of fox density (Lindstrom 1980; Macdonald 1980). In instances where foxes were previously thought to be absent (for example Tasmania, Kangaroo Island, far north Australia) it may be necessary to confirm sitings through identification of footprints, scats, hair, fox vocalisations etc. (see Triggs 1984; Newton-Fisher et al. 1993; Brunner and Coman 1974; Morrison 1981 for guidance).

'Estimates of fox abundance are difficult to obtain and usually inaccurate.'

7.3.2 Breeding den counts

Breeding den counts is considered to be the only accurate method to determine fox density, provided the size of family groups and social organisation is known (Trewhella et al. 1988). This technique is especially useful in urban areas where householders can help identify the location of all breeding earths (Harris 1981; Page 1981), or in uniform rural habitats by systematic searches (Insley 1977; Pelikan and Vackar 1978; Coman et al. 1991). Dens are most prominent in early summer when cubs become active, trampling the surrounding area and accumulating prey debris and droppings around the entrance (Kolb 1982).

Aerial survey techniques can be employed to identify breeding earths in very open habitats (Sargeant et al. 1975). The disadvantages of this technique are that in most habitats dens are difficult to locate or may be confused with rabbit burrows. Dens are occupied annually for a limited time, making them useful only for measuring changes in the population from one year to the next.

7.3.3 Relative density estimates

Estimates of relative population densities can be obtained by a variety of indirect measures. These include the hunting indicator of population density or HIPD (Wandeler et al. 1974), used commonly in Europe to calculate threshold densities for rabies transmission (Anderson et al. 1981). These estimates have many inbuilt inaccuracies (Zimen 1980), particularly that hunting records are as much dependent on hunting habits and intensity as on fox population density, and may underestimate the fox population by 50–75% (Steck and Wandeler 1980).

Scent stations or track counts use chemical attractants or baits placed regularly at points along established routes of travel (Roughton and Sweeny 1982; Phillips 1982). The presence of fox tracks in a one-metre circle of sifted dirt placed around each scent station is considered as a visit. This process is repeated over three to five consecutive days to calculate an index for the activity of foxes.

To the land manager wishing to gain some initial understanding of fox distribution and abundance and the short-term effect of a management program, the most appropriate technique is spotlight counting. Spotlight counts can be particularly useful in the case of open country (Newsome et al. 1989) where a large area is being considered for fox control. Foxes are counted at night from a vehicle with the aid of a spotlight. For consistency between counts and to gain maximum access to foxes in the management area, fixed length transects should be carefully planned before commencing the survey. All foxes seen within a search distance either side of the vehicle, say 100 metres, are counted. This distance will vary according to sightability in different habitats.

A reliable index of the population size will require a minimum of three counts on consecutive nights. In order to gain a consistent level of precision, and where resources permit, counts should be repeated until they give similar indices. A rule of thumb when determining the number of counts is for the standard error of the counts to be within 10% of the mean. Possible sources of variation between counts should be kept as low as possible. For example, conducted by the same person, from the same vehicle and height, travelling at the same speed and close to the same time each night. Some caution should be attached to spotlight counts as they tend to be biased towards including naive younger animals.

7.3.4 Population manipulation index

Absolute density can be derived from relative density estimates measured before and after a known number of animals are removed from the population (Caughley 1977; Eberhardt 1982). This technique is useful in determining the effectiveness of a management program. The only limitations are:

- the number of foxes killed can be counted, for example, by spotlight shooting or cyanide baiting;
- the indices used before and after will not be affected by the removal technique. For example spotlight counts of foxes after spotlight shooting may be biased because of changes in behaviour of surviving foxes;
- the pre-removal index has a constant relationship to the initial population size as does the post-removal index;
- the period over which animals are removed is short; and
- the changes in indices and the number of animals removed is not small.

7.4 Use of fox impact and density measurements

7.4.1 Introduction

As with any pest species, achievement of management objectives is enhanced with thorough planning (Chapter 8). This is facilitated by the routine recording of impact assessments, mapping of relevant information from the designated area, and allocating action to realistic and prioritised management units.

7.4.2 Recording assessments

Because direct survey of the fox population is difficult, and the relationship between fox density and the level of impact is unknown, assessment of impact is best determined by evaluating the status of prey populations be they native wildlife or lambs. The process of recording assessments is not necessarily an aid to interpretation but rather a way of ensuring that all the relevant information is documented. It is also a way of ensuring that information is recorded in a convenient form for transferring onto maps or computerised databases.

'The relationship between fox density and impact is largely unknown.'

7.4.3 Mapping

Maps can be of various types: simple hand-drawn charts, topographic maps, land system or land unit maps, aerial photographs, or the sophistication of interactive computerised geographic information systems (GISs). The choice depends on resources, scale of the treatment and the extent of the problem.

'Correlations between damage and fox habitat, will help determine where fox management needs to be targeted.'

Assuming that little is known about the distribution and abundance of foxes in the area, maps are important for determining and recording the relationships between variables associated with the distribution of prey species and features which will need to be identified in planning a fox management program. These will include tracks, trails, fence lines, lambing paddocks, refuge habitats for endangered species, property boundaries, natural boundaries, corridors, dens and fox refuges (Figure 15). Correlations between damage and habitat, where they can be identified, will determine where fox management needs to be targeted. A lambing paddock is an obvious example, however conservation problems are less clear. The refuge habitat for an endangered species may not necessarily be its preferred habitat, and the one which will need to be targeted if the species is to thrive. In these situations maps can be used to identify the distribution of both the refuge and preferred habitats, with efforts to remove foxes concentrated in each. Because foxes often depend on rabbits for food, mapping the distribution of warrens may also give some indication of where to concentrate control effort.

Several Landcare groups in Victoria and elsewhere are now involved in the production of customised maps of Landcare districts and individual farms for a variety of land management issues including pest management. In one example, the initial base topographic maps (scale 1:25 000) have been supplied to Landcare groups in digitised form. The groups share a single computer and software package which allows for overlays of information to be added to the maps. The original topographic map is then printed out in sections to correspond with individual farms or cooperatives. Landholders then assist in verifying the maps and adding information such as the location of particular weed problems or main areas of rabbit activity. Although foxes have not yet been included in this inventory, it may be practical to map all known fox breeding dens within the Landcare area. This in turn would allow for a coordinated program of fox den fumigation during the breeding season. Other possibilities include the recording of all fox poisoning trails/sites during a coordinated baiting campaign. Such records depicted on maps quickly indicate any gaps in the coverage of a baiting program.

Computer-based mapping systems also include the facility for a database related to the mapped areas. This then offers the means to keep highly accurate records of control inputs and outcomes as measured by reductions in damage or fox numbers (for example spotlight transect counts). On a broader scale, GISs can be used to determine correlations which might show, for example, where foxes potentially have their greatest impact on endangered species. Where fox impact correlates highly with fox population indices, changes over time in these indices can be used to monitor the progress of control operations.

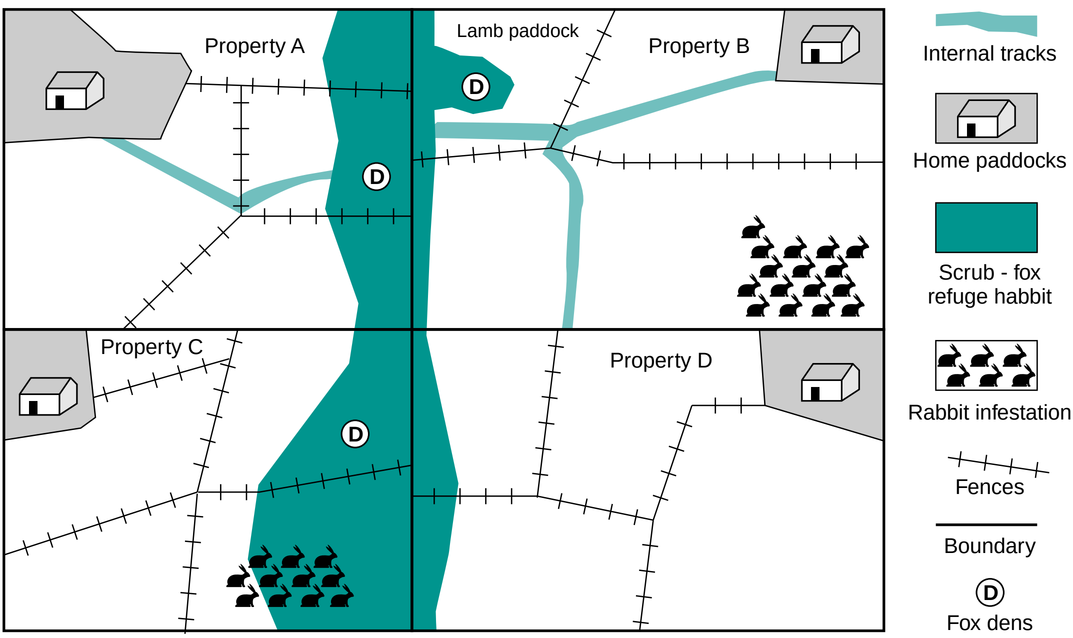

Figure 15: Example of a simple map of four hypothetical properties showing the key factors that landholders should record and use to plan fox management.

7.4.4 Allocating management units

The information collated on maps can be used to identify practical management units. Boundaries in the management unit will be evident from natural or artificial barriers or apparent changes in the distribution of prey species. An important difficulty which must be considered is the mobility of foxes. This can negate efforts to manage fox damage due to neighbouring foxes moving into vacated territories. This will influence the size of the management unit which is in turn influenced by the time-frame of the management program. For example, protecting a lambing paddock for one month will be a much smaller operation than ensuring the long-term survival of an endangered species in a nature reserve.

While the distribution and abundance of foxes in the management area may not be known, the size of management units based on known figures for density and home range for similar areas can be used as a guide (Chapter 2).

'Past fox management programs have generally been non-strategic and uncoordinated.'

In the past, fox management programs, principally poisoning, have mainly been carried out on small management units such as an individual property or nature reserve, with little coordination. As the damage foxes cause to native fauna has become evident, governments have increased inputs into planning and coordination of fox management. In many cases it may be necessary to coordinate management of foxes on surrounding agricultural land, say as a buffer zone. The extent to which this coordination takes place will also influence the size of management units.

7.4.5 Establishing priorities

Priority for treatment of management units will depend on a number of factors including:

- type and value of prey species. For native species it is their conservation status and their representativeness in other areas;
- severity of the damage;
- presence of and damage due to other pests and other threatening processes;
- feasibility of reducing damage in time to save the prey;
- size of the management unit;
- availability of appropriate management techniques;
- availability of funds, time, labour and equipment both for immediate action and for future sustained control;
- the ability to coordinate management effort; and
- the ability to prevent reinvasion by foxes.

7.5 Control techniques

7.5.1 Introduction

A variety of fox control techniques are used in Australia. These include hunting by trapping and shooting, poisoning, den destruction, exclusion by fencing, or changes to farming practices. In the case of agricultural protection, the methods used are mostly determined by the biology of the livestock being protected rather than the biology of the fox. As such, a variety of control techniques are employed on a reactionary basis with little consideration for sustained reduction of their agricultural impact. This may be the result of the lack of sufficient incentive and of cost-effective techniques.

'Fox control techniques used in Australia include trapping, shooting, poisoning, den destruction, fencing and changes to farming practices.'

For wildlife conservation the issue is much clearer. Fox predation is a significant threatening process to some wildlife species which is alleviated by the management of foxes. Apart from fencing and poisoned baits, no other method has been tested and shown to be effective.

7.5.2 Poisoning

General

Poisoning foxes using a variety of toxins and bait types has long been considered to be the most effective method of fox control. Strychnine was historically the recommended poison throughout Australia. Following the introduction of 1080 for rabbit control in the 1950s, its effectiveness against canids was soon realised and it became widely used for fox control from the late 1960s.

The preparation of strychnine baits has usually been the responsibility of landholders often with only general guidance: *'as much strychnine as will thinly cover half an inch on the small blade of a pocket knife is generally accepted as a lethal dose'* (New South Wales Agriculture memo 961). Baits included whole carcasses (although this is not recommended by state agencies), offal, cubes of meat or fat, chicken heads, day-old chicks, butter or dripping. The use of 1080 is much more tightly regulated. Only government or semi-government agencies are allowed to handle the poison and prepare baits.

Warning signs are essential to notify people that fox baits have been laid.

Source: Applied Biotechnologies

'The use of 1080 baits for fox control has risen dramatically in recent years.'

The number of 1080 baits distributed in New South Wales for fox control has risen dramatically from approximately 2000 in 1980 to over 300 000 in 1994 (J. Thompson, Department of Lands, Queensland, pers. comm. 1994.). Thompson et al. (1991) concluded that this increase has been due to a combination of factors including reduced hunting pressure resulting from the then high commodity prices for wool and lambs.

'The use of strychnine for fox control is being phased out in preference to 1080 which is more target-specific and more humane.'

The present requirements for fox poisoning in each state and territory are presented in Table 7. Restrictions on application refer to the laying of baits only, such as requiring them to be buried, and not on requirements such as the display of warning notices. Since the use of strychnine for fox control is being phased out in preference to the more target-specific, and probably more humane 1080, its use is not discussed in detail.

Sodium mono-fluoroacetate (1080)

Sodium mono-fluoroacetate or 1080 is the synthetic sodium salt of the naturally occurring mono-fluoroacetic acid. It is odourless, virtually tasteless and highly soluble in water. It is widely used in Australia for vertebrate pest control. Because of its toxicity and importance to agricultural production and nature conservation, by law

7

1080 powder (usually about 96% pure) can only be obtained by government or semi-government agencies which in turn prepare bait for use by land managers.

Fluoroacetate occurs naturally in a number of Australian plants of the genera *Acacia, Gastrolobium* and *Oxylobium* (Oliver et al. 1977) some species of which extend from south-west Western Australia, up through the Northern Territory and down into the central highlands of Queensland (Everist 1947). This natural occurrence benefits the use of 1080, particularly in Western Australia where some native fauna have evolved tolerance to the toxin relative to the introduced fox which is highly sensitive (King et al. 1981; McIlroy 1986; King and Kinnear 1991). For example, brushtail possums from Western Australia have an LD_{50} of over 100 milligrams per kilogram, whereas possums from near Canberra had an LD_{50} of 0.68 milligrams per kilogram (King 1990).

The implication for south-eastern Australia, where 1080 tolerance has not developed, is that species such as the tiger quoll (*Dasyurus maculatus*) and other carnivorous marsupials, and some rodents and birds may be at risk from fox management programs although this has not been demonstrated experimentally (McIlroy 1992; McIlroy and Gifford 1992; Korn et al. 1992). Despite these differences in tolerance to 1080 within the Australian fauna, this toxin remains the best choice throughout the continent (McIlroy et al. 1986; McIlroy and Gifford 1992). With 1080, there is scope for increasing target-specificity even in areas where the fauna has not evolved tolerance.

Selectivity of poisoning can be enhanced by:

- using baits highly attractive to foxes;
- minimising poison content and maximising bait size to achieve low 1080 concentration in the bait;
- placing baits in the best areas to encounter foxes; and
- burying baits.

The amount of 1080 required to kill a fox is about 0.15 milligrams per kilogram body weight (McIlroy and King 1990) via intraperitoneal injection or stomach intubation routes. As McIlroy and King acknowledge, it does not allow for incomplete absorption of 1080 from the gut when the toxin is delivered via a bait, nor does it allow for any loss of toxicity due to leaching or microbial degradation after a bait has been laid.

Newsome and Coman (1989) report a weight range for adult foxes of 3.5–7.5 kilograms for southern Australia. Recent shot samples from the wheatbelt of Western Australia (Thomson unpub) revealed a mean weight for males of 5.67 kilograms; range 2.7–8.5 kilograms. The sample size was 374 and 8.3% weighed more than 7 kilograms. Taking into account the heaviest fox sampled (8.5 kilograms) and based on a lethal dose of 1080 as 0.15 milligrams per kilogram, the minimum dose required is 1.3 milligrams. For females the statistics were: N=351; mean=4.82 kilograms; range 3.0–7.0 kilograms.

It is difficult to determine the absolute minimal dose because the minimum lethal dose has not been determined using meat baits and, perhaps more importantly, because of the uncertainties surrounding the fate of 1080 in a bait after laying. McIlroy and King (1990) recommend a minimum dose of 2.5 milligrams per bait. This amount should be sufficient to kill the largest fox sampled (8.5 kilograms), even if 50% of the 1080 were lost due to leaching, microbial degradation or incomplete absorption. The Vertebrate Pests Committee national recommended dose rate is 3 milligrams, and states are encouraged to adopt this.

Staples et al. (1995) tested the lethal efficacy of 3.3 milligram 1080 Foxoff baits (see below) after storage (10–39 °C) for 0.4, 7 or 11 months by giving a single bait to each of 6 female and 8 male foxes (3.3–6.5 kilograms live weight). Efficacy was 100% regardless of storage time. Mean time to first visible effect was 4.06 hours and to death 4.68 hours and appeared independent of weight or sex.

Table 7: State and territory legislative requirements for fox poisoning.

State / territory	Registered poison(s)	Recommended bait(s)	Bait application restrictions+
WA	• 1080 • Strychnine	• Meat (110 g) • Manufactured baits	• Distance restrictions* (except hobby farms subject to APB approval)
NT	• 1080	• Meat • Manufactured baits	• None
SA	• 1080	• Meat, fish, fowl heads, liver, eggs • Manufactured baits	• Property size restrictions • Distance restrictions* • Baits must be buried
QLD	• Strychnine • 1080	• Meat	• Distance restrictions*
NSW	• 1080	• Meat (100 g) • Fowl heads • Manufactured baits	• Distance restrictions* • Baits must be buried
ACT	• 1080	as for NSW	as for NSW
VIC	• 1080	• Cooked meat (25–500 g) • Manufactured baits	• Distance restrictions* • Baits must be buried

Note: Foxes are listed as vermin under the Vermin Destruction Act in Tasmania and so can be destroyed, but no poisons are registered for this use.

\+ All states and territories require erection of warning signs in areas where 1080 is used.

* In some states there are restrictions on the distance baits may be placed with respect to human habitation, water supply, and property boundaries.

A recent trial (D. King, APB, WA, pers. comm. 1993) has shown that meat baits containing 2.5 milligrams of 1080 are fatal to foxes weighing up to 4.2 kilograms. Three captive foxes (weights 3.0, 4.2, and 4.2 kilograms), acclimatised to their surroundings and food, died after consuming a single kangaroo meat bait of 120 grams, dried to approx 50 grams. This supports the above recommendation of 2.5 milligrams, although further trials using larger foxes are needed to confirm this.

Cyanide

Cyanide has been commonly used to kill foxes for the fur trade in Australia. The rapid action of cyanide ensures that the carcass is found close to the bait point for easy retrieval of the pelt (Lugton 1987). The manufacture and use of cyanide baits in capsule form is simple, inexpensive (Appendix B) and poses few hazards if routine safety precautions are followed. **However, as only 1080 and strychnine are registered for fox control in Australia, the use of cyanide baits is illegal and should only be used as a research or management tool by government agencies.**

Cyanide capsules are currently being evaluated in several studies. A number of different lures and capsule types have been tested. Tuna and aniseed oils have been incorporated into the wax capsule and a variety of blended meat types have been used as attractants to cover the capsule. The best results have been achieved when using a naturally white capsule coated with a mixture of condensed milk and icing sugar, and a red capsule covered with a lure of blood and raw liver blended together into a paste. Red capsules are made by mixing into the molten wax a commercial red dye used for imparting colour into candles.

Results have shown foxes display preferences for either capsule type and therefore a choice is routinely offered at each bait station. Bait stations are activated at dusk and inspected at dawn. Recent tests designed to assess fox preferences for other bait materials such as fish and cooked liver, have revealed that fish is less palatable. Cooked liver was as effective as raw liver.

Foxes are guided to the stations by a scent trail created by dragging a carcass from a vehicle along the track. An incision is made in the abdomen to allow body fluids to trickle out slowly. Tests have shown that artificial lures, such as meat meal or fish meal, to be significantly less effective than carcasses.

In Victoria, surface baiting is discouraged and not permitted for routine fox control on the basis of non-target risk. The above procedures, developed in Western Australia, are being modified to suit this requirement (C. Marks, DCNR, Victoria, pers. comm. 1994). Two types of sodium cyanide are under evaluation: a cyanide gel and a powdered sodium cyanide. Both preparations are placed into specially prepared 'brittilised' capsules which are made to withstand transport and handling and to improve the safety aspects of using the poison. These capsules require more pressure before fracturing than the softer wax ones. However, once the pressure threshold has been exceeded they will 'explosively' shatter.

Other poisons

The only widely recommended poison for fox control is 1080. Although strychnine is still registered in some states, its use is being phased out. Cyanide, because of its toxicity and volatility, is only available for scientific purposes. Potential alternative poisons include anticoagulants such as brodifacoum, bromadiolone and warfarin. Before these could be registered for use against foxes, extensive evaluations of toxicity, humaneness, non-target effects and bait delivery systems would be required. At this stage the expense associated with the evaluations of anticoagulants for fox control (and other alternatives) is not justified.

'The only widely recommended poison for fox control is 1080.'

Alternative poisoning techniques

One of the problems associated with fumigation of fox breeding dens is the fact that the adult animals are often absent from the den when the fumigant is applied. One technique that may possibly overcome this problem is the 'tarbaby' poisoning technique, developed for rabbit control in the late 1960s (Hale and Myers 1970). This technique utilises the grooming habit of rabbits by presenting the toxic agent in a sticky grease on the floor of the warren entrance. Experiments have tested mixtures of lanolin and grease containing 1.5–2.5% 1080 by weight which were extruded in a five-track strip. High levels of rabbit control were achieved in early experiments, but the method was not adopted for routine use for a number of reasons. The sticking agent contains a very high concentration of 1080 and this was seen to pose a substantial risk to other wildlife species and to people. Also reinvasion of treated warrens was rapid.

Applied to the entrances of fox breeding dens, the tarbaby technique is likely to kill both adult foxes and cubs. Timing of the operation would be critical as the den needs to be treated while cubs are still being fed by the parents but old enough to emerge from the den. The success of the technique would depend upon the animals entering

1080 may be injected into fresh meat baits which are highly palatable to foxes and relatively target-specific. *Source: R. Knox, APB*

the den and attempting to remove the grease from their paws by licking. This approach to fox management requires further investigation. Since foxes are highly susceptible to 1080, it may be that the concentration of 1080 used can be significantly lowered.

Bait materials

Meat has many desirable properties as a bait material. It is very palatable to foxes and is relatively target-specific, being attractive only to a limited number of carnivores and omnivores. Target-specificity can be further enhanced by the manipulation of size and by drying. By making the bait large, and thus lowering the overall concentration of 1080 within it, smaller non-target species are unable to consume enough bait to receive a lethal dose of 1080. Upon drying, meat initially forms a crust, and after further drying it takes on a biltong consistency. Tests have shown that smaller carnivorous marsupials and scavenging birds such as ravens, cannot consume it as it is too tough and stringy (Calver et al. 1989). However, the assumption that dried baits maintain their consistency in the field, and hence their target-specificity, has not been demonstrated in the higher rainfall areas of south-eastern Australia.

Surface application of manufactured or fresh meat baits, which are equally or more attractive than dried meat baits, may put non-targets at risk because they can be readily ingested. Dried meat is the preferred bait material in Western Australia especially for aerial application. In other regions of Australia where native fauna have little tolerance to 1080, it is important that bait consumption by non-target species is minimised. Where manufactured or fresh meat baits are used in conservation areas they should be buried, already a mandatory requirement in many states.

'Meat is a good medium for 1080 poison as it is highly palatable to foxes and relatively target-specific.'

The Agriculture Protection Board of Western Australia procedure for preparing dried meat baits is as follows:

- meat is cut into 120 gram chunks;
- the centre of each chunk is injected with 2.5–4.5 milligrams of 1080 dissolved in 0.15 millilitres of water; and
- baits are dried to a weight of 40–50 grams, equivalent to about a 60% loss in weight. Baits may be used within a few days or stored frozen.

Volume production can be achieved by forced air drying on racks over four days at 32°C. However this temperature is under review; a higher temperature, 40–45°C, would be more satisfactory as it would inhibit microbial growth.

Where meat bait is to be used on agricultural land, drying before application is not always necessary. Once baits are prepared by cutting into the desired size they should be left to drain on a wire mesh. This removes excess fluid which might otherwise leach out the 1080. Baits are injected with 1080 solution using an accurately calibrated vaccination gun.

Manufactured baits

With an increasing demand for fox baiting programs on agricultural land, the need for a more readily available and economic fox bait was identified. This led to the development of a manufactured bait (Foxoff) consisting of a soft meat-like substitute based on meat meal and containing animal fat, preservatives, binding agents and some proprietary flavour enhancers. There are a number of advantages associated with the use of a manufactured bait. These include: a prolonged shelf-life, ease of distribution, packaging incorporating education material which encourages responsible use, and factory quality control which allows for the accurate incorporation of 1080. Where necessary a manufactured bait could also include fox attractants, a vaccine for disease control and encapsulated 1080 which would potentially reduce non-target uptake. Foxoff baits are now used extensively throughout south-eastern Australia where they are fully registered by the National Registration Authority. Their use is also supported by appropriate state government agencies some of which issue instructions specific to Foxoff baiting procedures for fox control. An example is presented in Appendix C issued by the Land Protection Branch of the Queensland Department of Lands

A disadvantage of manufactured bait is the loss of regulation over the use of 1080 as a result of prolonged shelf-life compared to fresh meat baits which cannot be kept for later use.

Bait concealment: buried baits

As discussed above it may be desirable or necessary to bury baits to reduce the chance of non-target animals taking the bait (Allen et al. 1989). This increases the labour costs, but these extra costs can be offset to some extent by using fewer baits and ensuring greater target-specificity.

Baits should be covered lightly with litter or soil to a depth of 5–10 cm to ensure that the bait is not visible. It has been claimed by some that buried baits are more attractive to foxes than surface baits (Korn and Lugton 1990), although trials have not been conducted with foxes to confirm this. For wild dogs, Allen et al. (1989) found that buried baits were equally attractive and palatable compared to surface-laid baits.

How long a bait, buried or otherwise, retains its toxicity is difficult to quantify as there are many potential variables involved, particularly rainfall. A suite of soil microbes and others in water have been shown to rapidly degrade 1080 (Eason 1992; King et al. 1991). Staples et al. (1995) assessed degradation of Foxoff baits after two weeks in loam soil which was either kept dry or received 56.4 mm of rain. Mean minimum and maximum temperatures throughout the two weeks were 8°C and 17°C respectively. Degradation was faster in wet soil with only 21% of the initial 1080 dose remaining, whereas baits remained lethal with 75% of toxin remaining after two weeks in dry soil.

Aerial baiting

Western Australia is the only state that uses aircraft to lay baits for fox control. This method is illegal in New South Wales and Victoria. An eight-seater plane such as a Britten Norman Islander capable of carrying up to 6000 baits has performed well in Western Australia, although smaller air craft could be used. A chute in the floor for dispensing baits assists bait laying. A spotter with a sound knowledge of the area to be baited is required to keep the pilot on course and to advise the bait dispenser when to start and stop baiting. Preferred flying height is approximately 200 metres. The aircraft follows transect lines, one kilometre apart, across the site to be baited. The air-speed is dependent on wind conditions and drift. Baits are dropped at prescribed intervals depending on the baiting intensity required. Prior to the flight, the number of transects and the baiting intensity is calculated in baits per square kilometre. The transect length is then divided by the air-speed to give an even distribution of baits for the area.

'Aerial baiting of foxes is effective for covering large areas provided the risk of non-target bait take is minimal.'

Aerial baiting of foxes is an effective way of reducing fox populations where the risk of non-target bait take is minimal. To test its effectiveness, 11 resident foxes within a study area were radio-tagged immediately prior to a baiting program. Baits were dropped at an intensity of six baits per square kilometre as described above. Four days after baiting, eight radio-tagged foxes were confirmed dead and two more by 14 days. Assuming that the untagged fox population suffered the same mortality rate, then baiting at an intensity of six baits per square kilometre killed 91% of the foxes. Further paired trials at rates of 5 and 10 baits per square kilometre revealed bait uptakes typically greater than 80%; uptake at 5 baits per square kilometre was as great as for 10 baits per square kilometre (D. Algar, CALM, WA and P. Thomson, APB, WA, unpub.).

Frequency and intensity of baiting

A prescription for laying baits for the purpose of fox control will depend on the size of the area to be protected. Small areas of approximately 10 000 hectares or less require frequent baitings because they are rapidly recolonised by foxes. However, more information is required on fox territory size, dispersal behaviour and rates of recolonisation to better quantify the size of areas which can be protected and hence the area over which baiting would need to be conducted.

In Western Australia, small area baiting has been restricted mainly to nature reserves surrounded by farmland. These have been routinely baited once per month. Baits are laid from a moving vehicle travelling along the perimeter firebreaks by tossing baits under shrubbery at intervals of 100–200 metres. Any internal tracks are baited as well.

This baiting regime has been used for ten years at different sites. In each case, low density populations of marsupials have increased markedly, but it is expensive. Studies are required to determine the minimum intensity of baiting required to protect native wildlife at risk from fox predation. Kinnear et al. (1988) found that foxes rapidly invaded 160–300 hectare reserves following removal of resident foxes. It was on this information that a monthly baiting regime was adopted.

'Small management areas require frequent baitings because they are rapidly recolonised by foxes.'

In a recent baiting program, baiting frequency was reduced to three month intervals (four baitings per year) and baits laid every 200 metres. Bettongs were released into the area in 1980 without fox control but failed to thrive. Trapping capture rates were near zero before baiting and again two years later. In 1993 the trapping success had increased to 5%. This is still low, but clearly, bettong density is increasing. Monitoring will continue to see if the population will increase and stabilise at this baiting intensity. By way of comparison, a previous study showed that bettong capture rates reached as high as 30% after five years of baiting at monthly intervals.

Another factor that wildlife managers need to consider is the desired level of increase in the target wildlife species. For example, is it intended to have the prey to increase to the carrying capacity of the habitat, or is some

Manufactured baits have a prolonged shelf-life and ensure accurate and consistent 1080 concentrations. *Source: Applied Biotechnologies*

arbitrary percentage of the carrying capacity more desirable?

Factors such as available resources for sustained control, fox density, the rareness of the prey, amount of cover, prey vulnerability and area of habitat will determine the level of effort required to control foxes.

Baiting procedure: agricultural land

The most common fox poisoning strategy involves laying baits at regular intervals along a trail. Dragged carcasses, offal enclosed in a bag or any matter that leaves a scent trail, can be used to attract foxes from a distance. Scent trails can significantly increase the initial rate of uptake which is an advantage where time is limited. However, recent evidence indicates that foxes will find most baits regardless of scent trails. In many cases the use of scent trails can encourage individual foxes to find and remove many more baits than is necessary, particularly during the period after 1080 is first ingested and before it starts to take effect. Where scent trails are used, they should at least be interrupted at regular intervals to minimise the occurrence of multiple takes.

The trail should be accessible by vehicle and preferably follow known features such as fence lines, property roads, tracks or stock trails, and animal pads so that baits can be easily relocated. Foxes tend to follow these features when moving about their home ranges. Trails should be selected during the planning procedure.

'Baits are best buried in shallow depressions to reduce non-target risk and extend bait freshness.'

Baits are best buried at regular intervals (100–500 metres), in shallow depressions which reduces non-target risk and extends bait freshness. In some states this procedure is mandatory. As a general guide use 50 baits per 400 hectares. The baiting program should last about 2–3 weeks with baits inspected every 2–4 days and replaced if taken. It is common for large numbers of baits to be removed at the beginning of a program, disproportionate to the expected number of foxes. This could be related to the caching behaviour of foxes where they store surplus food without necessarily eating it. Bait should be offered until no more is being taken. If surplus baits are cached by foxes and remain uneaten there is a potential risk to non-targets. The issue of multiple bait take and the ultimate fate of all removed baits requires further research.

'The risk to non-target animals from cached baits needs further investigation.'

Free feeding with unpoisoned bait is not usual, although how much this might influence the success of the poisoning operation is unknown. Where there is special concern about local non-target animals such as bandicoots or quolls, free feeding in conjunction with sand plots can be used to assess risk before poison baits are offered. In some cases, where low densities of foxes exist or individual foxes are being targeted, the use of a carcass as a bait station or attraction point has been employed. Once foxes have been attracted to the area, poisoned bait can then be placed nearby. Caution is needed when using bait stations as they may also attract non-targets.

Timing of control: agricultural land

Fox control using poisons is usually conducted in the month leading up to lambing or kidding to reduce local fox populations and predation rates. This can occur from early autumn through to late spring depending on the region. The effectiveness of a poisoning operation may be improved by taking advantage of the peak demands for food by foxes (Chapter 2), although this has not been tested experimentally. For example, breeding vixens might be most vulnerable during late gestation and lactation (spring) when their food demands are sufficiently high to increase foraging activity, and hence the probability of locating bait. Dominant males may be more exposed to bait during the mating season (winter) when they are moving over much larger areas in search of mating opportunities. Late summer poisoning for autumn lambing is perhaps at a time when fox populations are under least food pressure due to an availability of alternative prey and when it is likely to be least effective, although sub-adults from the previous breeding season will be foraging for themselves at this time and are more likely to sample all food types (including bait). Similarly, any foxes poisoned at this time will be quickly replaced by sub-adults during the dispersal period. Conversely, if poisoning is not carried out prior to the peak predation time, any localised population reduction may be compensated by reinvasion. Maximum effect on foxes by poisoning for the purposes of agricultural protection may therefore necessitate two control programs per year depending on the time of lambing. One of these should coincide with the lead-up to peak predation while the other should take into account the behaviour of foxes.

7.5.3 Hunting

The hunting of foxes either for their pelts, a bounty or merely as a sport has long been seen by the agricultural community as a useful and economic way of regulating fox numbers. The commercial value of fox pelts as determined by export prices saw large numbers of animals taken for this purpose. The majority of these were shot with the remainder either poisoned or trapped.

Hunting of foxes is time consuming and few landholders carry out this control technique. It is more common for professional or experienced amateur hunters to be given the rights to take foxes from individual properties. With the falling value of fox pelts, and in the absence of bounties, this is now left to the more enthusiastic amateurs and a few remaining professionals.

Shooting

Shooting is usually done at night from a vehicle and with the aid of spotlights (100 W). Small bore, high-velocity rifles, for example .222 calibre, fitted with telescopic sights are preferred. Night spotlight shooting often relies on the ability of the hunter to lure inquisitive and inexperienced animals into shooting range by rabbit whistle, or to approach the animal without it retreating. Coman (1988) observed that fewer foxes could be taken by this technique as the season progressed due to either rapid removal of young or inexperienced animals or learned avoidance of shooters.

In many districts, recreational shooters with high-powered rifles are invited onto farms just prior to or during the lambing season and the resultant localised reduction in fox numbers may give some temporary respite to lamb predation losses. The method is not suitable where there is dense cover for foxes.

Newsome et al. (1989) removed foxes and cats from Yathong Nature Reserve by shooting and observed significant increases in rabbits compared to control areas with no fox or cat shooting. The effort was considerable, one week in every two or three. It is not known if this level of effort would have been sufficient to allow native prey species to increase or if the cost was justified. Replacement of shot foxes was high, particularly during the period when young foxes were dispersing.

Battues or fox drives

Fox drives are still common in some rural communities. Here, groups meet informally and use unarmed beaters, often with dogs, to drive foxes into a waiting line of guns. Usually it is only small areas of prime fox cover that are treated. Significant numbers of foxes can be taken but the area of land treated is usually very small with human resource requirements prohibitive. For this reason, the technique provides little long-term control of fox damage. The advantage of this method is that it is not selective in terms of the type of fox forced to bolt from its cover into the range of the hunter, and may help to further reduce populations already subject to baiting and spotlight shooting and which contain mostly wary adults.

Dogging

Another technique of fox hunting found in some parts of Australia is the use of small terrier dogs to flush foxes from dens. Dislodged animals are either killed with shotguns or coursed with large lurcher dogs. As with fox drives, this technique produces little more than a temporary and localised reduction in fox damage and also cannot be condoned on animal welfare grounds (Section 5.3).

Traps

Traps have been used for centuries to control predators or for commercial harvesting, although the capture of foxes is relatively difficult compared to other species. Recently there has been much opposition to their use on animal welfare grounds (Section 5.3) and considerable effort has been put into development of more humane traps (Novak 1987). The use of steel-jawed traps on agricultural land is either discouraged or banned in most states and territories. It is also a labour intensive technique which makes it impractical for large-scale operations. Steel-jawed traps have considerable non-target catches that are usually fatal or cause serious injury.

'Steel-jawed traps are not recommended and are banned in some areas.'

In some circumstances, fox damage may occur in situations where conventional control techniques are not practicable. The most common example is fox control in urban or semi-urban areas where use of poison baits is seen as an unacceptable risk to domestic cats and dogs. In Victoria, a treadle snare trap originally developed for wild dog control, has been used for the capture of foxes in urban areas (Coman, unpublished data). This leg-snare device is a more humane alternative to the steel-jawed trap and has been accepted as a suitable fox control technique by the RSPCA. However, such traps are difficult to set, and it is unlikely that they would be suitable for use by the general public.

'Steel-jawed traps may kill or injure non-target animals.'

The treadle snare consists of a thrower arm, activated by a conventional trap plate, which draws a cable noose about the animal's leg. Treadle snares are buried in a manner similar to that of conventional steel-jawed traps and are set on runs or used with lures. A small locking bracket is incorporated into the snare cable such that, once tightened about the animal's leg, it cannot be loosened.

The snare cable usually causes minimal injury and, importantly, non-target species can be released relatively unharmed. The snare plate is set to withstand a certain weight before triggering which minimises risk to most smaller animals. If animals are allowed to remain in these snares for a prolonged period, severe tissue damage and fractured bones may result. Treadle snares thus need to be checked at regular intervals, preferably every 4–8 hours, so that captured animals can be humanely removed and destroyed.

Queensland legislation allows the capture of foxes using soft catch traps which were developed in the USA as a humane spring trap (Section 5.3.5). Unlike the traditional steel trap, they have rubber-like padding on each jaw which cushions the initial impact and provides friction thus preventing the captured animal from sliding along or out of the jaws. They have several modifications that are designed to reduce the risk of injury to a captured animal. These are: offset jaws that have a gap of 6–8 mm between the jaws when closed; reduced spring strength; a spring added to the anchor chain; and a centrally attached bottom swivel to which the chain is attached.

Hunting effectiveness

The proportion of juvenile to adult foxes in a population is a good indicator of hunting intensity providing the population can be sampled with minimal bias towards any age group. Harris (1977) compared a fox population with relatively light control measures to other studies with differing levels of control. He found the ratio of juvenile to adult animals varied from 1:1 in low control areas to as high as 6:1 where intensive control was carried out. In a sample collected by Coman (1988) in Victoria between 1982–84 this ratio was 1.2:1, suggesting only a low level of fox control despite intensive hunting for pelts at the time. While hunting may have some effect on overall fox densities, it is generally agreed that reductions will be minimal. This has been observed throughout the fox's natural range where hunting has been used to reduce predation, to prevent the spread of rabies, or for commercial harvesting (Phillips et al. 1972; Hewson and Kolb 1973; Storm et al. 1976; Harris 1977; Macdonald 1980; Hewson 1986; Voigt 1987; Wandeler 1988).

'Hunting has minimal effect on fox numbers.'

7.5.4 Den destruction and fumigation

This can be an effective technique to reduce fox numbers at the time when cubs are born (August/September). The vixen only remains in the den with cubs for the first few weeks of life and the dog rarely inhabits the same den. From the commencement of weaning the adults will lay up away from the cubs, returning at frequent but short intervals with food. No fumigants are specifically registered for foxes. However, phosphine and chloropicrin which are recommended fumigants for rabbit warrens are commonly used, but phosphine is the preferred fumigant in terms of relative humaneness (Section 5.3.4).

Neither fumigant is humane, although other fumigants such as carbon monoxide could overcome these concerns (Section 5.3.4). Where the den is accessible it can be destroyed by deep ripping. Den destruction and fumigation can also affect non-target species. Due to pressure from humane societies and public opinion, den fumigation of foxes for rabies control was abandoned in most European countries after 1975 (Wandeler 1988). The major disadvantage of this strategy is that fox dens, other than in urban areas, are not easily located. Unless they have previously been rabbit warrens, fox dens only have a small number of entrances which are usually discretely hidden under tree roots or rocky outcrops. Where dens can be located and treated, surviving adults (except those in urban areas) will rarely reuse them in following years and in some cases may change their behaviour to avoid new den sites being discovered.

7.5.5 Exclusion fencing

A recent review of the effectiveness of exclusion fences for foxes (Coman and McCutchan 1994) found that although most of these fences provided a barrier to foxes, this barrier was not complete. The key to success is good fence maintenance, frequent monitoring of the enclosed area for the presence of foxes, and quick action to remove any animals which breach the barrier. Coman and McCutchan concluded that not enough consideration was given to the integration of control and exclusion methods available. When a barrier is breached by a fox, the damage to enclosed wildlife or domestic stock can be considerable. Foxes have been known to raise a litter within an enclosure, and to routinely scale a formidable electrified fence to hunt and to return with food for their young.

Exclusion fencing for foxes is only viable when protecting native species of high conservation value. *Source: R. Knox, APB*

'Foxes can scale electrified fences.'

There is a large range of fence designs, but generally little detailed information on their effectiveness. However, the review concluded that exclusion fencing remains an important tool in the management of threatened or endangered species. Exclusion of foxes by fences is difficult due to the agility of the animal and the prohibitive expense in large areas such as nature reserves or lambing paddocks. Decisions on whether or not to use predator-proof enclosures cannot be taken in isolation from the more general consideration of long-term management of the species being protected.

'Little is known about how effective fences are against foxes.'

The National Consultative Committee on Animal Welfare (Department of Primary Industries and Energy 1992) concluded that exclusion fencing had a limited role in vertebrate pest management. Simple wire-netting fences alone are rarely effective regardless of the height. However where zoos, private wildlife parks or intensive agriculture is subject to fox predation, exclusion fencing, preferably incorporating a roof or overhang, has been effective. Some success has been achieved using high netting fences with unstrained over hanging tops, for example Warrawong Sanctuary in South Australia. Apparently the floppy nature of the upper fence resists any attempt by foxes to climb it. Electrified fences may also exclude some foxes providing they are properly designed and maintained. Others have used fences incorporating a combination of wire-netting and electrified wires, but irrespective of fence type, maintenance costs can be substantial and frequent monitoring of the enclosed area for the presence of foxes is still necessary. Fences can have negative effects on non-target species through entanglements, accidents or restrictions on movement.

Natural water barriers such as remote islands are effective barriers to foxes and, indeed, some mammal species formerly widespread on the mainland are only found on such islands. It is therefore essential that these island refuges be kept fox free.

'Fences can interfere with the movement of non-target animals.'

7.5.6 Farming practices

Alternative stock management practices may reduce fox predation. Smaller lambing paddocks close to homesteads make it easier to monitor the flock and reduces the chance of young lambs being left unattended by the mother. Shed lambing of valuable animals can also be used. Foxes usually only kill lambs up to one week of age. Lambing can be restricted to as short a period as practicable so that susceptible lambs are only available over a limited period. Ideally this should be done in collaboration with neighbouring properties. The timing of lambing may also be critical (Section 7.2.3). Fox densities are lowest during early spring, prior to reproduction and after completion of dispersal. Selection of flocks for more protective mothers may deter foxes from approaching lambs. Some producers have successfully used trained guard dogs to protect flocks from lamb predation. The success of Mediterranean stock guard dog breeds in the goat industry is well documented by dog and goat breeders (E. Scheurmann, International Wool Secretariat, pers. comm. 1994).

'Foxes usually only kill lambs up to one week of age.'

The density of fox populations depends on the productivity of the environment. Lambs are a minor component of the fox diet. Catling (1988) and Pech et al. (1992) found that the size of a fox population in summer was dependent on the availability of rabbits over the preceding rabbit breeding season. With the importance of rabbit in the diet of foxes throughout Australia (Chapter 2), manipulation of this prey species may indirectly reduce the fox population and hence levels of lamb predation. Catling (1987) also suggests that removing carrion such as kangaroo carcasses may have a similar effect, or alternatively, providing carrion during lambing may remove predation pressure without reducing the fox population. Neither of these strategies have been tested.

'Domestic dogs can be trained to protect sheep flocks from foxes.'

Newsome (1987) suggested that integrated fox management was essential if levels of predation were to be reduced. Ad hoc management is not effective. A combination of adaptive farming practices (Section 8.3), an effective fox management program, and reductions to their natural food supply to limit breeding success is required. While this approach is logical, the optimum combination of strategies to obtain economic relief from lamb predation may be difficult to identify.

7.5.7 Fertility control

Reductions to the reproductive performance and hence population densities of predators by oral administration of anti-fertility agents has been attempted in the past with only marginal success (Linhart and Enders 1964; Linhart et al. 1968; Oleyar and McGinnes 1974; Allen 1982). Diethylstilbestrol (DES), a synthetic oestrogen, has been commonly used for this purpose. While DES causes temporary sterility, its value is limited by problems with bait acceptance, the requirement for precise timing of baiting relative to the animal's breeding cycle, and the carcinogenic properties of the drug (Bomford 1990).

'Reducing fox fertility is not yet a practical technique for reducing fox numbers.'

Orally active steroid hormones or antihormones that induce abortion have also been proposed as a method for fertility control (Short 1992). These compounds show a degree of species specificity due to variation in the structure of the uterine progesterone receptor and could be useful for species with short breeding seasons such as the fox. In preliminary baiting trials on wild foxes, an abortifacient was tested at a combination of urban and rural den sites (C. Marks, DCNR, Victoria, pers. comm. 1995). Bait uptake approached 90% indicating no aversion to treated baits. The resulting observations of cub activity was also markedly reduced at treated dens when compared to untreated dens.

While a range of techniques and substances are now known to reduce the fertility of foxes, reducing fertility will not necessarily lead to a decline in population density or in damage caused by foxes. Large-scale field experiments would be needed to determine how practical it is to deliver these compounds to wild foxes and to evaluate their effectiveness for reducing population size. Delivery of fertility control drugs to wild foxes is likely to be expensive and they may be less effective for population control than poisons (Bomford 1990; Bomford and O'Brien 1992).

Recent understanding of the molecular basis of fertilisation makes it possible to develop new strategies to suppress reproduction in free-living animals. Such research is being undertaken by the Cooperative Research Centre (CRC) for Biological Control of Vertebrate Pest Populations established in 1992 and targeting initially the rabbit and fox (CSIRO 1992). The theory behind the research is that the genes for proteins that are critically involved in fertilisation or implantation of eggs can be inserted into a virus that infects the target species. An animal infected with the virus would simultaneously raise antibodies to the virus and reproductive protein, resulting in the prevention of pregnancy, but at the same time not impair the normal endocrine function and reproductive behaviour of treated individuals. Among social species reproduction by subordinate members of the group may be inhibited by dominant members (Mykytowycz 1959), while in other species there is active competition among males for access to breeding females. In both situations sterilisation of dominant members could theoretically reduce the productivity of the target population (Caughley et al. 1992).

For the fox, no specific virus has been found that will not also affect dogs. The current approach of the CRC involves the direct presentation via a bait of a selected protein or a recombinant virus (Tyndale-Biscoe 1994). The latter has been used very successfully in Europe to immunise wild foxes against rabies (Artois et al. 1987). National concerns about the eventual outcome of this work are the possible consequences to human health, domestic stock, companion animals and native fauna. International concerns are directed at the risk to foxes in countries where the species is indigenous. Close scrutiny is maintained on any potential domestic risks, and since the work on the fox is currently directed at oral delivery of non-disseminating vectors, this poses no risk internationally (Tyndale-Biscoe 1994).

An effective form of biological control of foxes appeals as a long-term and cost-effective method for fox management over large areas. Although the risks involved in developing a suitable technique are high, so are the potential benefits. ANZFAS strongly supports the development of fertility control measures as a more humane technique for controlling pest animals such as foxes. However, while these techniques have potentially enormous benefits, it is not yet possible to assess the likely outcome of such research. If successful it may still be many years before any tangible benefit accrues. In the meantime, and probably as an adjunct to biological control, conventional fox control strategies still need to be developed and employed by land managers.

7.5.8 Habitat modification

There is some evidence that the western ring-tail possum (*Pseudocheirus occidentalis*) can withstand fox predation if the forest canopy is closed (P. de Tores, CALM, WA, pers. comm. 1993). Protection is needed in open woodland where possums have to travel across open ground between trees and also during periods of extreme temperatures when possums seek heat refuges on the ground. While this might be an isolated example, it illustrates that habitat modification may have a role in protecting wildlife from fox predation. Kinnear et al. (1988) concluded that fauna subject to fox predation can only survive in sites that act as a refuge from predators. Removal of predators allows prey to utilise less protected sites. Conversely, not changing habitat where susceptible species are present or recreating necessary habitat may also prevent fox predation. Logging activities and the establishment of roads through undisturbed habitat for example, may allow foxes to colonise new areas which contain endangered or vulnerable species (Mansergh and Marks 1993).

7

8. Strategic management at the local and regional level

Summary

This chapter outlines the process for planning and implementing the strategic management of fox impact at the local and regional level. The components of a strategic management program are problem definition; developing a management plan; implementing the plan; and monitoring progress.

Defining the problem *— With limited (but important) evidence the authors conclude that the fox has a significant impact on Australia's native wildlife. The difficulty for the land manager is that the extent of the problem can only be revealed by long-term evaluations of prey recovery after intensive and continuing fox management. In most circumstances it has to be assumed that where the distributions of foxes and susceptible, endangered or vulnerable species overlap, fox predation occurs. Therefore, fox control may need to be initiated before the extent of the problem can be accurately defined. The impacts of foxes on agricultural production are not well understood. However, because the prey — lambs and goat kids — can be intensively monitored, fox impact can more easily be defined.*

Management plan *— The first step in management planning, setting management objectives and performance indicators, recognises that the specific conservation objective for fox management is to promote increases in population of endangered fauna to viable sizes. For agricultural production the objective is to maximise the benefits of fox control compared to the costs. Objectives for particular situations should include interim and long-term goals, a time-frame for achieving them and indicators for measuring performance. Because of inherent difficulties in determining fox populations, the success or otherwise of fox management must be measured by the response in the prey species. For conservation values, the best performance indicator is a sustained increase to viable densities of a threatened and vulnerable species when fox management measures are implemented and maintained. For agricultural production, lambing (or kidding) percentages are the obvious indicators. Precautionary management is needed to prevent expansion of the fox's range either northwards or to Tasmania and other islands.*

The second step requires the selection of the appropriate management options. Generally, the two options most suitable for foxes are strategic, sustained management, which is continuing fox control implemented on a regular basis, and strategic, targeted management, which aims to reduce impact at a particular time of the year. With present knowledge, strategic, sustained management should be employed where native wildlife is being protected while targeted management to coincide with lambing is the best option for agricultural systems. Having selected a management option, the next step is to develop an appropriate management strategy. Poison baiting with 1080 is the only tested and proven option in both conservation and agriculture. However, factors still need to be considered such as methods of application, non-target risks, resources, other pests and supplementary control techniques.

Implementation *— Group action is an essential element of the implementation stage. All those who will benefit from fox management or have a significant stake in the outcome should be involved in the coordinated development and implementation of the management plan. This will help foster a strong sense of ownership of the plan, and successful management which satisfies all relevant players is more likely.*

Monitoring and evaluation *— Operational monitoring ensures that the control operation is executed in the most cost-effective manner. It includes the recording of what was done, where and at what cost. Performance monitoring assesses the effectiveness of the management plan in meeting the conservation or agricultural objectives for the program. Both forms of monitoring enable the*

continuing refinement of the management plan where necessary.

Economic frameworks are needed to assist in the assessment of the relative value of alternative fox management strategies. Such frameworks require: definition of the economic problem; data on the relative costs and benefits of fox control; and an understanding of why the actions of individual land managers may not lead to optimal levels of fox control and how such problems can be addressed by land managers and governments.

Hypothetical examples of the strategic management of foxes at the local and regional level for conservation and agricultural production scenarios are presented.

8.1 Economic frameworks

Economic frameworks need to be developed to assist land managers assess the relative value of alternative control strategies. Such frameworks require: definition of the economic problem; data on the relative costs and benefits; and an understanding of why the actions of individual land managers may not lead to optimal levels of fox control and how such problems can be addressed by land managers and governments. Land managers can use such economic frameworks to select the most appropriate fox management strategy for their circumstances.

Such economic frameworks might be used to determine the most cost-effective fox management strategies for the conservation of biological diversity. First, however, it would be necessary to estimate the economic value the community places on the conservation of native species threatened by foxes, and also the cost and effectiveness of fox control techniques for protecting these species. The process might indicate a case for government assistance if for example the community placed a high value on fox control on private farm land to protect remnant populations of endangered native species, but most individual landholders did not, and only implemented the lesser levels of fox control necessary to meet their livestock production goals. Such government assistance would only be warranted, however, if scientific data verified that implementing fox control on private land would have conservation benefits for endangered native species. Another consideration would be whether or not assisting private landholders to control foxes was the most cost-effective option for meeting these conservation goals, compared to other options, such as investing more resources in fox control on reserve lands.

Collecting the economic data required to assess the economic costs and benefits of fox control to protect livestock from fox predation is likely to be easier, although there is still often uncertainty around estimates of fox contributions to lamb mortality (Section 7.2.3).

8.2 Strategic approach

The components of the strategic approach to fox management have been described in the Introduction. The four steps involved are defining the problem; developing a management plan; implementing the plan; and monitoring and evaluation of the program. The challenge for local and regional land managers and others with a major interest in fox management is to use the knowledge described in the preceding chapters, and processes described in this chapter, to develop a strategic management plan to address the damage caused by foxes.

The process is illustrated for two hypothetical cases, one for a conservation area and the second for an agricultural production area.

8.3 Problem definition

Section 7.4 sets out the initial steps in defining the problem of any fox management program, involving the measurement of fox impact and density measurements using techniques described in Sections 7.2 and 7.3. Mapping techniques are very valuable in defining the problem, allocating management units, and establishing priority areas for treatment (Section 7.4).

Conservation

As discussed in Chapter 3, there is conclusive evidence, albeit geographically and species limited, that the fox has a significant impact on Australia's native wildlife. Some preliminary indications of fox impact for a particular site might be available from direct observations of fox predation or from indirect measures such as scat analyses. However, the difficulty for a land manager is that the extent of the problem can only be revealed by long-term evaluation of prey recovery after intensive and continuing fox management. With present knowledge there are no other useful correlates for fox damage. It therefore becomes necessary to make certain assumptions about the initial problem. Foremost is where the distributions of threatened native species and foxes overlap, the assumption must be made that predation does occur. This means initiating management without necessarily accurately defining the problem. Once fox control has been initiated, the extent of fox predation and other factors which might influence the desired outcome can be assessed (Section 7.2.2).

GIS-based databases such as the Environmental Resources Information Network (ERIN), linked to equivalent state and territory databases, contain information on the habitat, conservation status, threatening processes, and vulnerability of native plants and animals. These databases can help managers determine species most at risk and help plan a coordinated approach to protecting those species and areas believed to be most at risk from fox predation. These lists of species most at threat may be at the regional, state and territory and/or national level.

Agriculture

The impact of foxes on agricultural production is not well understood. However, because the prey (lambs or kids) can be intensively monitored, the impact can be more easily defined and used as a basis to determine the extent of fox control required, or indeed whether any control is necessary (Section 7.2.3). Care is needed in assessing impact, because although fox densities may be monitored, the cause of lamb mortalities is less easy to determine.

'An assessment of fox impact should be based on an accurate determination of the cause of lamb mortality.'

8.4 Management plan

8.4.1 Objectives

The specific conservation objective of fox management is to promote and maintain population increases of endangered or vulnerable fauna to viable densities. This can be assisted by creating more populations through introductions and translocations to areas or sites where the species formerly occurred. Another objective is to prevent future declines in populations of native fauna through fox predation.

'The conservation objective of fox management is to promote viable populations of endangered fauna.'

For agricultural production the objective is clear: where fox impact has been identified, the level of predation must be reduced to an acceptable level, predetermined by the value of the enterprise and the cost of control.

8.4.2 Management options

Flexible management

There are some new approaches to managing complex natural systems. One is known as adaptive management. As described by Walters and Hollings (1990), it is based on the concept that knowledge of such systems is always incomplete. Not only is the science incomplete, the system itself is dynamic and evolving because of natural variability, the impacts of management and the progressive expansion of human activities. Hence management options must be ones that achieve an increasing understanding of the system as well as environmental, social and economic goals desired. The management of foxes, and other vertebrate pests, using 'best practice' suggested in these guidelines, embodies many of the concepts of adaptive management, particularly that of 'learning by doing'.

Given the paucity of information, including scientific information, about many of the factors that drive natural systems, Danckwerts et al. (1992) recommend that managers need to adopt the adaptive management approach of 'learning by doing'. That is, managers learn from their own past successes and mistakes (and those of their neighbours), and from technical information, and make management decisions based on experience in situations where few facts are known, but where decisions cannot be postponed.

A key to the flexible management approach suggested by Danckwerts et al. is the monitoring of three key variables in the system — livestock productivity (biological and economic); vegetation changes; and environmental conditions and management responses. These issues are further canvassed in Section 8.5.

Braysher (1993) discusses management options for managing vertebrate pests and they are summarised below. In selecting an option it is important to match it to the desired objective and to be realistic in terms of available resources and technical feasibility. A useful aid to this selection process can involve the construction of a 'decision matrix' to evaluate which option is most appropriate and a 'pay off matrix' to determine the benefits (Norton 1988).

Local eradication

Local eradication involves the permanent removal of the entire population of an area. This option is unrealistic for foxes except in special circumstances such as islands where there is no potential for recolonisation, or possibly on mainland reserves where long-term perimeter control of foxes is economically and technically feasible. For local eradication to be a viable option, a number of key conditions must be met (Bomford and O'Brien, 1995). These are set out in AppendixD.

Strategic management

Strategic management of foxes is an option where local eradication is not feasible. It involves integrating fox control operations into overall land management planning to achieve a specific fox density or fox impact outcome. There are three major types of strategic management: sustained, targeted or one-off.

'Strategic, sustained management involves an initial campaign to reduce fox populations to very low levels, followed by maintenance control to prevent population recovery.'

Strategic, sustained management involves an initial widespread and intensive control campaign to reduce fox populations to very low levels, followed by maintenance control to further reduce or at least prevent population recovery. This is the only practical option available in most cases for managing fox predation on native fauna. It is important to realise before embarking on this approach that resources must be allocated to this action for the foreseeable future. Managers need to determine the level of effort at which the benefits of control at least equates with the costs of control. However for fox populations cost–benefit relationships are largely unknown. Furthermore, with the most important impact being on endangered or vulnerable species, it is difficult if not impossible to place an economic value on the benefits of wildlife conservation.

'The cost–benefit relationships of fox control for different situations are largely unknown.'

One-off management involves a single action to achieve the long-term or permanent reduction of fox damage to an acceptable level. Examples might include construction of a permanent fox-proof fence or release of an effective biological control agent. Fencing is likely to be prohibitively expensive except in small areas protecting high-value species. Development of an effective biological control agent is in its infancy.

'Fencing is usually only a cost-effective option for protecting high-value species in small areas.'

In the case of strategic, targeted management, control effort is targeted to manage fox damage at a particular time of the year. Advantage may be taken of biological factors of the fox (for example, when it disperses or when vixens are most food stressed) or when the prey is vulnerable (during lactation and gestation for example). As with strategic, sustained management, cost–benefit relationships for this option are largely unknown. However, should it be found to be economically justified, strategic, targeted management is the most appropriate option for agricultural protection where control effort can coincide with lambing (Section 7.5).

Commercial harvesting (hunting)

This form of management aims at providing a sustained yield of animals which can be continuously harvested without any long-term population reductions. With the demise of the fox pelt trade, most harvesting effort is now by recreational hunters. As outlined in Section 7.5, hunters have little impact on fox predation on lambs and native fauna. The only situation where this option may be of use is to assist a poisoning program to target surviving foxes.

'Recreational fox hunting does little to reduce the impact of foxes on lambs and native animals.'

Crisis management

In some situations it may be environmentally or economically justified to undertake no fox control. This will particularly be the case in a great deal of agricultural land where fox predation is not an issue and conservation values are judged to be not significantly threatened. However, if foxes have intermittent impacts, it may lead to managers undertaking crisis management, killing foxes in an unplanned manner as they appear to affect resources. This form of management is unlikely to protect resources.

Precautionary management

It is important to ensure that the fox does not expand its range northwards or on to Tasmania or other islands where it is currently absent and where native fauna that are vulnerable to fox predation exist. This will require vigilance in detecting wild foxes in these regions and public education on the risks of keeping or releasing foxes.

8.4.3 Management strategy

Having determined the most appropriate management option the next step is to choose appropriate management techniques (Section 7.5) and to integrate them into a management strategy. Variables which might influence this need to be identified and evaluated. These can include:

- the conservation status of the population of the animals at threat;
- the potential for applying strategic control to have maximum effect on fox populations at a particular time of the year, for example, through den fumigation at cubbing;
- resources to implement options, for example, where funds are limited but human resources are abundant, ground baiting is preferable to aerial baiting;

- nature of the habitat (dense canopy, open woodland or range land) and size and location of the management unit have obvious implications to technique selection, for example, access to management area or rates of bait application;
- potential for non-target losses;
- presence of other pest species such as feral pigs, rabbits or feral cats;
- the potential for recolonisation by foxes from surrounding land and the effect this will have on management objectives;
- the bias in some control techniques (shooting for example) towards younger age groups, leaving the breeding population intact; and
- predator–prey interactions.

'Animal welfare is an essential consideration of any control program.'

Mapping may be an important step in determining and recording the relationship between variables (Section 7.4.3). Consideration of animal welfare issues should be an integral part of any feral animal management plan, including foxes. ANZFAS considers that the current approach to feral animal management, namely the ad hoc, opportunistic options based on short-term reduction in populations are inappropriate. They consider that a well planned and coordinated strategy, as advocated in these guidelines, is likely to be more humane in the longer term.

8.4.4 Performance indicators

Conservation

For conservation values, the best performance indicator for fox management is a sustained increase in numbers of endangered or vulnerable species. Likewise, in the case of translocations, the best indicator is the successful establishment of translocated or introduced fauna followed by a sustained increase of the population.

An additional performance indicator, and often the first positive sign, is an increase in the use of the available habitat — species increase and occupy areas of the habitat otherwise denied them.

'The best performance indicator for fox management in conservation areas is the sustained viability of endangered or vulnerable species.'

The lack of a significant population increase of a prey species, despite apparently adequate fox management, would indicate a failure to achieve the objective. However it may indicate that other factors, in addition to fox predation, may be affecting production and survival of prey, for example food supply or quality; mortality due to drought; disease and parasites; or mortality due to other predators such as feral cats, birds of prey, reptiles and poachers. For example, in a study of the survival of translocated malleefowl chicks to Yathong Nature Reserve, food was identified as a limiting factor (Priddel and Wheeler 1990). This study suggests that, given adequate protection from foxes, the chicks would ultimately starve. Conversely, given adequate food and no protection from foxes, chicks would be preyed upon.

Therefore several factors besides fox predation may limit prey response. Furthermore, failure of prey populations to respond to predator control does not exclude fox predation as a limiting factor. Complex factorial experimental designs, where feasible, may be necessary to resolve multiple limiting factors and modelling based on such experimental testing may be valuable for investigating prey population dynamics under different fox management strategies (Pech et al. 1995). Alternatively, sequential management of likely limiting factors might be possible. Performance may need to be measured over long periods before a positive response is evident. For example, with malleefowl perhaps only occasional years provide sufficient food for recruitment.

Agriculture

Performance indicators for agricultural production are both straightforward and short term. Where fox predation is shown to be a limiting factor, lambing percentages, and hence net income, should immediately improve on previous years' production with effective fox control prior to lambing; and should continue to improve where longer term or sustained management is implemented. The only word of caution here is that allowances may need to be made for other factors influencing production before and after fox control. These include variation in seasonal conditions. Where fox management does not lead to increased lambing percentages (criteria for failure), other causes of low lambing percentages should be considered, such as poor ram fertility. Rapid recolonisation by foxes may also be reducing the effectiveness of fox control.

8.5 Implementation

Implementation of fox management is described in Chapter 9. The value of the group approach to pest management has been discussed in detail in the earlier guidelines for rabbits (Williams et al. 1995). The group approach requires local community support, based on an understanding of the damage foxes cause and how it can be addressed. The group approach fosters a strong sense of ownership of the management plan, and successful management which satisfies all participants.

8.6 Monitoring and evaluation

'Performance monitoring is critical to ensure management programs remain focused on the cost-effective reduction of fox damage.'

Operational monitoring and performance monitoring (evaluation) are often forgotten but essential aspects of implementing a management program. Both provide information which can be used to improve the effectiveness of the control strategy or modify the objectives as necessary.

8.6.1 Operational monitoring

Operational monitoring aims to assess the efficiency of the control operation, to determine what was done, where and at what cost. Most states and territories have developed, or are developing, Pest Management Information Systems (PMIS) which can assist land managers, whether government or private, to monitor management operations both for operational and performance monitoring (Fordham 1991).

8.6.2 Performance monitoring

Performance monitoring aims to assess the effectiveness of the management plan in meeting the objectives of the program. Performance monitoring begins when it is suspected or assumed that foxes are causing significant environmental or agricultural impact.

The primary management objective is the reduction to an acceptable level of fox damage. Therefore, the index monitored to assess the effectiveness of the fox control program should be the response of the prey species targeted for protection (Section 7.2). This may take several years to achieve, particularly in relation to population recovery in native species. Performance monitoring allows for the effectiveness of the program to be evaluated and modified where required, or to identify the need to set new objectives and performance indicators.

Achievement of management objectives should be qualitatively assessed based on performance indicators. Dispersal may soon negate the benefits of localised fox control thus necessitating expansion of the management area. In the case of lamb predation, the cost of fox control needs to be economically justified in terms of increased lambing rates. Evaluation techniques need to take all of these factors into account.

Where practicable, knowledge of the distribution and relative abundance of foxes helps to plan the management program (Section 8.4). However, estimation of these parameters is very difficult and a land manager may have to rely on crude estimates or assumptions based on experiences elsewhere.

In conservation areas, performance assessment of the management program depends on comparisons of census estimates of the prey species carried out before and following the implementation of predator control. In general, if the fox is the primary limiting factor, as appears to be the case for some Western Australian marsupials, the methods need not be sophisticated or sensitive because census estimates or indices, before and after a suitable period of fox control, are markedly different.

Irrespective of how management is evaluated, for example reductions in fox population, increases in distribution and abundance of native prey species or increased lambing rates, monitoring programs should:

- consider the use of equivalent non-treatment areas to compare the effectiveness of the management program;
- consider changes in the parameter being assessed over time, that is, immediately before and after control and then annually or more frequently if required;
- use measurement indices and recording procedures that are standardised to enable comparisons over time and between different habitat types;
- use methods that are compatible with the resources and skills available to the land manager; and
- include as many between-site comparisons as resources allow.

8.7 Hypothetical example of strategic management at local and regional level — conservation

8.7.1 Scenario

This hypothetical case study is set in a 3000 hectare national park such as might be found within the Grampian Ranges of Victoria. Throughout the park, containing mostly dry sclerophyll forest, are a number of granite outcrops which are known to harbour the threatened brush-tailed rock-wallaby (*Petrogale penicillata*). Other important native species including the southern brown bandicoot (*Isodon obesulus*) and spotted-tailed quoll (*Dasyurus maculatus*) also occur. Foxes and feral cats are commonly sighted while rabbits predominate in more open areas. The park is surrounded by agricultural land consisting of grazing, crops and open woodland most of which tends to be rabbit-prone.

Information collected as part of the preparation of a management plan for the park suggested that rock-wallaby populations were significantly smaller than might be expected from historical records. The previous wide-ranging distribution of the species signified that it might be an adaptable generalist, apart from its preference for rocky terrain, yet its numbers had declined drastically throughout its range with many recent population extinctions. Studies of similar species indicate that fox predation is likely to be a major factor in population decline.

8.7.2 Defining the problem

In response to these observations, the Parks and Wildlife Service launched a preliminary investigation of all rock-wallaby populations within the park. These censuses provided the following information:

- the populations were small and declining; three sites supported less than ten individuals;
- the populations were confined to areas where the rocks were fragmented forming break-aways which provided protective cover from environmental and predation stresses while larger areas of suitable habitat were not being used;
- Brush-tailed rock-wallaby hair was found in two fox scats taken from the area;
- periodic assessments revealed that there was no population growth even though

8

most females were carrying pouched young. Recruitment was low and the age structure consisted of predominantly mature animals;

- there was little or no evidence that the wallabies were subject to severe physiological stresses. Weight losses were minimal and body condition was good even during a drought-declared year; and
- there was no evidence of disease.

The preliminary survey indicated that the conditions seemed favourable for population growth, yet there was none. Observed was a population of fit and healthy animals unaffected by physiological stresses or shortages, producing young and therefore possessing potential for growth, but population growth was essentially static. Clearly there was an unknown source of mortality preventing population growth. By inference it was concluded that foxes were the greatest threat to rock-wallaby conservation. Other limiting factors may have existed such as the lack of an essential habitat requirement. However these could not be revealed unless the threat of predation was first removed. It was therefore decided that a fox management program should be implemented within the park. The implications of this decision also needed to be considered in association with fox predation on rabbits and the potential of reinvasion by foxes from surrounding agricultural land.

Removal of foxes could result in an increase in rabbit densities within the park which could in turn encourage greater inward dispersal of foxes to replace those removed. Similarly, the control of foxes in areas surrounding the park in order to establish a low fox density buffer zone could see an increase in the already significant agricultural impact by rabbits. The problem was therefore defined as being not only one of fox management within the park, but also one of needing to involve adjacent land managers in parallel rabbit and fox control activities, especially in the buffer zone of 20 kilometres around the park boundary.

8.7.3 Management plan

Management objective

The extent to which fox predation affected rock-wallaby densities, although not known, was considered to be significant. Providing they were able to utilise additional habitats in the absence of fox predation, it was decided that a realistic objective was to increase rock-wallaby density within the park by 400% over the ensuing four years. The primary performance indicator would be an increase in the rock-wallaby population derived from continued rock-wallaby census. The need to have all adjacent land managers participate in a parallel rabbit and fox management program was identified as a supplementary objective.

Management options

Strategic, sustained fox management (Section 8.4.2) was considered to be the most feasible option within the park if rock-wallabies were to re-establish. Local eradication, while the preferred option, was not realistic in the absence of exclusion fencing around the perimeter of the park. With limited resources in surrounding agricultural land, strategic fox and rabbit management in this area was the appropriate choice. Similarly, strategic rabbit management would be carried out within the park.

Management strategy

Sustained 1080 baiting programs have proven to be the most effective means of removing the impact of fox predation in conservation areas (Kinnear et al. 1988). The techniques used to prepare and deliver baits for this purpose can depend on local legislative requirements (Section 6.2). In Victoria, for example, baits must be buried to a depth of at least 8–10 cm. This requirement is partly to protect non-target species such as the tiger quoll which is susceptible to 1080 baits laid indiscriminately. Similarly, where agricultural land is involved, farm dogs need to be protected. Baits can be provided as either dried meat or purchased as a manufactured product. Sustained management of foxes requires regular and continuing poisoning of foxes for the foreseeable future. To what extent this can be maintained depends on available resources.

'Sustained 1080 baiting is the most effective strategy for reducing fox impact in conservation areas.'

In this example, it was decided that baiting frequency should not be less than at three-monthly intervals. This could be supplemented by den fumigation during the breeding season or by spotlight shooting if time permitted. Fox management on surrounding agricultural land would usually require management effort to be targeted to protect production (for example, lambs) at the appropriate time of the year. Therefore, it was essential to encourage neighbouring graziers to participate in the program. From the perspective of protecting the park from reinvasion by foxes, control during the peak fox dispersal period (autumn) would have the greatest benefit.

'Rabbit control should be incorporated into fox management programs.'

Due to the reliance of foxes on rabbits, it was decided that the fox management plan needed to incorporate a rabbit management strategy. Strategies suitable for rabbit control will be similar for both agricultural and conservation areas. For areas of low conservation value, these include removal of surface harbour, destroying warrens by ripping, followed by re-ripping or fumigation. The use of 1080 poison to control rabbits was not considered to be an option because of potential non-target effects, particularly secondary poisoning of tiger quolls from eating 1080-poisoned rabbits within the park.

8.7.4 Implementation

The nature of this program requires that the park management work cooperatively with neighbouring landholders. The advantages are twofold: the protection of conservation values and the reduction of agricultural impact.

'Park management should work cooperatively with neighbouring landholders to protect conservation values and reduce agricultural impacts.'

The entire park is the unit for fox management. Mapping of tracks and trails within the park will serve as a useful guide to bait placement and also assist in the relocation of baits on a regular basis so that those removed can be replaced. The same applies to neighbouring agricultural land. Because the latter involves only strategic baiting, mapping and selection of management units is perhaps more important. Previously selected rabbit management units should be treated in order of priority. Recolonisation can be minimised by treating adjacent management units in sequence (Williams et al.1995).

8.7.5 Monitoring and evaluation

'Ineffective baiting programs may be a result of incorrect baiting techniques, bait-shyness or fox immigration.'

The overall effectiveness of the program will be determined by the continuing rock-wallaby census, the desired outcome of which is a significant population increase. A factor which might contribute to this is an increase in habitat use by the rock-wallabies. This should be monitored as a performance indicator. Failure to effectively control foxes could lead to false assumptions being drawn about the effect of predation. It would therefore be essential to monitor fox density within the park (Section 7.3). Possible causes of failure might include incorrect baiting technique or bait-shyness by foxes and immigration from buffer zone. If these problems are identified, management techniques will need to be modified. As a useful encouragement to continuing landholder participation, the impact of fox predation on agricultural production should also be monitored (see next case study for an example).

The essential message that has emerged from similar but real examples for conservation agencies and wildlife managers in particular, is that an exotic predator such as the fox is a major factor in the extinction process of many small and medium-sized mammals. Predation keeps population densities precariously low, thus increasing the risk of extinction from other causes. The fact that a species still persists in an area in the presence of foxes is no guarantee that the species will continue to survive. A properly implemented predator removal program can also reveal the presence of other limiting factors affecting the abundance of native species.

In Western Australia, predator removal by baiting has resulted in large increases in native prey populations. In these instances, it may be concluded that predation is the principal (proximate) factor responsible for limiting population size, and that the prey is existing at levels far below the carrying capacity of the habitat. With predation mortality minimised, these Western Australian populations have increased without restraint over a considerable period. Eventually growth will slow and cease when the carrying capacity of the habitat has been reached or as other limiting factors come into play.

Undoubtedly, not every predator removal program will mirror the Western Australian response where appreciable increases in prey numbers have been the rule. Given that predator control has been adequate, there are two possible causes for a less spectacular response. It may be due either to the fact that the species is not vulnerable to predators, or the carrying capacity of the habitat is low due to other limiting factor(s). Priddel and Wheeler (1990) have demonstrated this in the case of malleefowl (Section 3.1.2).

Clearly, in situations where another factor(s) is limiting the population growth of a threatened species, studies will be required to identify the limiting factor(s). This may or may not be a simple task but whatever the outcome, the initial control of predators is essential. To take an example, suppose that food was limiting the density of an endangered mammal that was also vulnerable to fox predation. If it is assumed that food supplements were provided there would be a number of possible outcomes. In the absence of predator control one may observe that individuals are in a better nutritional state, but with no population increase. Subsequent removal of predators and the addition of food would result in a population increase. Conversely, predator control alone would not result in a population increase as food would also be limiting. Another example might be that reduced fox numbers allows an increase in rabbit numbers. This could result in increased competition for food, and suppressed population increase of a threatened mammal. These examples illustrate how predation can confound ecological experiments (and our understanding of the factors affecting wildlife), and conversely, how other limiting factors can obscure the potential or actual impact of predators.

8.8 Hypothetical example of strategic management at local and regional level — agriculture

8.8.1 Scenario

This hypothetical case study is based on a sheep grazing property of about 20 000 hectares in semi-arid western New South Wales. Paddocks consist of open woodland, chenopod scrubland and pastures of annual forbs and grasses. Sheep-carrying capacity is 20 per square kilometre with the production of lambs and subsequent sale of surplus stock making up 40% of the landholder's income. Foxes are common as are kangaroos, feral pigs, feral cats and rabbits. No endangered or vulnerable wildlife species are known to occur in the district. A series of good seasons produced lamb marking percentages of approximately 50% on this property which fell below the district average of approximately 70%.

8.8.2 Defining the problem

In an effort to identify the possible cause of reduced lamb production, the landholder compared his operation with neighbouring and more successful properties. Aspects assessed included stocking rate, pasture condition and timing of lambing, all of which can affect a flock's nutritional status and hence reproductive performance, as well as ram fertility, and blood lines. In all of these comparisons he could find no differences which might be causing his problem. In the previous season the landholder also compared wet and dry statistics for one of his larger lambing paddocks with a similar paddock on a neighbouring property. In both cases around 90% of ewes were diagnosed as pregnant; however at lamb marking the differences were substantial. From this comparison the landholder concluded that lamb loss rather than flock fertility was the primary cause for the lower number. Few lamb carcasses could be found suggesting that scavenging of dead lambs or predation of live ones was the cause and not lack of cover in the lambing paddocks. For those carcasses which could be found, predation was identified as the probable cause (Section 7.2.3).

The landholder also observed that a small lambing paddock adjacent to his living area always produced more lambs per ewe than the remainder of the property. This paddock had a constant exposure to farm dogs and humans, and because of attacks on his domestic poultry, foxes in the immediate area were shot on sight. Local shooters had also observed larger than normal numbers of foxes on the property, particularly in association with sandhills carrying high rabbit densities. With a combination of circumstantial and real evidence, the landholder discounted feral pigs as a major factor and concluded that fox predation on his property was resulting in a significant impact on lamb production. Having defined the problem he decided to implement a fox management program.

8.8.3 Management plan

Management objective

The available evidence suggested that fox predation may have been causing up to a 20% loss in lamb production. The management objective therefore became the reduction of fox impact through effective management using lamb marking percentages as performance indicators. Because the landholder was unsure of the costs involved in fox control a first year objective of a 10% increase from the previous three-year mean in lamb marking percentages with effective but low-level fox control was set. In the second and third year the objective would be raised to a 20% increase with the level of fox control adjusted according to the first year results.

Management options

The only feasible management options were either strategic, sustained or strategic, targeted management (Section 8.4). No fox control or crisis management might also have been considered. However, because the landholder lacked information on the cost–benefits of fox control it was decided, as a guide, that some form of fox management should be undertaken in order to compare possible increases in net income from higher lamb production. With no prior experience in fox management it was decided that strategic, targeted management was a more appropriate choice than the more resource demanding strategic, sustained management.

Management strategy

The local Rural Lands Protection Board advised the landholder that poisoning with 1080 was the most cost-effective fox control technique for semi-arid areas. Because of the difficulty in obtaining freshly prepared baits from the Board office which was 200kilometres away, the landholder purchased manufactured baits at a cost of $1 per bait.

A targeted baiting program was aimed at protecting lambs at birth. This meant starting fox poisoning operations a week before lambing commenced and continuing them through at weekly intervals until no further bait was taken. The recommended procedure for baiting (Korn and Lugton 1990) was to bury baits at 100–500 metre intervals along a dragged scent trail. Bait application rate in the vicinity of lambing paddocks was 50 baits per 400 hectares.

The landholder was aware that foxes rely on rabbits as a year-round food source. He had also observed dead foxes after a previous rabbit poisoning program. As a result, a supplementary objective was undertaken that routine rabbit control using 1080 poisoning followed by ripping of warrens would be conducted throughout the year commencing after the next lambing. He also decided to modify his farming practices by shortening the lambing period as much as possible.

8.8.4 Implementation

Where practicable, fox management for the reduction of agricultural impact should be undertaken cooperatively with adjacent landholders. Apart from obvious cost-effectiveness through benefits from bulk purchases and sharing equipment, this further reduces the immediate problem of recolonisation particularly when strategic baiting aims to protect lambs.

The selection of management units on a property will depend partly on available resources. One landholder attempting to protect all lambing paddocks equally would necessarily treat the entire property as a management unit. Where some lambing paddocks are more susceptible to predation than others, smaller management units would be necessary with priority given to those at greatest risk.

Because it is difficult to predict the distribution of foxes, mapping is important to identify the location of lambing paddocks, areas of high rabbit density where foxes might be concentrated, and features such as fence lines, tracks and property boundaries where bait trails will need to be laid. Mapping will also be an aid to monitoring bait uptake.

8.8.5 Monitoring and evaluation

With virtually no information on the cost–benefits of fox control for agricultural protection, the landholder should place a high priority on monitoring and evaluation. Fox management is too often implemented without hard evidence about losses due to foxes. The cost associated with all aspects of the management program should be carefully tabulated and compared with the perceived increase in production. Where performance indicators show that the management program is unlikely to reach the objectives, other causes of lamb loss need to be carefully reconsidered. The landholder must also consider that strategic, targeted fox management was not effective and that more intensive control may be required.

9. Implementing management of fox damage

Summary

While governments have endorsed the principle of beneficiary pays, it is not always possible to clearly identify the beneficiary, especially where foxes are causing damage to both production and native fauna. Landcare and similar community-based groups can provide a useful mechanism in these cases for developing a common approach and for determining appropriate input of resources.

The Commonwealth, states and territories have a number of programs and other initiatives which can help agencies and land managers to add to the knowledge of fox damage, to develop better management strategies and to help disseminate relevant information. These include the Endangered Species Program, Feral Pests Program, Vertebrate Pest Program and the Victorian Land for Wildlife initiative.

Effective management of fox damage requires local community support. The community needs to be aware of and understand the damage foxes cause and how it can be addressed. Techniques for achieving this include brochures, field days, public addresses and pilot projects to demonstrate the effective strategies.

9.1 Introduction

Historically, the management of fox damage in Australia has relied mainly on sporadic control of foxes at the local level with little or no information about the associated costs and benefits. Although widespread bounty schemes have operated in the past there has been no real attempt to assess their value. Based on overseas experience bounties are not an effective method for preventing fox damage (Whitehouse 1977). Existing legislation related to fox management applies largely to the types of poisons and baits permissible for use (Section 6.2), and the legal status of the animal as a pest. In fact, the only detailed strategies for fox management in Australia are those in Western Australia for protection of native fauna and the national and state contingency plans for eradication of exotic disease.

9.2 Role of governments and landholders

Commonwealth, state and territory governments have endorsed the principle of beneficiary pays (Braysher 1993). The difficulty is in accurately determining the beneficiary. For conservation reserves, it is the community, state or national, and they should pay. For agricultural production the landholder is the beneficiary and should bear the bulk of the costs. However, the difficulty arises where control over and above what a landholder may require to protect production is necessary to protect native fauna. Similar conflicts can occur where private land abuts conservation land containing pests. In these cases the various interest groups should coordinate to develop common approaches and to determine input of resources. Landcare and similar community-based groups provide a useful mechanism for this (Braysher 1993).

'Most states and territories provide a fox management advisory service.'

Most states and territories provide an advisory service for managing foxes and other pests. They can also assist with preparation of poisoned bait, but in many parts of Australia this has been poorly coordinated. Government programs to manage fox damage have, in general, been confined to national parks and nature reserves in order to protect native wildlife. Where fox management is also essential on surrounding cropping or pastoral land, government usually takes the lead in organising the control and supply of poison (see Example 2, Braysher 1993 for the Murray Mallee of South Australia).

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'Government programs to manage fox damage have generally been confined to national parks and nature reserves.'

The Commonwealth Government has a number of programs which can assist in managing foxes and other pests. Generally, the Commonwealth encourages studies which add to the knowledge of fox damage to wildlife and to the development of suitable control strategies. Those that are relevant to fox management are:

- *Feral Pests Program (ANCA)* — This program aims to develop and implement projects in cooperation with other Commonwealth authorities and state and territory agencies to reduce the damage caused by feral animals to native fauna and/or the natural environment, particularly in areas important for the recovery of endangered species. Foxes, feral cats, feral goats and rabbits are given priority as these are listed as key threatening processes under the Commonwealth *Endangered Species Protection Act 1992.*
- *States Cooperative Assistance Program (ANCA)* — The aim is to develop nature conservation projects of national or international significance in cooperation with the states and territories. Elements of the program include wetlands conservation, conservation of migratory species and control of environmental weeds. Additionally, the program covers education and extension for the broader area of management and maintenance of biodiversity, and as such does not preclude investigations of fox predation.
- *Endangered Species Program (ANCA)* — This program aims to ensure that endangered and vulnerable species and ecological communities can survive and flourish, retain their genetic diversity and potential for evolutionary development in their natural habitat, and to prevent further species and ecological communities from becoming endangered. Foxes have been one of the priority areas for this program in the past but with the creation of the Feral Pests Program (FPP) in 1992–93, most feral animal projects were transferred to the new program.
- *Vertebrate Pest Program (Bureau of Resource Sciences)* (see Introduction).

There are also initiatives at the state and territory level with respect to broader implementation of fox management strategies. In Victoria, for instance, fox control is being promoted as an activity for LandCare groups. The Department of Conservation and Natural Resources has joined with private industry in a venture to provide a shelf-stable fox bait for poisoning (Foxoff® — Applied Biotechnologies). Schemes to promote the value of private farmland as wildlife habitat such as Land for Wildlife in Victoria may also help implement fox control measures.

9.3 Use of community groups

In the past, most fox management work has been conducted either by government agencies (on public land) or by individual farmers (private land). Almost all of the management has involved either poisoning or shooting and, generally speaking, the operation has been a reaction to perceived damage rather than a preventative measure taken in advance.

Although community fox drives have been a longstanding tradition in some rural communities, such initiatives are based more on social and sporting outcomes rather than upon a clearly defined aim to reduce fox numbers for some economic or environmental objective.

Given our knowledge of the movement of foxes and their ability to quickly recolonise small cleared areas, it is evident that small and sporadic reactive operations are unlikely to give long-term respite from damage. Cost-effective management of fox damage, especially to protect vulnerable wildlife, is likely to require control operations which cover relatively large areas so that immigration can be confined to buffer zones on the perimeter of the treated area. Implementation of such management requires coordinated effort across the area to be treated.

'Sporadic and small-scale control operations are unlikely to provide long-term respite from fox damage.'

The importance of group action for the effective management of fox damage needs emphasis. Based on experience with the group approach to rabbit management, groups should be relatively small, involving 10–50 landholders. Where the nature of the fox problem or the land type/land use varies markedly within a large target area, it is advisable to consider the formation of subgroups such that each smaller group shares a common approach and a common goal. Most importantly, the impetus for formation of a group should come from the community itself and not from the pest control authority. It is the function of the latter to encourage and facilitate group formation but not to impose it such that local landholders will have no real sense of ownership of the problem or of the proposed solution.

'Control operations which cover relatively large areas are required to protect vulnerable wildlife.'

It is important that the damage caused by foxes is seen as a community problem — not a problem to be solved by governments or the next-door neighbour. In this context, it is necessary to promote the fact that community ownership involves more than just the landholders themselves. Under the principle of beneficiary pays, fox damage to wildlife, for instance, is a cost to the whole community, not just those who actually own or occupy the land.

Part of owning the problem can be explained or promoted in terms of an individual landholder's responsibility to neighbours. It is generally accepted that no person has the right to interfere with a neighbour's legitimate business. This is easily demonstrated in say, the case of marauding farm dogs which begin killing sheep on neighbouring properties. Here, there is generally little dispute regarding the responsibilities of the dog's owner — they are expected to either remove or destroy the offending animals. With foxes preying on lambs, no such clear responsibilities exist. One farm running cattle, for example, may provide suitable cover for large numbers of foxes which then kill lambs on a neighbouring sheep farm with few or no resident foxes.

Unlike the damage caused by many other pests of agriculture or the environment, that caused by foxes to wildlife may not be immediately evident. Very often, decline in wildlife populations is slow and insidious in nature. In a situation where the damage has been incremental over a very long period of time and, more particularly, where it is exacerbated by other factors, land managers can often fail to perceive the true nature of the problem. Indeed, as pointed out in other sections of this document, the measurement of fox damage can be difficult. Even in the case of fox predation on lambs, recent studies (Section 3.2.1) suggest that simple examination of lamb carcasses may not give an accurate measure of total losses to foxes.

'Fox impact on wildlife affects the whole community — not just those who actually own or occupy the land.'

Thus, one of the first requirements for successful group action is a general knowledge of the local impact or at least suspected impact of fox predation in the district. Following this, the group will need some appreciation of the scope and magnitude of the task ahead, particularly the fact that it is likely to require a long-term commitment to management activities. Mapping of the area is perhaps the simplest way to convey this information. As an example, many LandCare groups put together composite aerial photographs of their territory, and by using overlays, determine various classes of habitat or farming country at risk.

Some of these groups are now showing interest in digitised mapping and linking into a computerised GIS. This approach has considerable potential for it can accommodate an enormous amount of useful information. Maps can be produced at any required scale and the particular features shown on those maps can be varied at will (Section 7.4.3). For instance, a fox management group may require a map which combines a particular vegetation type (for example, dense bush or high tussocks which may be favoured refuge areas for foxes) with cadastral information and information on the local distribution of wildlife species considered to be at risk due to fox predation. One of the major benefits of this approach is the ability for individual land managers to supply information to the data bank and to get back from the system detailed maps of individual farms showing the features required. The landholder, under these types of mapping schemes actually becomes the provider as well as the receiver of the mapping information.

'The impact of foxes on wildlife may not be immediately evident.'

One of the major problems associated with the implementation of fox management strategies is determining the level of control activity required to produce some measurable and stable response in the chosen indicator wildlife species. In fact, it will require that those implementing fox management gain some skills in measuring the responses of particular prey populations. This is likely to be a difficult task and one where assistance from expert staff in the wildlife management authority will be required.

Landcare and similar community-based groups offer an effective mechanism for identifying common objectives for management and to coordinate action across a region. Most groups use a catchment-based philosophy and no longer think in terms of single farms. Many are now also involved in detailed mapping and the collection of other data such as information on native flora and fauna. These databases are useful for planning and implementing fox management. Examples of how a community group might coordinate fox management would include some or all of the following:

- surveys designed to identify the location and abundance of wildlife species considered to be in decline and known to be preyed upon by foxes;
- initial survey to determine the magnitude of lamb losses to predation in the district;
- routine spotlight transect counts or other measures designed to give some general index of fox abundance;
- planning and execution of a coordinated campaign of bait-laying such that large areas of country are treated on a grid basis;
- where applicable, identification of fox den sites on local maps so that subsequent fumigation of dens in the breeding season can be conducted in the relevant areas; and
- where applicable, the inclusion into local maps of known lay-up points for foxes such as swamps, thickets and bracken patches.

9.4 Community awareness

It is clear that the issue of harmful predation by both foxes and cats is now receiving much more attention in the media and that community awareness in this particular area is increasing. Feral and wild pest animals and their impact upon the Australian environment are now popular school essay topics or school projects and more and more media attention is being given to the problem.

'Community awareness programs usually concentrate on problems rather than possible cures.'

Nonetheless, current community awareness programs often tend to concentrate on perceived problems rather than providing a detailed analysis of the actual problem including identification of all major causes. Wildlife management authorities and those concerned with vertebrate pest management need to foster informed debate on the impacts of predation, including fox predation. This would involve explaining what we know of predator–prey relationships and such information as the dietary range of the predator and other aspects of its biology which have some bearing on management.

Effective management of fox damage in any area that covers a mix of land uses will require local community support. To achieve this the community needs to be aware of and understand the damage that foxes cause and how it can be addressed. Currently in rural communities it can be expected that attitudes toward foxes will range from indifference to the belief that they are the primary cause of lamb loss or wildlife decline.

'Fox management requires local community support.'

A variety of techniques are available to assist information transfer and adoption of appropriate practices. These include brochures, media releases and public addresses which target the relevant audience. Probably one of the most effective education tools is the establishment of small demonstration projects that involve the relevant community in the damage assessment, planning and implementation of the management program. Braysher (1993) outlines an example of such a program between the South Australian National Parks and Wildlife Service and the local farming community to conserve malleefowl in theSouth Australian mallee. First-hand involvement is often a strong motivating influence to undertake appropriate action.

Finally, in fostering community awareness of the problems caused by foxes in Australia (particularly in the area of wildlife conservation), it is important to discern between perceived problems and actual problems. Actual wildlife benefits of fox management are known, although only for a limited number of species in a limited range of habitats. Given this, major management programs should not be promoted unless either good — or at least circumstantial — evidence is available to implicate the fox, or evidence by way of inference from other studies strongly suggests the involvement of foxes in some harmful predation. For example, the continued existence of a small and remnant colony of rock-wallabies in the Victorian Grampians might reasonably be thought of as being at high risk to fox predation based on the fate of similar isolated rock-wallaby colonies in Western Australia, where effective fox control led to a dramatic rise in population size of the prey.

10. Deficiencies in current knowledge and approaches

Summary

Apart from the relatively recent studies in Western Australia, quantifiable information on the damage foxes cause to native fauna is lacking. While there is good reason to believe that foxes are having similar impact in other parts of Australia, control strategies cannot be planned without reliable data. The identification of the range of species at risk is an area where reliable information is needed both in relation to predation by foxes and competition between foxes and native wildlife. There is also reason to believe that the economic losses due to lamb predation by foxes may be greater than previously thought. Studies are required to quantify the losses.

Although a number of techniques can be used to minimise the harmful impact of foxes, there has been relatively little scientific assessment of these techniques. With poisoning, for instance, much more information about the required baiting intensity and frequency, the timing of the poisoning operation, the best toxin to use and the likely impact on animals is needed. Likewise with den fumigation, there is a need for more humane and effective fumigants. In the case of exclusion fencing, now used in a number of important recovery programs for endangered species, little scientific work has been conducted on the cost-effectiveness of various designs.

There are a number of deficiencies in non-technical aspects of managing fox damage that can be improved. These include wide variation between states and territories in thestatus and requirements to manage foxes,poor organisation and coordination of management programs, the lack of a community or district approach, and a general failure to communicate to the general public the scope and nature of the fox problem or potential problem in Australia.

10.1 Introduction

It is clear that more information is required to determine the significance of fox predation in Australia and, more specifically, to define and improve techniques for minimising this damage. Until relatively recently, the fox has not been a species that has attracted widespread interest in Australia. Apart from studies in Victoria (Newsome and Coman 1989) and recent work in Western Australia, research on the fox has been sporadic. In contrast, it has been extensively studied in Europe and North America because the fox is a major vector of rabies. Since Australia is rabies free, and because for some time the fox was not perceived to be a conservation problem or a significant threat to primary production, there was little incentive to study the animal.

Recently this attitude has changed considerably due to the growing information about the threat foxes present to native fauna. As a result the Commonwealth is supporting large-scale research programs on biological control of foxes in Australia (Section 7.5.7). However this research is long-term and high-risk, and even if this biological control approach is successful, more conventional techniques will still be needed. Considerable work is required to improve the efficiency and effectiveness of these techniques.

The Commonwealth, through ANCA, is also supporting research programs on conventional techniques. A major research program is under way in Western Australia involving the Western Australian Department of Conservation and Land Management and the APB of WA with financial support from Alcoa. The research is aimed at determining the most appropriate baiting regime when 1080 is used for fox control over large areas of conservation estate. Specific aspects being addressed are:

- assessing the effectiveness/conservation value of buffer zones of 1080-baited agricultural land abutting conservation estate;
- determining the level of 1080 bait uptake in forested areas;

- estimating fox densities in large areas of forested conservation estate; and
- assessing the effectiveness of different 1080 baiting frequencies when applied to large tracts of forested conservation estate.

10.2 Specific deficiencies

10.2.1 Understanding predator–prey relationships

Developments required

A more thorough understanding of the relationship between the fox and its prey is needed. In particular, questions regarding the impact of foxes on vertebrates other than mammals requires investigation. This must include a better understanding of the way in which other processes of extinction (the destruction of wildlife habitat for example) impinge upon predation and vice versa. A related area is the important question of the role of rabbits in maintaining high fox populations, and the possible increased predation pressure on wildlife when rabbit populations suddenly collapse due to factors such as myxomatosis or an effective rabbit poisoning program. The relationship between fox density and impact on prey populations also needs to be quantified. Another significant question is whether cats will replace foxes as wildlife predators if fox populations are reduced. These developments are of fundamental importance, and until there is more precise knowledge of the consequences of fox predation, management of foxes or fox damage will always include a large degree of speculation.

'A greater understanding of the relationship between the fox and its prey is needed.'

Wildlife management agencies need more information on the benefits to wildlife of fox control. The adaptive management approaches used in Western Australia need to be trialled in other areas and for other species.

Consequences

It would enable sensible and efficient allocation of scarce management resources so that fox management or exclusion is limited to those species or particular habitats where predation is a definite threatening process.

10.2.2 Improvements to baiting techniques

Developments required

Chief amongst these is the need to determine the appropriate intensity, frequency and timing of baiting in much the same way as has been done for rabbit baiting in Australia. This entails such elements as the number of baits per hectare, the number of baiting episodes needed per year and the most suitable times to carry out such baiting exercises. These aspects are now being addressed by the ANCA-funded research in Western Australia.

'The appropriate intensity, frequency and timing of baiting needs to be determined.'

The other important aspects of baiting requiring further research are the presentation of the bait, the choice of toxin and the possible non-target effects of the technique, particularly associated with fox caching behaviour. With bait presentation, some of the factors requiring work include bait preference trials, particularly to cover possible seasonal changes in fox diet, optimum size of baits, the value of burying baits, the value of lures and, importantly, the biodegradability of the bait-toxin combination.

The issue of multiple bait take and the ultimate fate of all removed baits also requires further research. It is common at the beginning of a baiting program to have large numbers of baits removed, disproportionate to the expected number of foxes. If surplus baits are cached by foxes and remain uneaten there is a potential risk to non-targets.

Choice of toxin is an issue in some areas where use of 1080 is not advisable. In general terms, 1080 must be regarded as the most effective toxin currently available for the Canidae although cyanide could be considered more humane. Experiences with the use of cyanide baits for research work in Western Australia suggest that this toxin is both highly effective and humane. Further studies on the safety to human operators, non-target effects and how best to use this toxin are required. Since fox control in urban and semi-urban areas is a growing issue, some attention to the development of a safe bait for urban foxes is warranted. In all areas of baiting research, the possible non-target effects of the technique must be considered. Further investigation is needed to improve the selectivity of the bait/toxin combinations and their methods of deployment so that other wildlife species and domestic animals are not put at risk.

Other important factors to be considered include:

- the effect of long-term reliance on poisons to suppress fox populations in inducing neophobia and bait-shyness. There may already be evidence for these developments in dingoes (D. Berman, CCNT, pers. comm. 1994);
- the frequency and intensity of baiting in relation to the size of the area treated; and
- the use of buffer zones and variations in baiting regimes in different habitats.

Consequences

Improved efficiency and target-specificity of fox baiting. More humane control of foxes.

10.2.3 Improved den fumigants

Developments required

Den fumigation, although used widely for fox control in Europe, has rarely been used in Australia. With the current interest in community land management initiatives such as Landcare, it may well be that den fumigation can be used as part of an integrated program to control foxes. The two fumigants currently being used for rabbit fumigation in Australia have a number of shortcomings, chief of which is the fact that they cannot be demonstrated to cause humane death. One possible alternative, which should be considered as a den fumigant, is carbon monoxide, since it is generally believed to be a humane and effective fumigant when used correctly.

Allied with the use of den fumigants is the possibility of using the tarbaby technique at entrances to the breeding dens (Ryan and Everleigh 1975). This technique is worth investigation since it would ensure that any fox visiting the den, but not necessarily living with the cubs, would be exposed to the mixture of toxin and grease. However, this technique may have some problems of target-specificity.

Consequences

Increased control options for foxes, particularly in areas where poisoning is not advisable. May provide a more humane technique for fox destruction.

10.2.4 Fox-proof fencing and other barriers

Developments required

With increasing concerns about predator impacts on threatened mammals in Australia, emphasis has been placed on the concept of predator-proof enclosures as a means of arresting the decline in some endangered species. An example is the eastern barred bandicoot in Victoria.

A considerable investment has been made in predator-proof fences, and their effectiveness has recently been reviewed (Coman and McCutchan 1994) (Section 7.5.5). The main issue concerns its cost-effectiveness. It is possible, using existing fence technology, to produce designs which are effective against foxes. However the cost of such fences is usually prohibitive, and many of the designs, particularly those employing energised wires, suffer from maintenance problems.

The evaluation of fencing thus involves a matrix of the following: initial costs, maintenance costs, expected life, ease of erection, degree of effectiveness, suitability for rough terrain, dangers to other wildlife, and wildfire hazards. This matrix of factors then needs to be assessed in relation to other methods for protecting wildlife from predators, such as the cost-effectiveness of controlling predators rather than simply preventing their access. An example is the successful use of fox poisoning by Kinnear et al. (1988) in Western Australia.

Consequences

The most suitable and cost-effective designs for fox-proof fences can be determined for various types of terrain and habitat. This will be of considerable importance in the management of some vulnerable, endangered or locally endangered wildlife species.

10.2.5 Fostering public awareness

Deficiency

The damage caused by pest animals in Australia has received relatively little publicity compared with other environmental management issues such as tree decline, salinity and the greenhouse effect. In part, this lack of public understanding of the problem reflects a dearth of scientific knowledge regarding the level and severity of predation and other negative aspects of foxes. Nonetheless, sufficient knowledge of the potential of fox predation to cause significant damage, particularly in endangered species recovery programs, is available to promote a much wider discussion and community involvement in the problem. There is also, from the European experience, a good idea of the potential significance of wild foxes as vectors for some strains of the rabies virus. Both of these negative values of foxes require much wider exposure to the public.

Examples of how public awareness of these problems or potential problems might be raised include the provision of a well-presented textbook on introduced predators in Australia and the inclusion or increased emphasis in school curricula of information outlining the harmful impact of foxes. Current community awareness programs tend to concentrate on perceived problems rather than a detailed analysis of the issue including identification of all major causes.

Consequences

An informed public, particularly in rural areas, will be better able to understand the nature of fox predation on livestock and wildlife and to carry out efficient and target-specific control measures.

10.2.6 Ecology

Deficiency

Relatively little is known on the ecology of the fox in Australia (Chapter 2). There is a lack of information in key areas such as regional differences in behaviour, reproductive potential, mortality factors, and movement and responses to culling. There is also an absence of accurate data on population densities, attributable in part to a lack of reliable census techniques. The importance of this problem ranges from the necessity to monitor the presence of very small numbers of foxes in areas where previously they might have been absent, to high densities of foxes where the impact on native species needs to be assessed.

The potential role of the fox as a competitor of native wildlife is poorly understood. This information is needed to protect native species that may be at risk through competition with foxes (Section 3.1.7).

Consequences

With better ecological information, it will be possible to develop more specific fox management strategies in different regions and environments. It will also considerably benefit the preparation of contingency plans for fox management in the event of an exotic disease outbreak (Chapter 4).

10.2.7 Organisation of management programs

Deficiency

At present, much of the management of fox damage in Australia is reactive and conducted by individual landholders. There is relatively little emphasis on larger-scale coordinated programs. If any real and lasting gains are to be made, it will be because fox management is viewed in much the same way as rabbit control — viz. the key to success being large-scale management programs involving groups of landholders or even whole districts. As is the case with rabbits, recolonisation of small, cleared areas is likely to be rapid. Another important deficiency in organisation is the lack of measurable goals in terms of reducing fox damage and of benchmark data on which to gauge progress towards any such goals. Indices or measures of changes in important indicator species are required.

'The best approach is large-scale fox management programs which coordinate groups or even whole districts of landholders.'

Consequences

Fox management will change from being a sporadic and remedial technique carried out by individual land managers to one which integrates the control process over larger areas and achieves some lasting gains in a cost-effective and measurable manner.

10.2.8 Legislation and administration

Deficiency

It is clear that the administrative procedures and legal status of foxes varies considerably between the various states and territories (Section 6.2). Historically, the administrative procedures set in place to deal with fox predation arose almost entirely from a consideration of the animal as a predator of livestock. With a growing realisation that fox predation is heavily implicated in the decline of some native species, a review of the legal status of the animal is now timely. As far as practicable, legislation at state and territory level should be consistent so that there can be a national focus on the problem. The Victorian *Flora and Fauna Guarantee Act 1988* and the Commonwealth *Endangered Species Protection Act 1992* are the exceptions. In particular, the requirement to prepare and implement Threat Abatement Plans under the Endangered Species Protection Act is a major advancement in the initiation of strategic fox management. A concern with these Acts is that they provide no guidance to the scale and pattern of management operations which are necessary to address a threatening process. Such a scale could range from highly localised to national. Without careful consideration the pattern and demand on resources could become disproportionate to the distribution of key endangered species. Guidelines for the selection of scale and pattern of actions within Threat Abatement Plans should be prepared by relevant agencies. The process adopted by the Department of Conservation in New Zealand for Himalayan thar, possums, and feral goat control is a useful guide (New Zealand Department of Conservation 1993,1994,1995).

Closely allied to the need to review legislation is the need to ensure that adequate attention is given by the relevant vertebrate pest control authorities to extension and training in the management of predator damage. This is particularly so for Victoria and Tasmania, where there are major recent changes in the management of pests. Any move to use external contractors for pest control operations when they were previously performed by vertebrate pest agencies, must ensure that standards are maintained and that the availability of trained operators is not diminished.

Consequences

A more rational and more uniform set of legislative procedures to deal with the problems caused by fox predation. Improvements in the dissemination of information related to fox management strategies.

10

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APPENDIX A

Native species believed to be at risk from fox predation

The following list, although far from comprehensive, gives some indication of species at risk from fox predation:

Marsupials

Bilby, *Macrotis lagotis*
Black-footed rock-wallaby, *Petrogale lateralis*
Brush-tailed bettong, *Bettongia penicillata*
Brush-tailed rock-wallaby, *Petrogale penicillata*
Dibbler, *Parantechinus apicalis*
Eastern barred bandicoot, *Perameles gunnii*
Kowari, *Dasyuroides byrnei*
Long-footed potoroo, *Potorous longipes*
Mountain pygmy possum, *Burramys parvus*
Mulgara, *Dasycercus cristicauda*
Numbat, *Myrmecobius fasciatus*
Red-tailed phascogale, *Phascogale calura*
Rufous hare-tailed wallaby, *Lagorchestes hirsutus*
Sandhill dunnart, *Sminthopsis psammophila*
Southern brown bandicoot, *Isoodon obesulus*
Spectacled hare-wallaby, *Lagorchestes conspicillatus*
Western ringtail possum, *Pseudocheirus occidentalis*
Western quoll, *Dasyurus geoffroii*
Yellow-footed rock-wallaby, *Petrogale xanthopus*

Rodents

Central rock-rat, *Zyzomys pedunculatus*
Dusky Hopping mouse, *Notomys fuscus*
Heath rat, *Pseudomys shortridgei*
Plains rat, *Pseudomys australis*

Birds

Bush thick-knee, *Burhinus magnirostris*
Ground parrot, *Pezoporus wallicus*
Little penguin, *Eudyptula minor*
Little tern, *Sterna albifrons*
Malleefowl, *Leipoa ocellata*
Night parrot, *Geopsittacus occidentalis*
Nullabor quail-thrush, *Cinclosoma alisteri*

APPENDIX B

Technique for the manufacture and use of cyanide capsules

The technique involves laying dry, commercial grade sodium cyanide (NaCN) powder encased in a capsule comprised of a mixture of 90% paraffin and 10% micro-crystalline wax. This combination of waxes produced a robust yet brittle capsule, with a relatively high melting point. The two waxes are melted together and heated to a temperature just below boiling. Stainless steel rods are placed in a lubricating agent of soapy water and then dipped briefly in the heated wax. The wax capsules are then prized off the rods. Each capsule is approximately 8 mm in diameter and 50 mm in length. Capsules are then inverted and left to dry at room temperature for 48 hours.

The capsules are two-thirds filled, approximately 1.0 g, with NaCN powder. A cotton wool plug, through which a length of looped wire (hair pin) is inserted, is placed into the capsule at its open end. Melted wax is then used to seal the capsule. Next, cyanide capsules are placed in water to wash off any excess cyanide and to ensure that they are correctly sealed. NaCN readily absorbs and reacts with moisture causing caking in the capsules. Dry, powdered NaCN is rapidly lethal but caked NaCN can be spat out so the animal escapes (Connolly et al. 1986). Because the capsules are only partially filled it is possible, by gently shaking the completed unit, to see whether the cyanide powder is free-flowing. These capsules are then air-dried and securely stored.

Two capsules are used at each bait station spaced 200 metres apart along tracks or firebreaks. Each capsule is tethered to a buried plate (or other suitable anchors) using a fishing wire trace which is attached to the wire loop embedded in the capsule. When sited, each capsule is coated with an appropriate lure dispensed from a squeeze bottle.

Anchoring the capsule prevents the fox from carrying off an intact capsule. If a fox picks up a capsule with the intention of moving off, the capsule ruptures when it reaches the end of the tether and cyanide spills into the fox's mouth. This arrangement has made the procedure more reliable, and safer to use as it prevents intact capsules from being carried off.

'Brittilised' capsules are of the conventional gelatine variety which are freeze-dried after treatment with acetone or formaldehyde. The dehydration process causes the capsules to become brittle and the chemical treatment causes a cross-linkage in the gelatine which makes it resistant to rehydration. The capsules are then coated with a mixture of paraffin wax and animal tallow. Captive trials have shown that foxes will easily rupture the capsules, but the exact field presentation of the bait is not yet decided (C. Marks, DCNR, Victoria, pers. comm. 1995).

Wax capsules can also be presented in a buried bait system utilising a capsule deployer. The deployer is an all hardwood construction consisting of two holding blocks attached to a base plate. The holding blocks are a set distance apart to allow the placement of half a Foxoff Free Feed Econobait. Holes in the holding blocks allow a wax capsule containing powdered sodium cyanide to be placed horizontally above the Foxoff. The capsule is secured into position with a locating pin which passes through the wire loop embedded in the capsule. Tent pegs hammered through holes in the base plate are used to prevent removal of the deployer from the bait site. The capsule deployer offers a degree of protection to the capsule during excavation and it prevents removal of the intact capsule from the bait site. The fox is forced to break the capsule before it can access the Foxoff Econobait (C. Marks, DCNR, Victoria, pers. comm. 1995).

APPENDIX C

Instructions for the use of FOXOFF® baits

LAND PROTECTION BRANCH, DEPARTMENT OF LANDS, QUEENSLAND

(revised 25/10/94)

Foxoff baits are a meat-based manufactured bait for the control of canid pests, particularly foxes. The poison is absorbed into the centre of the bait and defined by the presence of red dye. 60 and 35 gram versions are available. READ THESE INSTRUCTIONS BEFORE USE.

Vertebrate pest species

Baits are to be used for no purpose other than for the destruction of foxes unless otherwise approved by the Director.

Minimum distances

All baits must be distributed on the land described in the indemnity form only. Unless otherwise approved by the Regional Inspector, baits must not be laid:

- WITHIN 1 KILOMETRE of any habitation (habitation includes any dwelling excluding the owner's), or public amenity, or
- WITHIN 5 KILOMETRES of a town area, or
- WITHIN 5 METRES of a fenced property boundary, or
- WITHIN 50 METRES of the centre-line of a road
- On properties smaller than 40 hectares*

* With the approval of the Regional Inspector, baits may be used on smaller properties, if cooperation between neighbours allows consolidation of landholdings for the purpose of determining the minimum property constraints.

Unless approved by the relevant local authority, baits must not be laid on any stock route or reserve for travelling stock.

Notification to neighbours

Notice must be given of the intention to lay baits at least 24 hours prior to the commencement of the poisoning program. Notice must be served by mail or direct telephone on every resident and/or occupier of the land adjoining or having frontage to the holding, or area on which poison baits are to be laid.

In general, fox control will be more effective if action is taken over a wide area. Thus it is appropriate for neighbours to cooperate in coordinated campaigns. This reduces the burden on individual landholders, achieves a greater control area, reduces the rate of reinfestation and enables synchronised action and precautions within an area.

Warning signs

When baits are laid and while baits remain present on the baited area, poison signs which are provided with the Foxoff product must be placed at all entrances to the property and at the extremities of property boundaries fronting a public thoroughfare. Poison signs must be removed once the poisoning campaign is completed. Additional large plastic poison signs are available from Lands Department officers.

Bait storage and retrieval

While the 2–3 week program is under way and while additional baits are required to replace those at sites where bait take has occurred, baits may be stored in a dry lockable area, away from children, pets and foodstuffs. Foxoff does not require refrigeration.

All baits which have not been taken, and any baits supplied which have not been used, should be collected and destroyed by incineration or deep burial at the end of the baiting campaign.

In any case, all baits supplied should be used or destroyed within one month of supply. LONG-TERM STORAGE OF BAITS IS STRICTLY PROHIBITED.

Safety precautions

The 3 milligram dose of fluoroacetate (1080) poison used in the Foxoff bait is precisely controlled to provide a certain lethal dose to the largest fox and is also adequate to kill most small to medium-sized dogs and cats which ingest a bait.

However, the dose in a single bait is generally below that necessary to kill most native animals, birds and reptiles due to their higher resistance to this poison. Approximately 8 baits eaten would provide a lethal dose to a sheep and 67 should be lethal to a cow. Sheep show no interest in baits. Cows occasionally investigate sand-marked bait stations.

Extensive research in a variety of habitats has shown that very few animals other than foxes and dogs are likely to dig up and eat Foxoff baits. Thus, there is a high safety margin in respect of danger to non-target animals when baits are used as directed.

Nevertheless fluoroacetate is toxic to all species including man and there is no known antidote. Dogs are highly susceptible so it is important to restrain working dogs and pets and advise neighbours and guests while baiting campaigns are under way.

HANDLE BAITS WITH CARE AND CAUTION

It is essential that baits are:

(a) kept away from food, pet food and food preparation areas

(b) kept away from children and pets and working animals

(c) disposed of safely by deep burial (preferably in wet hold more than 50 cm deep) or by incineration.

Following the use of bait, destroy the disposable gloves provided and wash hands before eating, drinking or smoking. Empty bait trays can be disposed of in a local authority landfill or buried in a deep hole.

Regional Inspectors or other authorised persons may determine additional conditions and restrictions on use if local circumstances pose additional risks. The supply of baits may be restricted if local risks are considered to be unacceptable.

If in doubt always seek expert advice from your local Lands Department officer.

In case of emergency the Queensland Poisons Information Centre number is (07)253-8233.

Degradation of Foxoff baits

Foxoff baits have been formulated to remain stable while in original packaging. However once placed in moist soil the baits absorb moisture and this allows the toxin to be degraded to harmless residues by common soil bacteria and moulds. There is minimal long-term environmental hazard from the use of these baits at buried placements.

The rate at which the baits degrade will vary with soil moisture and temperature. In controlled tests, baits in dry soil retained 75% of their toxin after two weeks whereas in wet soil toxin reduced to 21% by two weeks.

Despite this degradation feature, it is recommended that all bait stations are marked (for example with spray mark on dropper posts, or ribbon tied to a tree or fence) to facilitate regular checking and replacement of baits taken and recovery of baits not taken at the end of the program.

Placement of baits

Foxoff baits should be buried just beneath the surface within a shallow hole (8–10 cm deep) and covered with soil. Foxes are readily able to find and excavate buried baits whereas other animals or stock show little or no interest.

Baits should be placed at intervals of **at least** 200 metres, usually along internal fence lines or vehicle tracks. Placement of baits close to each other will result in several baits being taken by a single fox. Since only one bait is needed to kill a fox, the uptake of several baits by the same fox should be minimised.

Use of lure trails

The use of lure trails such as carcass drags or other scent markers is NOT necessary. While the use of lure trails does result in more baits being found in the early phase of the program, this may be due to some foxes progressing along the trail to find several baits.

Lure trails may be used if it is necessary to complete the baiting program over a short period, but it will usually be necessary to replace baits several times at sites where baits are taken (see below).

Bait replacement

Since the action of fluoroacetate in the fox is delayed, the fox remains active for approximately four hours after taking a bait. During this time foxes may search for additional baits and return to lairs or dens before succumbing to the toxic effects. Carcasses are seldom found near to bait stations but may be found in groups in long grass or other cover eventually.

Fox mark sites of baits by urinating and may leave a pointed scat at the bait station. Other foxes can visit the same station so for effective control it is necessary to replace baits several times at some sites. The extent to which this is required depends upon: local fox density; location of the station (for example, near a major thoroughfare); surrounding habitat (for example, forest, swamp, creek); presence of lambs; and level of control undertaken by neighbours.

Just one round of bait placement will generally NOT be sufficient to kill all foxes. Bait replacement is necessary in most situations.

Bait density

This requires local advice but about 50 baits will be needed per 400 hectares (1000 acres). This allows for a fox density of about four foxes per square kilometre, for some baits to not be found and for some foxes finding more than one bait.

Replacement should continue until take stops. This often shows that the true fox problem is greater than anticipated. Fox density may exceed eight foxes per square kilometre in some areas.

Free feeds

Unpoisoned 'free-feed' baits are manufactured to allow for the testing of non-target risk in sensitive areas, prior to placement of poisoned baits. Free-feed baits are buried and fine damp sand is spread over a one-metre diameter area around the bait station. Examination and sweeping of the sand every morning enables the detection of the tracks of animals which visit the station and/or take the bait.

Extensive research has shown that in most farming areas the risks to non-target native animals is so low that the pre-testing with free feeds is not necessary. Seek advice from your local Lands Department Officer if there is a special concern about non-target risk.

Fate of carcasses

The toxin in a fox carcass is destroyed as the carcass putrefies and bacteria degrade the toxin to harmless residues. It is unlikely that any animal can receive a secondary poisoning from eating a fox carcass. For example it is estimated that an eagle would need to eat approximately 13 whole carcasses to receive a lethal dose.

Carcasses do not need to be recovered. Many foxes will return to lairs or dens before succumbing to the toxic effects of the poison. Such carcasses are not easily found.

The key to responsible and effective use of baits is to plan and implement a thorough program, with bait replacement and proper spacing. Best results are obtained if cooperative campaigns are conducted by neighbours and Landcare groups. Ensure that pets are protected and neighbours are properly notified. Seek advice if any aspect of these instructions is unclear.

APPENDIX D

Criteria for eradication

Eradication is the permanent removal of all individuals of a species from a defined area within a defined time.

There are three essential criteria which must be met for eradication to be possible (Bomford and O'Brien 1995). If all three criteria cannot be met, eradication should not be attempted:

- **Foxes can be killed at a rate faster than replacement rate at all densities.** As the density declines it becomes progressively more difficult and costly to locate and remove the last few animals.
- **Immigration can be prevented.** This is possible for offshore islands or small mainland populations which are geographically isolated, or where completely effective barriers can be erected and maintained, such as well-maintained fox-proof fences.
- **All reproductive foxes are at risk from the control technique(s) used.** If some animals are trap-shy or bait-shy, through either inherited or learnt behaviour, then this sub-set will not be at risk.

There are three additional criteria identified by Bomford and O'Brien (1995) that need to be met for eradication to be preferable to long-term fox control:

- **Foxes can be monitored at very low densities.** This can be difficult to achieve.
- **The socio-political environment is suitable.** For example, if certain groups object strongly to the eradication of foxes they can directly thwart or politically influence the program.
- **Discounted cost–benefit analysis favours eradication over control.** Discount rates are used to estimate the value of future benefits against the costs of actions in current dollars. This criterion is difficult to meet because of the high initial cost of eradication and because benefits accrue over a long period. At high discount rates, eradication is unlikely to be cost-effective. Eradication has a large initial outlay but, if it can be achieved, there are no continuing costs apart from maintaining the outer protective boundary. For cost-effective eradication, each situation where eradication is technically feasible should be assessed to determine whether eradication costs outweigh discounted benefits.

APPENDIX E

Best practice extension in pest management

Quentin Hart and Dana Kelly

Achieving sustainable land management, including pest management, can be facilitated by new approaches to extension. Traditionally, extension has been defined as the dissemination of information. In this definition, it is seen as the link between the producers of information (researchers and others) and the end-users of the information (generally land managers). Researchers, public policy makers and industry tend to refer to research transfer, technology transfer or information diffusion. Bennett (1993) emphasises the need for mutual interdependence and cooperative action combining these two approaches. If extension is to achieve adoption, it must facilitate understanding and involve a participatory rather than prescriptive approach.

Some characteristics and principles inherent in innovative extension programs are:

- ownership;
- benchmarking;
- participatory learning based on principles of adult learning;
- equity and respect for everyone's views (Kelly 1995);
- problem definition with stakeholder consensus (Ison 1993);
- client driven or responsive to the needs of clients (McGuckian and McGuckian 1994);
- consider the whole property or whole agribusiness chain (McGuckian and McGuckian 1994);
- incorporate processes to create learning opportunities that lead to locally meaningful and adaptive changes (Ison 1993), that is, 'learning by doing' (Section 8.4.5 and Walters and Holling 1990); and
- incorporate an evaluation strategy to ensure the program is flexible and responsive to external changes such as the environment or market (Kelly 1995).

Decreasing state government resources limit the ability of extension workers to target individual land managers. Landcare groups provide a partial solution to this problem in that they allow extension workers to target groups rather than individuals, and the information diffusion process within these groups is relatively rapid. The group approach offered by Landcare can also be used to develop regional rather than individual management plans for pest management (Chamala and Mortiss 1990).

Extension should not dictate solutions but provide the underlying technical information and decision-making framework from which land managers can draw their own conclusions. In this way, both government and land managers will have a greater understanding of the complexity of the problems and the possible solutions. Such participatory learning approaches also provide land managers with ownership of the problems and solutions, and this facilitates adoption.

Involving land managers as co-learners and co-researchers is being encouraged in demonstration projects currently supported by the Vertebrate Pest Program (VPP) of the Bureau of Resource Sciences. The VPP funds state and territory government agencies and Landcare groups to determine best practice pest management for a particular area. The projects are generally large-scale field trials involving several properties and comparing several management strategies. Rather than simply providing land for the research, the land managers are integral parts of the projects and help determine management options which are practical and economically sensible for their particular area. Their involvement also facilitates the dissemination of project findings to other land managers. One of the roles of extension is to maintain the momentum of such projects once government funding ceases.

Relevance of information to the land manager in a framework of whole-property management needs to be considered by extension workers. Pest damage is a single and often minor issue amongst a wide range of management considerations a land manager has to contend with. This is particularly true for pests which inflict major but infrequent damage — for example, mice. Pest management is peripheral to most land managers' major activities, and their motivation relates to current rather than potential damage (Salleras 1995).

Extension workers and research workers 'must be able to understand the goals and reasons for motivation or otherwise of the various human stakeholders as well as the habits and habitat of [the pest animal with] the most effective solutions [being] achieved by examining differences in the human dimension rather than concentrating on the pest' (Salleras 1995).

The above assertions by Salleras, a rural land manager from Queensland, are probably a good representation of the attitudes of many land managers and provide an insight into effective extension methodology. Extension should:

- offer concise information specific to regional needs;
- offer a framework for making management decisions based on generic information combined with local observation;
- offer a range of options rather than be prescriptive;
- take account of the availability of pest management tools (for example, Global Positioning Systems and bulldozers for warren ripping) within a region so that recommended control techniques are appropriate;
- take a whole-property management approach by recognising that managers have to allocate budgets to deal with many risks and opportunities and are rarely able to fund pest control at optimal levels. Given limited budgets, the solution is to use cost–benefit analyses, which are relevant to the local area, to optimise where, when and how much control is conducted. As part of this, pest damage should be quantified and financial situation of land managers should be taken into account where data are available to do this (see Appendix B); and
- ideally, implement local field trials, and from these coordinate regional management strategies to achieve maximum (and hopefully long-term) adoption.

Computer technology may provide a partial solution to decreasing resources for physical extension. It will enable pest management information to be provided electronically and readily updated. This information can be linked to decision support systems to lead landholders step-by-step through a process of 'self-assessment' so that they may determine the best management options based on their own on-ground observations.

The potential value of these systems depends entirely on the extent to which land managers adopt such technology. In the foreseeable future, adoption rates of best practice pest management, which are currently low and vary between localities, will depend on extension and research officers working with land managers to determine what best practice is for their situation and becoming actively involved in its implementation.

APPENDIX F

This appendix refers to feral pigs, but the principles apply equally well to fox management.

Economic framework for feral pig management

(After Bomford and others 1995)

Land managers who wish to determine the optimal economic strategy for managing a problem caused by feral pigs could use the stepwise approach outlined in this appendix. We recognise that managers will have incomplete knowledge of the information necessary to fully complete many of these steps. Nonetheless, the exercise of attempting to complete the process, and recording the assumptions and best guess estimates that are made, may prove a useful aid to decision making for feral pig management.

Step 1 — Desired outcomes

Identify desired outcomes and estimate a dollar value for each of these. Where outcomes are commodities, such as increasing lambing percentages, this should be reasonably easy. Where outcomes are difficult to measure, such as reduced land degradation, or intangible, such as increased biodiversity, land managers may be obliged to estimate how much they consider is an acceptable amount to spend to achieve that outcome.

Step 2 — Control options

List all control options and how much they would cost to implement. Control options can be different techniques or combinations of techniques, or different levels or frequencies of application of techniques (Section 7.6). It is important that the options for control are expressed as activities that a manager can select either to do or not to do.

Step 3 — Density-damage relationships

Estimate the relationship between pest density and damage for each resource damaged by the pest (Figure B1). For

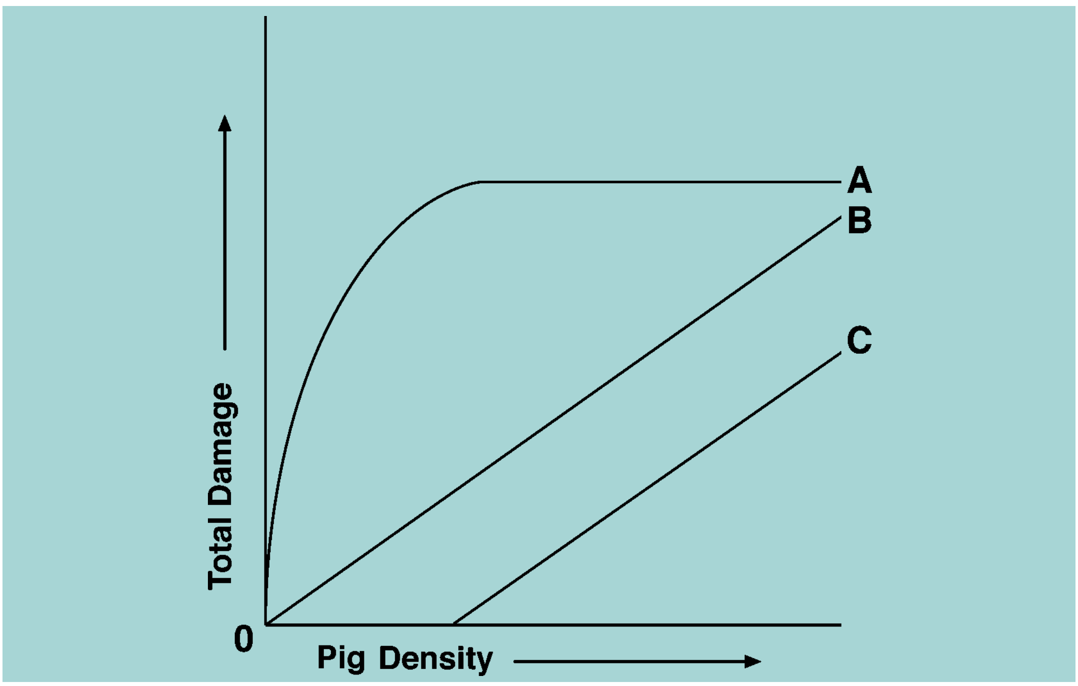

Figure B1: Possible relationships between pig density and the damage they cause. Line A is the relationship shown in Figure 9 and line B that shown in Figure 10. Line C might occur if, for example, only still-born lambs are preyed on by feral pigs at low densities, but if pig density increases, they start to kill healthy lambs.

example, if pigs are reduced by 50%, how much will this increase lambing percentages. There may be interactions between pest density and other farm management practices which will need to be taken into account. For example the increase in lambing percentage caused by reducing pig densities by 50% may vary with different levels of availability of shelter for lambs.

Step 4 — Efficacy
Estimate the efficacy of each control option. That is, how much will a given effort using a particular control option reduce pig density.

Step 5 — Cost–benefit relationships
Use the information from Steps 1–4 to estimate costs and benefits of implementing each control option, including options which combine more than one technique. Costs will be the cost of implementing each control option, and may include costs of monitoring pests and planning. Benefits will be the value of the reduction in damage to the valued resource caused by implementing control (that is the desired outcomes listed under Step 1 above), plus any profits (for example, those made from selling pigs or from allowing hunters on the property).

Different pest management options will generate a variety of cost–benefit relationships. Estimates of benefits and costs can be discounted back to net present values (usually using a discount rate equivalent to the interest rate the landholder pays on financing the control operation). This will reduce the value of costs and benefits accruing in the distant future relative to those accruing in the near future.

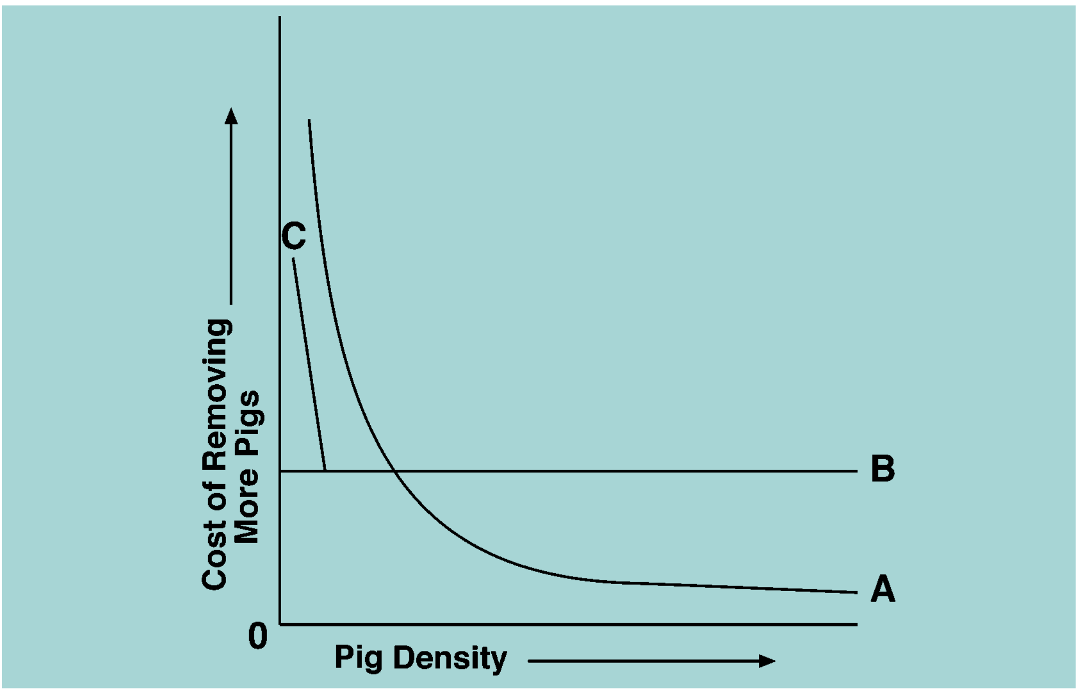

Figure B2: Marginal analysis plotting both incremental changes in the cost of reducing pigs to a given density and incremental changes in the cost of damage caused by pigs at a given density against level of control activity. Where the two lines cross is theoretically the optimal level of pest control. At higher levels of control beyond this point, costs will exceed savings in reduced damage.
Note: The x-axis units are for control effort (for example, dollars spent on control, hours of shooting or trap nights) not pig densities.

Step 6 — Marginal analysis.
Plot both the incremental change in the cost of pig control and the incremental change in the cost of damage caused by pigs against the level of control activity contemplated (Figure B2). Where the two lines cross is theoretically the optimal level of pest control. Further increases in control activity do not cause commensurate reductions in damage, so at higher levels of control beyond this point, costs will exceed savings in reduced damage. An example of marginal analysis for shooting feral pigs from helicopters is presented in Figure 20.

The problem for managers is that, because they often do not have good information on the damage-density relationship, it is hard to estimate the optimal control point. Further, even if they can make a good guess, it is not usually practical with most control techniques to simply cut off control efforts at some pre-determined pig density. It is preferable to have a range of control options ranked along the x-axis, with their associated cost and benefit values for implementation, so a manager can select which option is optimal. For example, different frequencies of shooting could be put along the x-axis.

Step 7 — Pay-off matrices
Construct a table listing all the control options and their associated costs and benefits (economists call this a pay-off matrix). For example, Section 8.8.3 compares the costs and benefits of two control strategies — shooting pigs from helicopters or poisoning with 1080. Managers may wish to construct different matrices for different conditions, such as different stocking densities, seasonal conditions, or commodity values for wool, lambs or pigs. Managers will also need to consider time-scales when constructing these matrixes — what time span is covered and how will this affect costs and benefits?

These matrices can then be used to select the option(s) which best meet the managers' goals. If the manager is risk averse, the best options will be those that bring in reasonable returns (benefits in relation to costs) under the widest range of conditions (that is, in most seasons and with a wide range of commodity prices). If the manager's priority is to maximise profit, the preferred options will be those that are likely to give the highest returns on investment, even though there may be some risk of having no returns or even a loss if the seasons and prices go badly.

Payoff matrices can also be used by a land manager to compare returns on investment in pest control with returns on using the money for some other purpose, such as fencing, new stock watering holes or fertiliser.

Steps 1–7 complete the basic model. The model can be made more accurate by adding additional features. Incorporation of such additional features will make the model more complex, but including at least some of them may be necessary to make it accurate enough to be useful.

One way of improving accuracy may be to replace single estimates with a range of possible values, and give associated probabilities for each value in the range.

Managers may also wish to add additional features to the model such as:

Social benefits could be included in Step 1, such as:

- off-site effects and good neighbour relations;
- biodiversity and endangered species management in agricultural areas;
- retaining rural communities; and
- animal welfare management.

Risk management for spread of disease by pigs could also be included in Step 1.

Effects of government intervention could affect value of benefits (in Step 1) or costs (in Step 2).

Commercial harvest of feral pigs, as an alternative to control as a pest, could be included as a control option in Step 2.

- Indirect effects of pest control (for example, controlling pigs may lead to an increase in rabbit numbers) could be included as interaction effects in Step 3.
- The form in which benefits come may be significant to a manager (Step 5). For example, cash 'bonuses' from the sale of feral pigs may be more attractive as immediate cash for spending, than future money from increased lambing percentages, which may be committed in advance to servicing debts or meeting farm running costs.

Much of the information needed to follow the steps outlined in this appendix is not available. Some projects being funded by the Vertebrate Pest Program in BRS aim to collect some of these data.

Index