Bureau of Resource Sciences
and
CSIRO Division of Wildlife and Ecology

Managing Vertebrate Pests: Rabbits

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The Bureau of Resource Sciences is a professionally independent Bureau established in October 1992 in the Department of Primary Industries and Energy. Its role is to enhance the sustainable development of Australia’s agricultural, mineral, petroleum, forestry and fisheries resources and their industries by providing scientific and technical advice to government, industry and the community.

The CSIRO Division of Wildlife and Ecology is part of Australia's national, independent, scientific organisation, CSIRO. It's goal is to develop the scientific knowledge required to manage Australia's wildlife, plant and land resources for ecological sustainability.

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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 rabbits. Others in the series include guidelines for managing feral horses, foxes, feral goats, feral pigs and rodents. The publication was developed and funded jointly by the Vertebrate Pest Program which is administered by the Bureau of Resource Sciences, and by the CSIRO Division of Wildlife and Ecology.

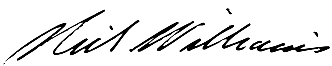
To ensure that the guidelines are widely accepted as the basis for rabbit management, comment has been sought from government including state, territory and Commonwealth agriculture, environmental and resource management agencies, and from other land managers, and community organisations, including the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

There are strongly held conflicting views among people interested in the management of rabbits. Some scientists judge rabbits as Australia's most pernicious environmental problem, and wish to see more resources allocated to their management. People involved in commercial or subsistence use of rabbits are alarmed at the prospect of rabbits being managed to levels too low to allow such uses to continue. Economists argue the spending on rabbit management should be fully justified in terms of the economic or environmental returns on such investments, and are concerned that the information necessary for this does not exist. People holding strong animal welfare concerns hope to see rabbit management and better control techniques reduce the level of suffering in rabbits subjected to control operations. Farmers would like to be sure that expenditure on rabbit control is not wasted by rapid reinvasion from adjacent areas. The authors have had a difficult task in considering these competing views in the preparation of these guidelines but believe they are a significant step forward in the management of rabbits.

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. A major difficulty faced by the authors was that despite numerous historical accounts and studies of rabbits in Australia, their impact on the environment and on agricultural production is poorly documented. Nevertheless, the weight of scientific and other information collected over many decades reinforces the belief that rabbits are a serious vertebrate pest for agricultural production and the natural environment. Demonstration projects funded under the Vertebrate Pest Program administered by the Bureau of Resource Sciences are helping to document the impact of rabbits in Australia and to test the effectiveness of different approaches to management.

The guidelines recommend that, wherever practicable, management should concentrate on reducing rabbit density to low levels and holding it there by routine maintenance control. The evidence suggests that, if undertaken as part of a local or regional group scheme, this is the most cost-effective way of managing rabbit damage. While there is hope that rabbit populations will in the future be controlled by new or modified micro-organisms acting as mortality or sterility agents, we cannot depend on such developments. Until they are proven it is essential that strong efforts to control rabbits by conventional means be maintained.

These guidelines will help land managers to reduce agricultural losses and environmental damage through the use of scientifically-based management that is humane, cost-effective and integrated with ecologically sustainable land management.



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CONTENTS

FIGURES

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TABLES

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Several individuals from the Bureau of Resource Sciences deserve mention. Dr Peter O'Brien was a continuing source of advice. Quentin Hart and Hazel Small helped edit the manuscript. Deborah McLeod, Joy Manly, Cass Coleman and Sarah Martin all helped at various stages in the preparation of the document. Dr Richard Williams helped collate the report and provided input to improve the quality of the document. Henryk Dekker redrew many of the figures.

Dr Mary Bomford provided extensive scientific and other editorial comment and organised the final collation and publication of the guidelines.

Many other people and organisations, too numerous to acknowledge individually, gave us the benefit of their experiences by commenting on the manuscript at various stages of its evolution. The document was sent for comment to:

- Commonwealth Department of Primary Industries and Energy Divisions
- Standing Committee on Agriculture and Resource Management (SCARM)
- Australian and New Zealand Environment 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
- Australian Wool Research and Promotion Organisation
- Australian Conservation Foundation
- National Consultative Committee on Animal Welfare
- National Farmers' Federation
- Murray Darling Basin Commission
- Australian Veterinary Association
- Anangu Pitjantjatara Land Council

We wish to thank all these groups for their contributions.

The families of the authors deserve praise for remaining sane and helpful during its extended gestation.

Throughout the preparation of this report, the authors were reminded of the enormous contribution made by Dr Ken Myers, previously of CSIRO Division of Wildlife and Ecology, to our understanding of the rabbit in Australia. The research which he led with foresight, dedication and enthusiasm has in large measure made this report possible.

ACRONYMS AND ABBREVIATIONS

ACF	Australian Conservation Foundation
ACT	Australian Capital Territory
AEDP	Aboriginal Employment and Development Program (now ARRI)
AHC	Australian Heritage Commission
ANCA	Australian Nature Conservation Agency (formerly ANPWS)
ANZECC	Australian and New Zealand Environment Conservation Council
APB	Agriculture Protection Board (Western Australia)
APCB	Animal and Plant Control Board (South Australia)
APCC	Animal and Plant Control Commission (South Australia)
ARRI	Aboriginal Rural Resources Initiative
BRS	Bureau of Resource Sciences
CaLM	Department of Conservation and Land Management (New South Wales)
CALM	Department of Conservation and Land Management (Western Australia)
CCNT	Conservation Commission of the Northern Territory
CRC	Cooperative Research Centre (Vertebrate Biocontrol Centre)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCNR	Department of Conservation and Natural Resources (Victoria)
DPIF	Department of Primary Industry and Fisheries (Tasmania)
DSE	Dry sheep equivalent
ERIN	Environmental Resources Information Network
ESD	Ecologically Sustainable Development
ESP	Endangered Species Program
GIS	Geographic information system
GMAC	Genetic Manipulation Advisory Committee
Landcare	Commonwealth Landcare Program
LandCare	Victorian Landcare Program
NCA	Nature Conservation Authority
NCCAW	National Consultative Committee on Animal Welfare
NFF	National Farmers' Federation
NLP	National Landcare Program
NPWS	National Parks and Wildlife Services (various states)
NRIC	National Resource Information Centre
NRMS	National Resource Management Strategy
NSCP	National Soil Conservation Program
NSWAF	NSW Agriculture and Fisheries
pers. comm.	Personal communication
PMIS	Pest management information system
PPB	Pastures Protection Board
ppm	Parts per million
RCD	Rabbit calicivirus disease (RCD) also called rabbit haemorrhagic disease (RHD)
RLPB	Rural Lands Protection Board (New South Wales)
SCARM	Standing Committee on Agriculture and Resource Management
SCB	Soil Conservation Board of South Australia
SCS	Soil Conservation Service of New South Wales
SSC	Strategic, sustained control
SSCAW	Senate Select Committee on Animal Welfare
TAFE	Technical and Further Education
VPC	Vertebrate Pests Committee of SCARM
VPP	Vertebrate Pest Program

GLOSSARY

active entrance: a warren entrance that is being used as distinguished by obvious rabbit sign

active warren: an occupied warren

acute poison: a substance that kills an animal quickly, usually within hours, and after a single dose

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

antigen: a substance, usually foreign to the body, that stimulates an animal's immune system to make antibodies. Antibodies react with antigens in the body and can prevent the development of disease

biomass: the weight of living material in a specified area; often the amount of plant material covering an area of ground

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

calcareous: containing or like calcium carbonate

canids: members of the dog family

cementum: a thin, bonelike tissue that covers the root of a tooth

conservation values: aspects of the natural environment that society wants to protect, such as endangered species, wilderness and biological diversity

coumarins: a class of chemical compounds; some of which are used as vertebrate poisons (anticoagulants)

coupe: a forest plantation management unit containing trees of the same age

cumulative poison: a poison that builds up in an animal's body with successive doses or continued exposure. Usually more than one dose is required to cause death

discount rate: difference in value between present and future benefits. Calculating discount rates involves using the reverse equation to that used for calculating interest rates on invested money

dry sheep equivalent (DSE): the number of animals that eat the same amount of pasture as a non-breeding, non-pregnant ewe. For example, 12–16 rabbits are usually considered to be one DSE

ecotone: boundary region between different ecosystems, such as between forest and grassland

ectoparasite: a parasite that lives on the outside of an animal's body. Examples are fleas, ticks and lice

El Niño: name of a warm ocean current that appears intermittently off the coast of Ecuador and Peru. This is now recognised as part of a global climatic event that happens about every 3–6 years and typically lasts 12–15 months. It is associated with abnormally dry weather in much of eastern Australia

enclosure: an area of land fenced round to keep in wanted animals

endoparasites: parasites that live inside an animal's body, such as tapeworms and the bacteria in the digestive tract

enzyme: a substance that promotes natural chemical reactions in the body without itself being used up or changed in the process

epizootic: the occurrence or outbreak of a disease in a population or region at a much higher level than normally expected

exclosure: an area of land fenced round to keep out unwanted animals

felids: members of the cat family

fibrin: an insoluble fibrous protein produced during blood clotting

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

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

gross margin: the difference between the returns from the sale of a product from a farming enterprise minus the running costs. It excludes capital components such as the purchase of machinery

hypothermia: unnaturally low body temperature in warm-blooded animals

immunocontraceptive: same as immunosterilant

immunocontraceptive virus: a virus that causes an immune response leading to temporary or permanent sterility in infected animals

immunosterilant: a substance that triggers an immune reaction that causes sterility in a treated animal; acts as a contraceptive

knockdown: a control action that markedly reduces population size over a short time

LD_{50}: the quantity of a poison that will kill 50% of treated animals

leporids: animals of the rabbit and hare family

macropores: spaces in the soil that improve water penetration

mediterranean regions: regions with a climate similar to Mediterranean Europe, with hot, dry summers and cool, wet winters. In Australia these regions are around Adelaide and south of Perth

metabolic poison: a substance that is toxic to an animal's basic body functions through interfering with biochemical processes, such as oxygen transport

micro-arthropods: small insects, mites etc.

mustelids: weasels, ferrets etc.

myxomatosis: a disease caused by the myxoma virus that was introduced to Australia as a biological control agent for rabbits. The disease is effective in reducing rabbit populations in areas of moderate and high rainfall

neophobia: fear of new objects in the environment

net present value: discounted present value of all financial benefits produced by a project, minus the discounted value of the costs incurred

one-off control: a control measure that is implemented only once although it may have long-term or ongoing effect

parenchyma: essential or specialised supporting tissue of an organ

phosphorylation: attachment of a phosphate molecule to sugar groups. An essential biochemical reaction in plants and animals

primary poisoning: the death of animals that ingest the poison (see secondary poisoning)

quadrats: small plots of land used for sample measurements of such items as plants or dunes

rabbit calicivirus disease: an exotic viral disease that causes high death rates in rabbits. It is presently being investigated as a potential biological control agent for rabbits in Australia. Also called rabbit haemorrhagic disease

run-on areas: places where water tends to accumulate and which are moister and more productive than surrounding areas

scat: faeces

second generation anticoagulant: a new class of anticoagulant poison developed to control pests that have developed resistance to first generation anticoagulants. Warfarin and pindone are first generation. Bromodialone and brodifacoum are second generation. In contrast to first generation anticoagulants repeated ingestion may not be necessary to cause death

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

senescent: post-reproductive age

sign: any evidence of the recent presence of an animal such as dung, scratch and dig marks etc.

spotlight transect counts: a count of the number of nocturnal animals seen in the beam of a spotlight along a set or random transect. An estimate of population density can be extrapolated from this based on the length/width of the transect

squat: a shallow depression in long vegetation or under fallen timber where a rabbit takes shelter

sterilising agent: a substance that causes treated animals to become sterile; a contraceptive

stop: a shallow burrow dug by a pregnant female rabbit in which to have her litter. The entrance to a stop is covered with soil and is difficult to detect

tarbaby: a technique for killing rabbits where 1080 poison in grease is squirted into a rabbit warren. The rabbit dies from ingesting the poisoned grease while grooming the grease from fur and paws

thermoregulation: control of body temperature using a combination of external (e.g. the sun) and internal heat sources (metabolism)

total grazing pressure: the amount of pasture removed by all grazing animals present, including wildlife, domestic stock and insects. In practice, insects are usually not included in the calculation

transect: a rectangular plot in which data collection occurs

type locality: site at which the original specimen used to describe a species was collected

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

SUMMARY

The intro duced European rabbit *(Oryctolagus cuniculus)* is one of the most widely distributed mammals in Australia and, except for the house mouse *(Mus domesticus)*, the most abundant. Rabbits occur mainly south of the Tropic of Capricorn, and almost anywhere except at the highest altitudes, in dense forests or on poorly drained soils.

Rabbits are a major environmental and agricultural pest. Damage to the environment is particularly significant in semi-arid and subalpine areas where rabbit and sheep grazing has fundamentally altered the ecosystems. Rabbit control poses a significant animal welfare concern.

These guidelines contain a comprehensive review of the history of rabbits in Australia, their biology, the damage they cause, and past and current management. The attitudes of animal welfare groups, commercial, recreational and Aboriginal rabbit users, and other interest groups are examined. The authors recommend management techniques and strategies for control, illustrated by four case studies. Deficiencies in knowledge, management and legislation are identified. The guidelines are an essential reference and management guide for policy makers, land managers and others interested in rabbit management.

Why develop national guidelines?

These guidelines for managing the impact of rabbits have been developed under the Vertebrate Pest Program (VPP) which is administered by the Bureau of Resource Sciences (BRS). The project has been coordinated by the Vertebrate Pests Committee (VPC) of the Standing Committee on Agriculture and Resource Management (SCARM). These rabbit guidelines were funded by the VPP and the CSIRO. Similar guidelines have been published for feral horses, and others are being prepared for foxes, feral goats, feral pigs and rodents.

The purpose of the guidelines is to assist the development of strategies to reduce the damage rabbits cause to production and conservation values 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. Despite many decades of rabbit research we have little reliable information of this type for rabbit management. In developing these guidelines, the authors have used all available information, but they have also had to make assumptions about rabbit impact and the efficacy and cost-effectiveness of control techniques. These assumptions may need to be changed when more reliable information becomes available.

The rabbit problem

The results of the many scientific and other studies conducted on the effects of rabbits in Australia indicate that they are probably our most serious vertebrate pest, affecting agriculture, the pastoral industries and the environment.

There are no reliable figures for the national cost of rabbits to agriculture, but the annual loss to the pastoral region of South Australia alone is estimated at $20 million (1993-94 dollars, as are all money values in these guidelines unless otherwise indicated), an estimate that would be much higher if the reduction in production due to progressive deterioration of the land could be calculated. The effect on production is most apparent in drier areas where pasture production is low and rabbit numbers increase to high densities and compete with stock. In most higher rainfall areas rabbits can be managed, and are regarded as a moderately expensive nuisance to agricultural production, rather than a serious economic pest.

The serious impact of rabbits on native flora and fauna is now becoming recognised. Rabbits directly compete with many native animals for food and shelter and have extensive effects on native flora through ringbarking, grazing and browsing. The overall effects of rabbits on biodiversity are largely unquantified, though many species of vertebrates and invertebrates that depend on the vegetation damaged by rabbits are likely to be affected.

In the arid zone, rabbit densities below one rabbit per hectare can prevent regeneration of some native plants. The progressive deterioration of rangeland ecosystems may not be obvious because many trees and shrubs are long-lived. Mulga (*Acacia aneura*), for example, can live for 250 years. Tree and shrub populations become senile where rabbits destroy all seedlings. If rabbits are not reduced to very low numbers in these regions, the decline in native trees and shrubs through lack of seedling recruitment will continue. The potential ecological consequences of this decline are expected to include increased erosion and changes to plant and bird communities. There may be no safe rabbit density for some tree and shrub seedlings. Because other pests, domestic stock and native herbivores are also involved in browsing and grazing native plants, conserving biodiversity in the rangelands will require management of the total grazing impact by all these species.

Rabbits also have an impact on conservation values in higher rainfall areas. For example, rabbits at a density of three per hectare prevented regeneration of sheoak (*Allocasuarina verticilliata*) and sallow wattle (*Acacia longifolia*) in the Coorong National Park on the coast of South Australia. The effect of rabbits in modifying vegetation in conservation areas, however, has not been sufficiently evaluated for higher rainfall areas and may be unrecognised. It requires long-term evaluation.

Why do rabbits prosper in Australia?

Rabbits have a high reproductive potential. Adult females produce 15–40 young a year, but only 1–10% survive past the first year. The key to the success of the rabbit in Australia is the warren, which provides protection from weather and predators and enables rabbits to inhabit semi-arid and arid country. Contrary to popular belief, rabbits do not dig new warrens readily. Although they usually live in warrens, rabbits readily live above the ground whenever there is adequate shelter. In some areas a high proportion of adult rabbits live mostly above ground, such as the coastal scrub in south-western Western Australia and parts of Tasmania.

Another reason for the success of the rabbit in Australia is the absence of some diseases and parasites that keep its numbers in check in other countries. Moreover, the generally dry climate in Australia constrains the parasites that are present. Compared with Europe and America, Australia has few predators and, in particular, lacks wild mustelid species (*Mustela* spp.) such as weasels and ferrets, which kill young rabbits in warrens.

Factors affecting rabbit numbers

Rabbit populations in most of Australia fluctuate mainly in response to variation in rainfall. In the drier rangelands, rabbit numbers increase during favourable seasons and decline during droughts to around 1% of peak numbers. Therefore long-term trends are difficult to identify. In some higher rainfall areas, rabbit numbers have fallen in recent years because of cropping, warren ripping and property development. Rabbits often remain abundant in habitats where they are difficult to control, such as rocky hills and other refuges.

After the introduction and establishment of the virus causing myxomatosis in the early 1950s, rabbit numbers fell dramatically, and rabbits died out in some marginal habitats. The impact of the disease was greatest in the semi-arid areas where the carriers (vectors) of the virus, mosquitoes, are seasonally abundant. The impact was less in those areas where there are few mosquitoes, such as Tasmania, Western Australia and some tableland regions. The introduction in 1968 of the European rabbit flea (*Spilopsyllus cuniculi*), an alternative, more perennial vector, resulted in large reductions in rabbit populations in Tasmania, south-western Western Australia, on tablelands, and in parts of South Australia. The 1993 introduction of an arid-adapted Spanish flea (*Xenopsylla cunicularis*) is intended to cause similar reductions in the drier rangelands, and its spread and efficacy are currently being evaluated.

The efficacy of myxomatosis declined in the 1950s but has remained more or less constant since then and myxomatosis still plays a major role in limiting rabbit numbers. The present density of rabbits in Australia compared to the situation before myxomatosis was introduced is not known. On average, rabbit numbers are thought to be about 5% of premyxomatosis abundance in the higher rainfall areas and perhaps 25% in the rangelands. Although the resistance of rabbits to the virus has increased, this has probably been balanced by the evolution of more virulent strains of the virus. The effectiveness of myxomatosis in the long term cannot be predicted, so no reliance should be placed on its continued efficacy.

Development of a strategic management approach

Colonial governments and their successors relied on stringent legislation requiring landholders to undertake control. Various techniques were used, including shooting, poisoning, fencing, and even the intentional spread of predators such as cats. Most techniques were relatively ineffective, although with determination and persistence, and using rabbit-proof fences as boundaries, some landholders achieved sustained, low rabbit densities and occasionally complete local eradication.

Most evidence indicates that successful rabbit management requires integrated action at the state, regional and local level. Land managers need a clear understanding of techniques and goals and they need to accept responsibility for the action required. Extension programs increase general awareness and understanding of the damage rabbits cause and what can be done to alleviate the problem. An essential part of raising public awareness will be well-trained and motivated state and territory workers. Technical and Further Education Colleges can have an important role in training people in techniques of extension, damage assessment and control.

What is the strategic approach?

The emphasis in these guidelines is not on killing rabbits, but rather on their efficient and strategic management to reduce the damage they cause to production and conservation values in the most cost-effective way. Rabbits are but one factor in a complex and changing agricultural environment that includes a highly variable climate, fluctuating commodity prices, other animal and plant pests, farm stock and the profitability of farming businesses. Farmers need to consider investment in rabbit management in the context of investment in other areas of the farm business unit. Rabbits also need to be considered in relation to their impact on natural and semi-natural ecosystems, and on the biodiversity within them.

A strategic approach to the management of rabbits developed in these guidelines is based on four key activities:

Defining the problem — The problem should be defined in terms of rabbit damage and the reduction in rabbit 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 rabbit management include local eradication, strategic management, crisis management and no management. Eradication will rarely be a feasible goal.

These guidelines strongly recommend sustained, strategic management as the principal management option.

Implementing the plan — A local or regional approach to rabbit management is usually most effective. This generally requires coordinated action by individual property owners and government and other agencies.

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.

Community attitudes

Various segments of the community see rabbits either as appealing characters from cartoons and literature, a commercial resource, a subsistence food source, an animal welfare concern or a major pest. It is unlikely that these deeply held attitudes can be changed quickly, but the public needs to understand the damage caused by rabbits and its implications. Scientists and state and territory land management agencies must communicate to legislators, land managers, landholders and the public the damage caused by rabbits and ensure these people have sufficient information to make appropriate rabbit management decisions.

Rabbits as a resource — Rabbits are harvested in the wild and domestic rabbits are farmed for food and raised as pets and show animals. The associated industries are small; for example, the annual value of wild rabbit harvesting is estimated to be about $10 million. The promotion of wild harvesting and other forms of commercial use may inhibit effective rabbit management through, for example, providing a case against the introduction of new biological control agents. The authors believe the commercial use of wild rabbits has no role to play in managing rabbit impact, mainly because wild rabbit harvesting is usually from high density rabbit populations, and this will not reduce densities to a level where damage is effectively managed.

Aboriginal use of rabbits — Some Aboriginal groups include rabbits as a major part of their diet and perceive them as an integral part of the land. It is important that Aboriginal communities have access to information on the long-term consequences of high rabbit numbers, which may include loss of traditional values as well as ecological impacts. State and territory land management authorities need to work closely with Aboriginal people to assist them to make land-use decisions which meet their needs and enable ecologically sustainable land use.

Animal welfare — Some rabbit control practices are inhumane. The steel-jawed trap should be banned. The fumigant chloropicrin should be phased out once a more humane alternative is found. While some suffering must be expected with the use of techniques recommended in this report, their strategic application would minimise suffering by maintaining reduced rabbit populations, thereby minimising the need for repeated treatments.

Myth of the super bug — The success of myxomatosis in the 1950s has caused unrealistic expectations of biological control. Consequently many land managers may not put much effort into conventional rabbit management because of high hopes of future control by new biological control agents such as myxomatosis transmission via the arid-adapted Spanish flea, rabbit calicivirus disease (RCD), also called rabbit haemorrhagic disease (RHD), and virally-borne immunocontraception. Release of such new agents will be years away, however, even if these research projects succeed. Virally vectored immuno-contraception in particular, is long-term high risk research, and it is too early to predict whether it will be successful. New techniques will only complement, not replace, conventional control, and the challenge will be to use conventional control techniques to take maximum advantage of lowered rabbit densities following biological control. Maintenance control was rarely undertaken after the release of myxomatosis. Land managers cannot afford to rely on the potential of new agents to save them from action now.

Impact assessment methods

There is a pressing need for low-cost techniques to assess rabbit impact. At present, managers usually rely on estimates of rabbit abundance as an indicator of damage. There are risks in this approach because rabbits, at densities almost undetectable to a casual observer, can prevent regeneration of some native plants. Thus, the perception of low numbers may give an inaccurate measure of impact.

Rabbit distribution and abundance is best estimated from counts of semi-permanent features such as warrens and burrow entrances; these counts also indicate the proneness of the land to rabbit infestation. They are not suitable, however, where rabbits are mainly surface dwelling. Here, techniques such as dung and spotlight transect counts must be used, and these are less reliable.

Rabbit management techniques

Maps which show the relationship between distribution and abundance of rabbits and topographic, soil and other land features are an invaluable aid to planning and implementing rabbit management.

Over most of Australia where rabbits use warrens, the primary control technique involves destroying warrens and associated refuges, possibly after initial poisoning if rabbit densities are high. Following primary control, sustained maintenance control by warren ripping or by fumigation is essential. Using dogs to drive rabbits underground increases the effectiveness of ripping and fumigating. Poisoning without maintenance control provides only short-term relief. The primary role of poisoning is to reduce rabbit density before warren ripping. When rabbit populations are reduced by drought or myxomatosis, managers should take advantage of the reduced rabbit populations to apply other control techniques, to further reduce and maintain the low densities.

Management is more difficult where a proportion of rabbits dwell on the surface, a situation more common than was previously realised. Poisoning and, where practicable, refuge destruction are important techniques. A major risk with repeated poisoning is the development of bait and poison avoidance, as has occurred in Western Australia and New Zealand.

Impact of rabbit control on native wildlife

Predator–prey interactions are complex and little is known about those involving changes in the abundance of rabbits. The following hypotheses are based on ecological theory and limited experimental and anecdotal knowledge. Field experiments are needed before more reliable predictions can be made.

When rabbit numbers are greatly reduced, foxes and cats may turn to native wildlife as alternative prey in the short term. Such increased predation may occur after widespread rabbit control and is similar to the recurrent increased predation which occurs after droughts and myxomatosis outbreaks. Since rabbits are the primary food of foxes and cats in most of Australia, a long-term reduction in rabbit density might also reduce fox and cat densities, and so reduce their effect on wildlife in the longer term. Reduced grazing pressure from rabbits might also allow vegetation to recover which could increase habitat and shelter for wildlife and so reduce predation. Reducing rabbit numbers could also reduce numbers of native birds of prey, as rabbits are the main food of many raptors during their breeding seasons. On the basis of these hypotheses, fox and cat control should be implemented following rabbit control in areas containing susceptible, rare or threatened native species. More information may enable these procedures to be modified.

Strategies for reducing rabbit damage

These guidelines describe strategies for managing rabbits in four classes of land use:

- high production cropping and grazing land;
- low production rangeland;
- forestry plantations; and
- conservation areas.

The management option recommended for all classes of land use is sustained, strategic management. Ideally, rabbit management aims to reduce rabbit damage to the level where the benefits of management are greatest relative to the costs. This approach requires knowledge of the relationship between rabbit density and the costs and benefits of management. This is difficult and costly to determine, and it is unlikely that the rabbit, with its high reproductive potential, could be managed with this degree of precision.

For most circumstances, it is assumed that rabbit damage is related to rabbit density, although it is recognised that there is not always a direct correlation between rabbit numbers and levels of damage. For example, there is evidence that in the rangelands of New South Wales, competition between sheep and rabbits only occurs when pasture biomass is less than 250 kilograms per hectare. The relationship between rabbit density and level of damage will vary with both the type of damage being considered and other factors, such as the total grazing impact from all species and variation in the vegetation cover. This has implications for the selection of appropriate management strategies for rabbits in relation to different land uses and changes in market prices for wool, other commodities and for conservation values which are affected by rabbits.

In the authors' opinion, based mainly on the experience of state rabbit control authorities, data from small-scale field trials, and on rabbit population ecology, reducing and maintaining rabbit populations at minimum densities is more likely to be successful and profitable for damage management than some lesser level of control to densities from which rabbit populations can rapidly rebound. Even where resource damage only occurs when rabbit numbers are high, it may still be most cost-effective to maintain rabbits at very low densities at all times. Such a strategy could bring the greatest benefits at the onset of drought, when the impact of rabbits on both production and conservation values is likely to be high, and when land managers may have inadequate time, labour or funds to mount a rabbit control program. The relative cost-effectiveness of aiming for sustained minimum levels as a long-term strategy will depend on the cost of this level of rabbit control relative to the benefits resulting from the control, in comparison to the cost–benefit ratios of some lesser level of control or no control. The initial extra cost of achieving very low rabbit numbers could be offset by the reduced costs of continuing control to maintain these low numbers and reduced impacts. Strategic, sustained management (SSM) to reduce and maintain rabbits at minimum densities is most likely to be profitable in places where uncontrolled rabbit densities would usually be moderate or high (greater than three rabbits per hectare).

Rabbit control to achieve and maintain minimum densities is also likely to be profitable in conservation reserves where a high value is placed on the resources being protected from rabbit damage. In the rangelands, the high cost of reducing rabbits to very low densities might prevent this from being a feasible goal. Although there may be high benefits from rabbit control in such areas, in terms of increased wool clip and land values, the large areas involved mean that initial control costs may be high and land managers may lack sufficient funds, especially at times of low wool values. Rabbit control to increase production may not be profitable in areas which naturally have low rabbit densities (less than one rabbit per hectare). More information on the relationships between rabbit density and damage, and between control costs and benefits, is needed for assessments of the most effective strategies for rabbit management for different areas and land uses, and on the best approaches for integrating rabbit management with other property operations.

A goal of reducing rabbit numbers to as close to zero as possible and then maintaining them at that level has the advantage of providing land managers with a clear, readily monitored, long-term goal. This may counter any tendency of land managers to develop tolerance to rabbits which could undermine efficient long-term management. Land managers need to be committed to a long-term strategy for a successful outcome.

Wherever practicable, SSM includes assessing the effectiveness of the management program in reducing rabbit damage, especially when aiming to protect conservation values.

Local eradication is achievable only in special situations such as on small islands and on properties protected by natural barriers or rabbit-proof fences and monitored continuously for reinvasion by rabbits.

Economic frameworks need to be developed to assist in the assessment of the relative value of alternative control strategies whenever this is feasible. Such frameworks require: definition of the economic problem; data on the relative costs and benefits; an understanding of why the actions of individual landholders may not lead to optimal rabbit management; assessment of the means by which governments can overcome identified market failures; and an assessment of the likely returns from alternative rabbit management strategies.

Implementing rabbit management

For effective rabbit management, land managers must be motivated by an awareness of potential or actual rabbit damage. They need to know what can and should be done to alleviate it, and to be involved at all stages of the management process: planning, implementation, monitoring and evaluation. State and territory pest management authorities with appropriately trained field staff operating at the regional and local level have a primary role in motivating landholders to take appropriate action. Locally-based schemes such as Landcare groups are a primary means for governments to work with landholders. Successful examples of this approach include the Bathurst Scheme and the Pine Creek Rangecare Group. Further studies are required, however, to determine the essential elements of successful schemes, and whether these will continue to operate after government assistance is withdrawn.

Public lands — Governments manage large tracts of land infested with rabbits. While private landholders are required by governments to manage rabbits, there is often no such obligation on governments. Private landholders see this as inequitable. As a minimum, governments should manage and maintain an adequate buffer zone between public and private land to protect adjacent properties. If there are insufficient resources for effective, sustained management across all public land, efforts should be concentrated in high-value areas.

Legislation — Legislation should clearly state the responsibility of land managers for rabbit management and facilitate appropriate action. Equally important is the ability and commitment to enforce the legislation. Legislation is also needed to regulate the use of toxic chemicals.

Who should implement control? — Many aspects of rabbit management require trained, experienced advisers and operators. While some landholders and land managers have skills in rabbit management, those without such skills may wish to be trained. Where this is impracticable, hire of government services or use of contractors is an alternative.

Training — States and territories which do not have the resources and expertise to train field staff may be able to access training programs in states such as South Australia and Western Australia, which could recover costs for this service. Training in rabbit control needs to be part of integrated vertebrate pest management which, in turn, is part of a holistic approach to management. This document and the associated documents on other vertebrate pests may be useful in training vertebrate pest managers.

Research needs

The basic biology of the rabbit is well known. Less is known about the interaction between rabbit numbers and production losses and disruption of ecosystems. Research priorities are:

Impact — (1) Rangelands: measure rabbit impacts on native vegetation including regeneration, and on pastoralism; (2) rangelands and cropping areas: quantify the relationship between rabbit density and impact; and (3) conservation areas: measure rabbit impact on native vegetation, including regeneration, and on fauna for all climatic regions.

Monitoring — Develop low-cost techniques for rapid assessment of: (1) rabbit impact on crops, native vegetation, native fauna and soil; and (2) rabbit abundance where warrens and burrows are little used by rabbits.

Economics — Determine cost–benefit analyses of different levels of rabbit control for both cropping and grazing lands. Examine the cost-effectiveness of various combinations of control techniques and prescriptions for control.

Traditional control — Determine optimal methods for controlling rabbits that live in scrub, rocky areas and on steep slopes; improve humaneness of techniques, particularly fumigation; improve baiting techniques and target specificity; develop alternative toxins; reduce impact on predators and native fauna; and improve integration with other farm management practices.

Biological control — Further development of myxomatosis and rabbit calicivirus disease (RCD): host/vector/virus interactions; strain variants and manipulation; mass production of virus; and improved knowledge of transmission by vectors.

Creating an appropriate administrative environment

An appropriate administrative environment is crucial to the success of strategic rabbit management. The following are key activities:

- Review the adequacy of existing legislation, policies and institutional arrangements for the formulation and delivery of programs for managing rabbits and other vertebrate pests at all levels of government.
- Improve humaneness by prohibiting steel-jawed traps and phasing out chloropicrin.
- Review and improve effectiveness of support for Landcare groups and other land management groups, consistent with the National Landcare Program.
- Review policies on land subdivision.
- Investigate introduction of caveats on land titles relating to removal of rabbits.
- Investigate means by which financial institutions can value effective rabbit management as capital improvement of property values.

Training and extension

Attention to training and extension is essential, with the following as key activities:

- Update training courses and manuals on vertebrate pest management to include information contained in these guidelines and to integrate rabbit management with other aspects of land and property management through the property planning process.

- Investigate feasibility of courses on rabbit control being included in the curricula of appropriate tertiary institutions.
- Coordinate approaches of the various states and territories to cooperate on development of pest management information systems, and on interstate training of vertebrate pest control officers.

Enlisting community support

Rabbit management in Australia needs widespread public support for success; education is the key to this. Educational packages for schools should be reviewed and, where necessary, expanded or improved.

Extension and advisory services to Landcare and other land management groups should be augmented. These services are essential to improve community and land manager understanding of research findings, to engender a sense of ownership of the problem and to place rabbit damage in the context of ecologically sustainable development.

INTRODUCTION

These guidelines for managing the impact of rabbits have been developed under a project managed by the Bureau of Resource Sciences (BRS) and coordinated by the Vertebrate Pests Committee (VPC) of the Standing Committee on Agriculture and Resource Management (SCARM). The project is funded by the BRS and the CSIRO. Similar guidelines have been published for feral horses, and others are being prepared for foxes, feral goats, feral pigs and rodents.

These guidelines are primarily for state and territory land management agencies to use in consultation with private land managers and other interest groups, to prepare state, regional and local strategies for reducing the impact of rabbits on agricultural production and the environment. The guidelines should be read and used in conjunction with *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993), which explains why the guidelines were developed, their aims, the development process, their use and the principles of pest management.

Various interest groups were consulted during preparation of these guidelines, notably state and territory land management agencies, the National Farmers' Federation (NFF), the Australian Conservation Foundation (ACF), the National Consultative Committee on Animal Welfare (NCCAW), the Australian Veterinary Association (AVA), and the Anangu Pitjantjatjara Aboriginal Land Council.

Effective rabbit management, particularly in the rangelands, is central to the success of a number of Commonwealth Government conservation programs, including the Ecologically Sustainable Development (ESD) Strategy, the Endangered Species Program (ESP) and the Decade of Landcare (which incorporates the National Resource Management Strategy (NRMS), the National Landcare Program (NLP), and the One Billion Trees and Save the Bush Programs).

Consistent with the holistic approach to land management advocated under the Ecologically Sustainable Development Strategy and Landcare, all the management guidelines for feral animals, including this one, consider interactions between all pests, other species and aspects of land management. A holistic and integrated approach to management is necessary for Australia's rangelands, where rabbits and many other vertebrate pests are common.

The guidelines should assist state and territory land management agencies to more effectively manage pest damage through better coordination, planning and implementation of regional and local management programs. Achieving the strategic management of rabbits and other pest animals involves four key components (Figure 1):

Defining the problem — Ideally the problem should be defined in terms of rabbit damage and the reduction in rabbit density required to reduce or prevent the damage. Unfortunately the relationship between rabbit density and damage has not been quantified in most cases. Until research establishes this relationship, most managers will rely on measuring the abundance and distribution of rabbits or warrens, and assume that damage is directly related to rabbit abundance.

Developing a management plan — Land managers must establish clear objectives in terms of the desired production or conservation outcome sought. Options for rabbit management include local eradication, strategic management, crisis management and no management. Eradication will rarely be a feasible goal. These guidelines strongly recommend sustained, strategic management as the principal management option. The choice of initial and maintenance control techniques in the management strategy will depend mainly on whether the rabbits shelter in surface cover or in underground warrens or burrows.

Implementing the plan — A local or regional approach to rabbit management is usually most effective. This generally requires coordinated action by individual property owners and government and other agencies.

Monitoring and evaluating the operation — 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. Both forms of monitoring help determine whether the management strategy should be modified.

In most cases, rabbit impact on one property or area is influenced by their presence in neighbouring properties or areas. Thus the problem is often one that is shared by many people or agencies who need to cooperate to find a solution.

The objective of these guidelines is to change rabbit management from crisis management by individuals and agencies to strategic management based on cooperative action. Adopting a whole property approach to management, preferably linked to a regional or total catchment plan, is advocated. The strategic approach to rabbit management involves encouraging a group approach in an initial control campaign and following this with sustained control measures.

The criterion for success of these guidelines will be the acceptance and implementation of the strategic management approach to the rabbit problem by a significant number of agencies and individuals.

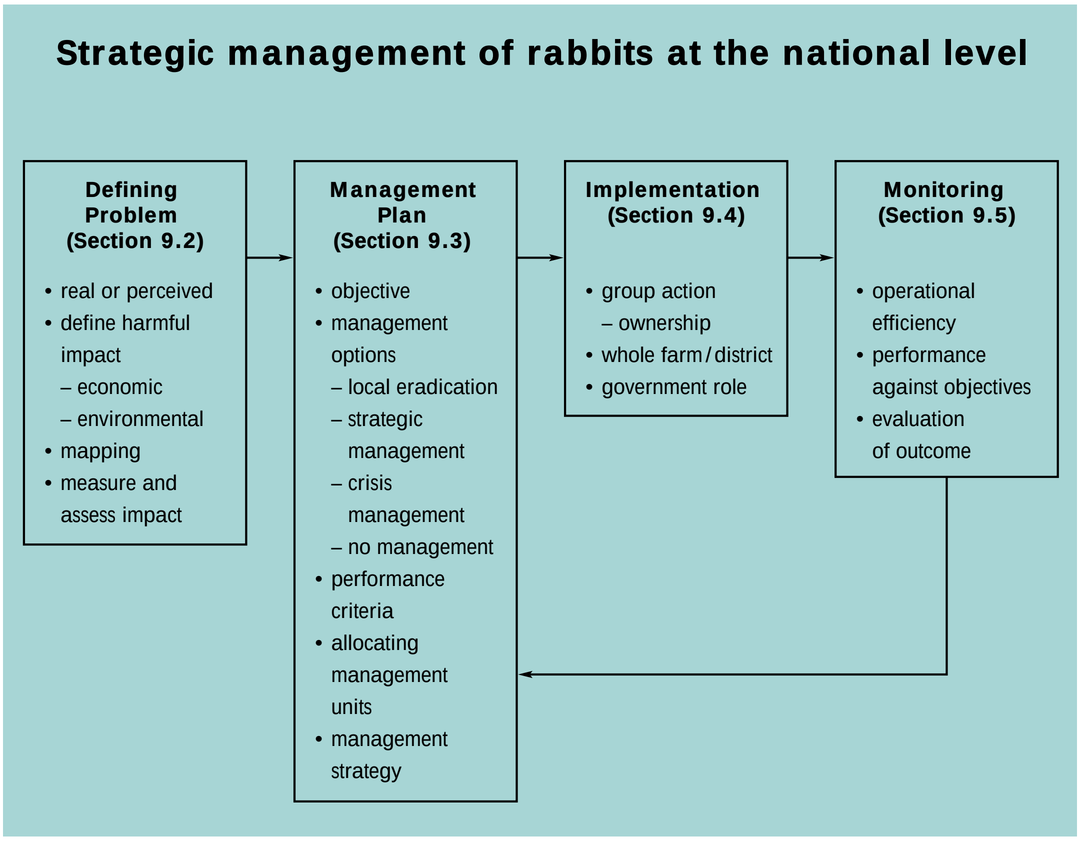

Figure 1: Strategic approach to managing rabbit damage.

To encourage the adoption of 'best practice' pest management, the Government, in its Environment Statement of December 1992, provided increased resources to the Vertebrate Pest Program (VPP) 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 rabbits, 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. Each of the guidelines will be reviewed periodically as knowledge of the strategic management approach increases.

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. Accordingly, preference in funding under the VPP is given to projects which involve collaboration between a number of appropriate government and/or non-government agencies and involve community-based groups in their design and implementation.

The VPP supports projects which address the impact pests have on primary production. The complementary Feral Pest Program administered within the Australian Nature Conservation Agency (ANCA) gives priority to strategic pest management in areas primarily used for conservation. There are strong linkages between the programs, and projects which address both agricultural and conservation damage due to pests may be jointly funded.

Note: All money values throughout the guidelines are in 1993-94 dollars unless otherwise indicated.

PART ONE

HISTORY, DISTRIBUTION AND BIOLOGY

1. History of Introductions and Spread

1

Summary

During the last ice age the range of the European rabbit contracted to the warmest parts of southern Spain and France. The rabbit appeared to be a disappearing species before man reversed its fortunes so dramatically. It is now found over most of Europe, on three other continents and on more than 800 islands.

In mainland Australia rabbits established near Geelong in Victoria following the first known release of wild stock in 1859. Their spread was rapid and was aided by the presence of burrows of native species, the paucity of predators, the modifications to the natural environments made for farming and occasionally by their deliberate transport.

1.1 Europe

Members of the family Leporidae (rabbits and hares) first appeared in the late Eocene (40–70 million years ago) in Asia and North America (Dawson 1981) and arrived in Europe during the Miocene (10–25 million years ago). The genus *Oryctolagus* was first recorded in Spain during the middle Pliocene period. Two European subspecies have been distinguished, *O. cuniculus cuniculus* from southern France (average adult weight 1500 g) and *O. cuniculus huxleyi* from Spain (average adult weight 1000 g). Recent evidence based on mitochondrial DNA has revealed that the two subspecies diverged more than one million years ago (Biju-Duval et al. 1991). During the last ice age the European rabbit was largely restricted to the warmest parts of Spain and southern France and its major spread did not commence until historical times. Domestic rabbits were derived from the French subspecies by monks some time between the fifth and tenth centuries (Sandford 1992).

Rabbits were introduced to England from France soon after the Norman conquest in the eleventh century. Rabbits remained scarce outside rabbit farms (called warrens) until the nineteenth century. At that time free-living populations increased due to changes in farming practices, the planting of hedgerows and an increase in the mortality of rabbit predators due to hunting by the nobility and trapping by tenant farmers. Colonisation took some 900 years in England and Wales and was still not complete in Scotland in 1950 (Sheail 1971).

The Spanish subspecies was transported around the eastern Mediterranean as early as 1500 BC by Phoenician traders. In Roman times Spain was renowned for its rabbits and the name of the country 'Hispania', later 'Espana', is thought to be derived from a Semitic word denoting rabbits. In the first century BC, the inhabitants of the islands of Minorca and Majorca asked Emperor Augustus for the help of the Roman army in controlling the impact of rabbits on their crops and trees (Barrett-Hamilton 1911; Harting 1986). The French subspecies of rabbit were often liberated on islands to provide food for shipwrecked sailors; they are now present on some 800 islands throughout the world (Flux and Fullagar 1992).

Free-living rabbits were rare in France in the sixth century but many colonies were held in enclosures or on islands for hunting purposes, and rabbits were often transported to start new colonies. Introductions were most successful on islands, perhaps because of high predator pressure elsewhere. The rabbit's colonisation of France was not completed until the nineteenth century and range expansion is still occurring elsewhere in Europe although the species may now be close to its ultimate limits.

The rabbit was introduced into Italy in the first century AD but the populations became extinct. Present populations near Padua, Milan and Pisa are all the result of recent introductions. There are no rabbits in Greece or elsewhere in the eastern Mediterranean although they were undoubtedly introduced many times. The reasons for the slow rate of spread and for so many failed introductions in Europe are unknown. However, the French subspecies seems to require intense agricultural and pastoral development for it to thrive and maintain itself in the wild.

The relationship of the rabbit to people is unique. It is farmed for meat and fibre and is a laboratory animal, a significant pest, a major game species, a household pet, a storybook character and a star in animated cartoons. It is the only farmed animal domesticated in historical times and the only pest mammal whose densities have been much reduced by biological control. The ownership of rabbits by the Lord of the manor and the persecution of poachers are credited with being the main cause of the radicalisation of the lower classes in England and a cause of the French revolution (Hopkins 1985). During the depression in Australia, and during the second world war in Europe, the rabbit was the main source of animal protein for many people. The scale of the impact of the rabbit in Australia is considered to be unique in the history of wild animal introductions.

1.2 Australia

Domestic rabbits arrived in Australia with the First Fleet in 1788. The first feral populations were in south-eastern Tasmania where they numbered in the thousands on some estates by 1827. The first person to introduce wild rabbits to the Australian mainland was Thomas Austin, an enthusiastic sportsman and member of an acclimatisation society. He also introduced hares. Twenty-four rabbits arrived from

Rabbit numbers reached high levels in south-eastern Australia prior to the introduction of myxomatosis. Bounties and the market for rabbit meat and fur, combined with the high numbers of rabbits, made rabbit trapping a profitable industry.

Source: NSWAF (duplicated from print: circa 1948, Cowra)

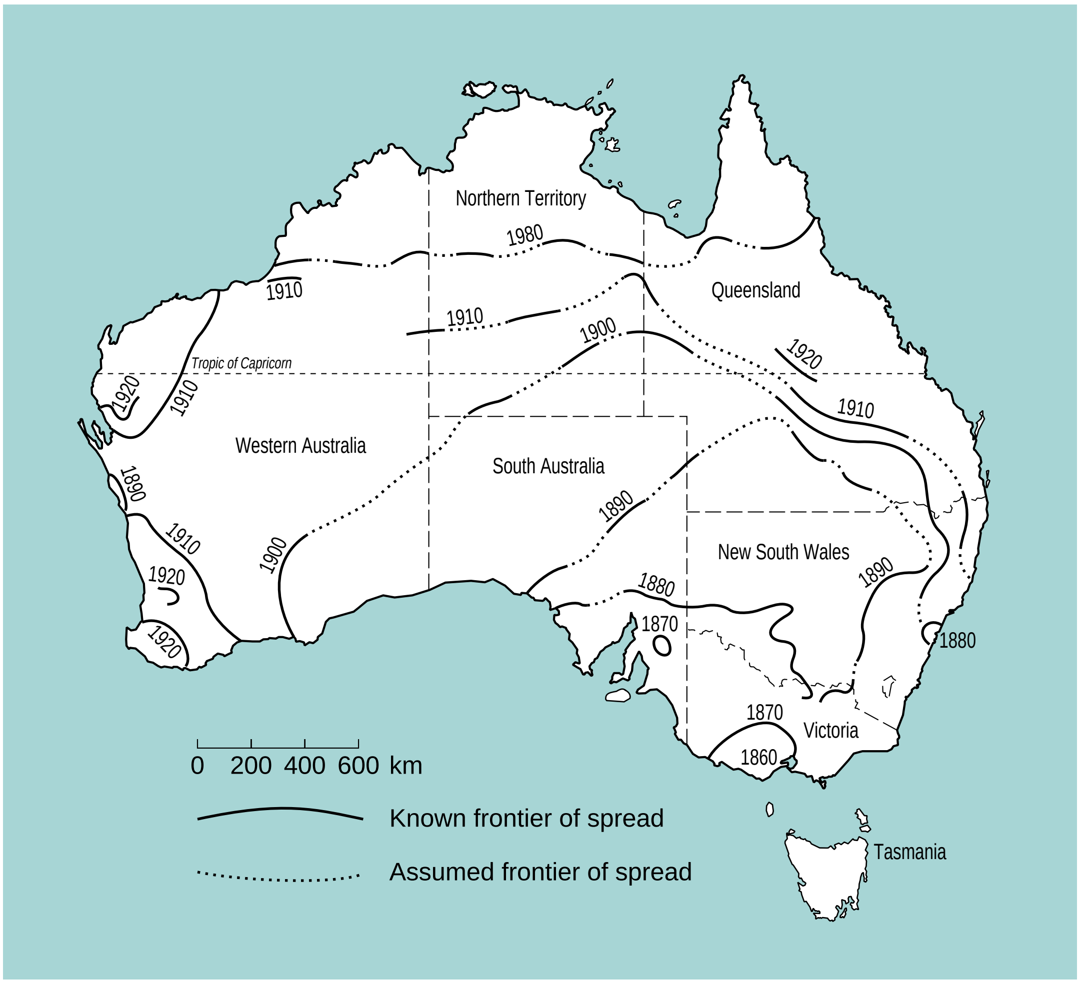

Figure 2: Spread of the rabbit in Australia (no data available for Tasmania) (after Stodart and Parer 1988).

England on Christmas Day 1859 and were put in enclosures at Austin's property, 'Barwon Park', near Geelong. Some were released or escaped soon after. One of Austin's descendants suggests that there were only 13 rabbits, some of which were caught in the wild and some of which were hutch-bred.

'Domestic rabbits arrived in Australia with the First Fleet in 1788.'

In 1866, 14 253 rabbits were shot on 'Barwon Park'. Initially, rabbits spread slowly from 'Barwon Park' and from a second release point at Kapunda in South Australia, taking about 15 years to reach the New South Wales border (Rolls 1969; Stodart and Parer 1988). Fifteen years later they were into Queensland, and by 1900 they were in Western Australia and the Northern Territory (Figure 2). The rate of advance varied from 10–15 kilometres a year in the wet and forested country to over 100 kilometres a year in the rangelands. The rate of spread was mostly faster than in New Zealand and in Argentina, where it was about 10–15 kilometres a year. It was the fastest rate of any colonising mammal anywhere in the world (Caughley 1977), although it was closely matched by the fox (*Vulpes vulpes*) and the hare (*Lepus europaeus*) in Australia (Jarman 1986a, b). The fox crossed from Victoria into New

South Wales 13 years after the rabbit and entered Queensland from the New England district at the same time as the rabbit; it entered Queensland in the far west 24 years after the rabbit.

As in Europe, human changes to the natural environment made it more suitable for rabbits. Rabbits moved up river systems, which were the first areas selected by pastoralists (Strong 1983). Felled timber provided abundant rabbit harbour, and the grazing of perennial grasses by domestic stock made the grasses more nutritious and available to rabbits. The introduction of more nutritious annual grasses and forbs of Mediterranean origin, which have a seasonal growth cycle more in tune with the rabbit's breeding season, also helped. The northward spread of rabbits in Queensland this century is the result of improvements in the nutritionally poor tropical pastures and the planting of winter crops (Parer 1987; Stodart and Parer 1988).

'The rate of spread of the rabbit in Australia was the fastest of any colonising mammal anywhere in the world.'

As the Australian environment was modified by people, many native species and the hare went through one brief eruptive phase, but only the rabbit remained at high densities (Jarman and Johnson 1977; Lunney and Leary 1988). The presence of burrows of native species (*Vombatus* spp., *Bettongia lesueur, Macrotis lagotis, Lagorchestes hirsutus*) aided its spread, as did the wholesale destruction of predators. At 'Barwon Park' in 1866 the shooting tally was 448 hawks, 23 wedgetail eagles, 622 native cats and 32 feral cats (Rolls 1969). In the early stages of the rabbit's spread, only short, shallow warrens were dug, but with the arrival of the fox deep warrens had to be excavated (Abbott 1913; Matthams 1921; Gooding 1956; Tunbridge 1991).

2. Distribution and Abundance

Summary

Rabbits are one of the most widely distributed and abundant mammals in Australia. South of the Tropic of Capricorn they occur almost everywhere except at the highest altitudes, in dense forests or on certain soil types. North of the Tropic of Capricorn their distribution is more fragmented, they are often restricted to deep or shaded warrens on the more fertile soils in run-on areas, or to areas with a shallow watertable.

After the introduction of myxomatosis in 1950, rabbit numbers fell by about 95% in most of southern Australia and by almost 100% in marginal habitats. The impact of the disease was greatest in semi-arid areas where mosquitoes are seasonally abundant, and least in the more arid rangelands and on the tablelands where mosquitoes are less abundant. The present density of rabbits in Australia compared to the density before myxomatosis is not known. On average, rabbit densities may be about 5% of premyxomatosis densities in the higher rainfall areas and perhaps 25% in the rangelands. In the more arid rangelands, numbers increase during favourable seasons and decline during droughts to around 1% of peak numbers. Because of these large fluctuations it is difficult to discern any long-term trend. In higher rainfall areas, numbers are generally decreasing due to the expansion of cropping, the increased use of warren ripping and property development. Numbers may be increasing in some districts in locations such as rocky hills where control is difficult.

2.1 Distribution in Australia

South of the Tropic of Capricorn rabbits can occur almost anywhere except in dense forests, on black soil plains or above 1500 metres (Parker and Bults 1967; Parer and Libke 1985). North of the Tropic of Capricorn their distribution is fragmented. Tall tropical grasslands are nutritionally inadequate for rabbits, and pasture growth occurs at the wrong time for rabbit breeding. In the arid tropics, rabbits must contend with short breeding seasons, high warren temperatures, dry pastures on infertile soils and mineral deficiencies and imbalances (Cooke 1977a; Parer 1987). In these areas rabbits also have problems with water balance and thermoregulation and are often restricted to deep or shaded warrens on the more fertile soils in run-on areas, or to areas with a shallow watertable.

In the more arid areas below the Tropic of Capricorn, local distributions of rabbits change dramatically with time. After a run of good seasons, rabbits may be abundant over an entire region. During severe droughts they disappear completely from some land systems and their range contracts to refuge areas where there are large, deep warrens alongside drainage channels or dried-up swamps (Myers and Parker 1975 a, b).

'Rabbits prefer well-drained soils — they are not found in black cracking soils which become waterlogged.'

Soils are a major factor influencing local and regional distribution (Parker et al. 1976; Parer and Libke 1985). Warrens are larger and more dense in the deeper soils on lower slopes and flats. These areas are also the most productive areas for domestic stock and are important for drought fodder (Mutze 1991). Rabbits prefer well-drained soils. Warrens are never found on black cracking soils which become waterlogged and the few rabbits living on this soil type breed in hollow logs. Warren density is higher on deep sands than on shallow sands (Matsumoto 1985). This may be due to fox predation or to temperature effects (Wood 1980; Parer and Libke 1985). Rabbits are absent from the Pilbara and Ashburton districts of Western Australia due to a combination of shallow soils and a nutritionally deficient pasture (Newsome 1975; King 1990).

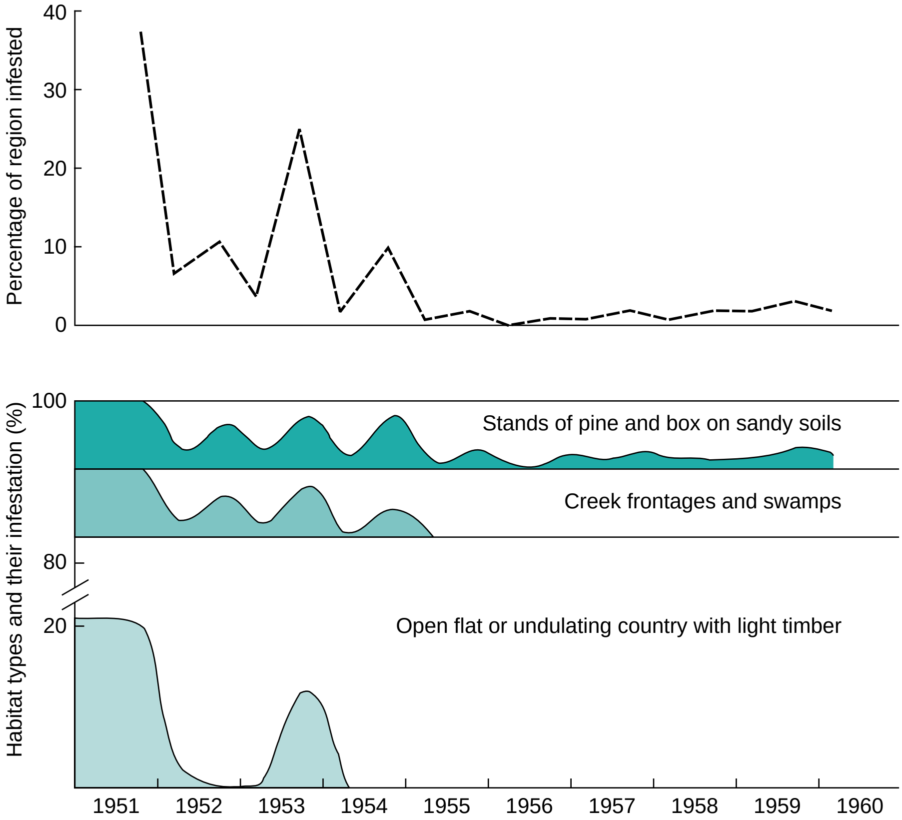

Figure 3: Rabbit infestation trends in different land types in the Riverina district of New South Wales after the introduction of myxomatosis (after Myers 1962).

Before myxomatosis, rabbits were not distributed evenly over southern Australia. Even in the climatically favourable Riverina district in New South Wales they were at moderate or high densities over only 35–40% of the district (Myers 1962). After myxomatosis was successfully introduced, their distribution changed dramatically in the Riverina. Within a few years they had almost disappeared from the flat or undulating country and had retreated to the well-drained sandy areas or to the rocky, timbered hills (Figure 3). Similar but unrecorded changes in local distribution probably occurred over much of Australia.

Rabbit numbers tend to be low in much of the sheep–wheat zone. In closely settled districts, cropping, pasture improvement, poisoning and warren destruction restrict high rabbit densities to places where vehicle access or warren destruction is difficult.

2.2 Changes in abundance with time and space

Although rabbit densities are rarely known precisely, references in this document to low, medium and high rabbit densities denote, approximately, less than 1.0, 1–4 and more than four rabbits per hectare respectively. Spotlight transect counts of low, medium and high rabbit densities in open country with low pasture are approximately less than 5, 6–30 and more than 30 rabbits per spotlight kilometre respectively.

'On average, the number of rabbits in higher rainfall areas may be 5% of pre-myxomatosis levels; in arid areas the figure may be around 25%.'

In the rangelands where rainfall is less than 300 mm, numbers build up after a series of good seasons and then collapse during drought (Figure 4) (Myers and Parker 1975 a, b; Newsome et al. 1989). The collapse is due to the low water and energy content in the available forage and/or to depletion of available pasture by rabbits and stock. Numbers may then remain low for some years. The rate of resurgence depends on rainfall, predator numbers and warren availability. In sand dunes 99% of warrens can disappear in a drought and population recovery is slower than in stony areas where warrens are more permanent (Figure 4). Rabbit densities tend to be higher and fluctuate less in the more lightly grazed parts

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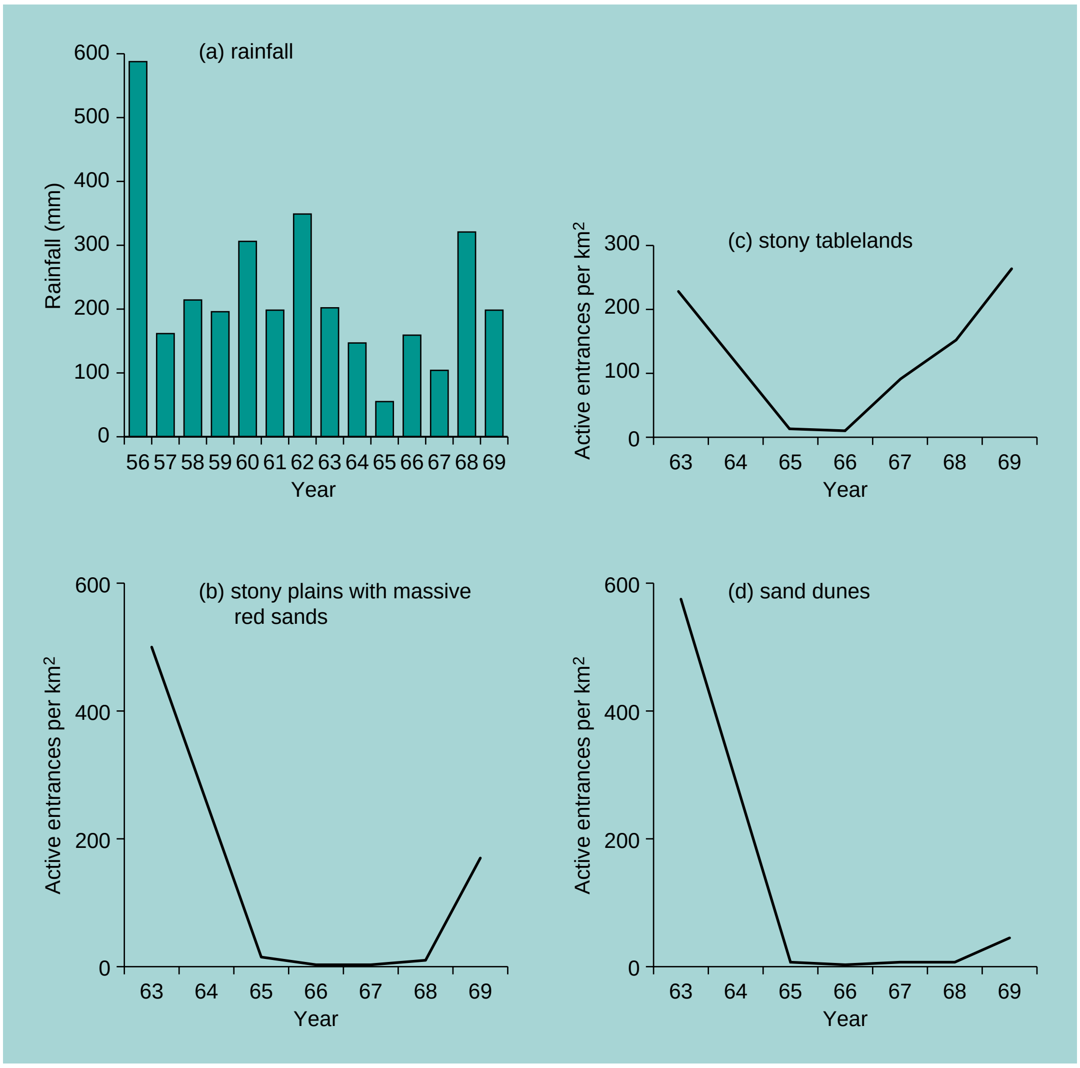

Figure 4: Rainfall and fluctuations in rabbit populations in different land systems in western New South Wales. Graphs for: (a) rainfall; (b) stony plains with massive red sands (rangelands); (c) stony tablelands; (d) sand dunes (after Myers and Parker 1975a).

Table 1: Percentage of New South Wales with rabbits at different levels of abundance (after Croft 1990).

Density*	1980	1985
Nil	34.7	23.7
Low	33.5	42.0
Medium	21.7	21.7
High	10.1	12.6

* Low: a few holes, some signs of scratching and dung.
Medium: active warrens present, some rabbits visible, considerable signs.
High: abundant active warrens, many signs, rabbits visible any time.

of a paddock that are distant from stock watering points (Newsome 1993). In semi-arid areas populations decline but do not collapse in droughts except locally where there are very high rabbit populations (Parer 1977).

Besides varying between years, rabbit populations have an annual cycle. The low numbers at the beginning of the breeding season increase by a factor of 2–5 to a peak towards the end of the breeding season (Gilbert et al. 1987).

The current density of rabbits in Australia compared to the situation before

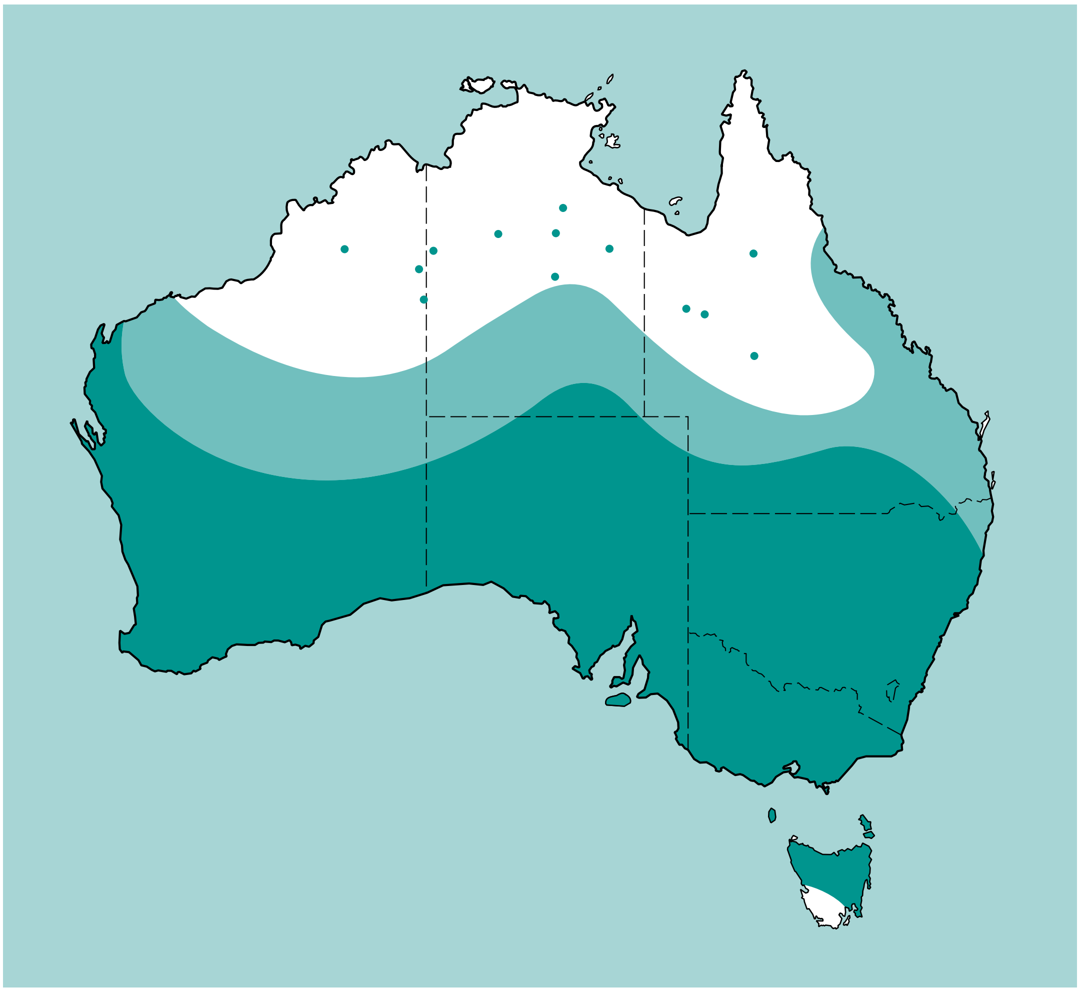

Figure 5: Present distribution of the rabbit in Australia. Bold stipple — widespread and common; light stipple — scattered populations; dots — isolated populations (after Myers et al. 1989). The density of the rabbit across its range varies considerably over time due to factors such as drought, myxomatosis and human control.

myxomatosis is not known. Averaged over good and bad years the numbers in better rainfall country may be 5% of the premyxomatosis numbers; in the arid zone the figure may be 25% (Myers 1962). Estimates of rabbit densities after myxomatosis for 27 sites ranged from 2–97 per hectare with an average of three per hectare (Wood et al. 1987).

In general, high rabbit numbers over large areas are found only in those areas where management is difficult or neglected, or in some rangeland areas where control is not obligatory (Northern Territory) or the legislation is not enforced because control is perceived to be uneconomic.

'The areas where rabbits are a major problem for economic or conservation reasons are the southern third of the Northern Territory, the northern three-quarters of South Australia, western New South Wales and the Nullarbor Plain in Western Australia.'

The areas where rabbits are a major problem for economic or conservation reasons are the southern third of the Northern Territory, the northern three-quarters of South Australia, western New South Wales and the Nullarbor Plain in Western Australia. Rabbits are low in numbers throughout most of the sheep–wheat zone because the area is flat, largely cleared, occasionally cultivated and the warrens are accessible and easily ripped. In higher rainfall country the main problem areas have a patchy distribution and are usually found on land with steep hillsides, gullies with steep sides, large rocks, abundant fallen timber, or low scrubby vegetation. In 1980 and 1985, 65–68% of New South Wales had few or no rabbits and 10–13% had high numbers (Table 1). The distribution of rabbits in Australia is shown in Figure 5.

In higher rainfall areas numbers are probably decreasing due to property development and the increasing use of warren ripping (Nolan 1981). In some areas of Victoria, however, where control is difficult, the increase in rabbit numbers is reflected in the ten-fold increase in the use of 1080 poison during the last decade (I. Nolan, Keith Turnbull Research Institute, pers. comm. 1992). In Queensland, rabbit numbers in a million hectare area around Stanthorpe/Inglewood/Texas/Goondiwindi seem to have decreased for reasons that are not obvious. Commencing in 1964, the Queensland Rabbit Control Authority, the functions of which are now undertaken by the Land Protection Branch of the Department of Lands, employed 12 operators who were continuously poisoning. The overall infestation declined to such an extent that by 1983 only five operators were employed for spot poisoning. However, because of the great variations in rabbit numbers with seasonal conditions, it is difficult to detect any long-term trend over much of the rangelands.

3. Biology

Summary

The European wild rabbit belongs to the family Leporidae which has 52 species of hares and rabbits living in grassland and savanna ecosystems on four continents. Unlike hares, which rely on speed and endurance to elude predators, the various species of rabbits live near dense cover to which they flee when threatened. The European wild rabbit is the only rabbit that constructs large warrens, and is the only species of rabbit that can live in open grassland, because the warren provides the cover it requires.

The optimum habitat for rabbits in Australia is the intermediate rainfall zone, where parasite numbers are low, droughts are uncommon and breeding seasons relatively long. Rabbits occasionally do well in Australia's hot arid zones even though physiologically they are not well adapted to arid conditions. When some green vegetation is available, they readily find the high protein, high water content diet they need to survive and reproduce. The key to their success in most environments, but particularly in the arid zone, is their ability to build warrens. The warren protects rabbits from predators and climatic extremes. However, during prolonged drought when food quality and quantity decline their populations crash.

Survivors of a population crash tend to be adult rabbits. After the breaking of a drought, rabbit populations are held at low densities for several years by a combination of native predators, foxes and feral cats. It is not until fox and feral cat numbers decline some time after the crash of the rabbit population, and good seasons return, that rabbit numbers build up again. Under good conditions, an adult female can produce 30–40 young a year.

Adult rabbits live as territorial monogamous pairs, or in social groups of up to ten individuals with separate hierarchies for males and females. Males fight to defend females and females fight to defend access to breeding sites within warrens. As many more young males than females disperse, the warren is a heritage passed on by adult females to female offspring. Resident rabbits rarely move more than 200 metres from their warren. Major causes of death are drought, parasites, rabbit management programs, myxomatosis, and predators such as dingoes, birds of prey, goannas, foxes and feral cats.

After the introduction of myxomatosis in 1950 there was a rapid increase in the resistance of rabbits to the disease and a decline in the lethality of the common field strains. Both resistance and virulence appeared to stay steady from 1960 to 1975. In this period, field death rates were about 40–60%. Since 1975 there has been an increase in both resistance of the rabbit to the virus and the killing capacity of the virus, perhaps as a result of the introduction of the European rabbit flea. These two trends tend to compensate each other, and overall death rates from myxomatosis may not have been affected.

3.1 The European wild rabbit and its relatives

The European wild rabbit (*Oryctolagus cuniculus*) belongs to the family Leporidae (Myers et al. 1987). The leporid (rabbit and hare) family consists of: (1) hares and jackrabbits (*Lepus*) — 29 species in Europe, Asia, Africa and central and north America; (2) cottontail rabbits (*Sylvilagus*) —13 species in the Americas, the closest relatives of the European wild rabbit are the cottontail rabbits; (3) European wild rabbit (*Oryctolagus*) — one species in Europe; and (4) eight other genera of rabbits with a total of ten species in Asia, Africa and the Americas.

The European rabbit was originally classified as a rodent in the genus *Lepus*. The name *Oryctolagus* comes from the Greek *orukter* (digging tool) and *lagos* (hare) and the Latin word *cuniculus* denotes both a rabbit and an underground passage. The type locality for *O. cuniculus* is in Germany. The English name rabbit, or rabett, is of French origin and originally applied only to young rabbits. The name for an older rabbit was cony (Barrett-Hamilton 1911).

Rabbits and hares inhabit open grassland, savanna and shrub-steppe. About five species of rabbits construct warrens with more than one entrance; only the European wild rabbit makes large warrens. Leporids share with marsupials the unusual anatomical feature of the scrotum being in front of the penis. Body weight of rabbits and hares ranges from 0.4–4 kilograms, with a mean of about two kilograms. Maximum running speed is correlated with body size (Cowan and Bell 1986); the larger hares rely on speed to escape predators, and the smaller rabbits depend on reaching the safety of some form of cover. They have a pivotal role in the predator–prey complex in most of the world's grassland ecosystems. Because of their size and fecundity, they are food for most birds of prey and for a whole range of mammalian predators as small as weasels (60–120 g) or as large as cheetahs (60 kg). It is generally considered that rabbit and hare populations are regulated largely by predation on, and dispersal of, young animals (Edwards et al. 1981; French and Heasley 1981; Henderson 1981; Stevens and Weisbrod 1981; Wagner 1981; Wolff 1981).

Hares have a gestation period of 37–46 days and have small litters (two to three) which are born fully-furred and mobile in rudimentary above-ground nests. In contrast, rabbits have a gestation period of about 30 days and have large litters (four to seven) of blind, deaf and almost naked young in short burrows or in elaborate above-ground nests. All leporids visit their young only once a day and feed them for about five minutes; this is thought to be a strategy to minimise the amount of scent which could attract predators. Mortality, particularly in the young, is high.

Although leporids do not usually consume a high proportion of the primary production, that proportion may be a large fraction of the highly digestible plants (Wagner 1981).

The only leporid in Australia, apart from the wild rabbit, is the European hare (*Lepus europaeus*). Despite the much larger size of the hare, the rabbit dominates it in aggressive encounters and female rabbits kill young hares (Evans and Thompson 1972; Flux 1981; Mykytowycz 1981). There is often an inverse correlation between rabbit and hare densities (Rothschild and Marsh 1956; Evans and Thompson 1972; Flux 1970; Broekhuizen 1975).

3.2 Body characteristics of the rabbit

European wild rabbits typically have grey-brown back fur and a white-grey belly. Males and females are similar in size and appearance, except that males have a slightly broader head. Colour variants usually comprise less than 2% of the population, although sandy coloured rabbits are common in some arid areas, and black rabbits are common in the high country in Tasmania (Barber 1954). Rabbits have a major moult in spring and a minor moult in autumn. Dark patches on the inside of the skin indicate the progress of the moult (Stodart 1965). Juvenile rabbits moult at three months of age; they frequently have a white star on their forehead

The most common form of the European wild rabbit, with grey-brown back fur and a white-grey belly. *Source: G. Chapman, CSIRO* which is lost at this moult. The feet are covered in fur which protects the foot pads from excesses of heat and cold and enables the rabbit to move very quietly. The eyes are placed to the sides of the head and are slightly protruding so that the rabbit has panoramic vision. The rabbit has a sensory pad partly concealed by hairy folds of skin at the entrance of each nostril, and a Y-shaped groove extends from the upper lip to the nose.

Rabbits have 16 teeth in the upper jaw and 12 in the lower. There are two pairs of upper incisors; the second smaller incisors are behind the first, a feature that distinguishes leporids from rodents. The incisors grow continuously. The cementum of the incisors is thicker in the front than at the rear and because of differential wear they are worn to a sharp chisel shape.

At birth the young weigh 35 g each. By the time they first emerge from the warren at 21 days they have increased their body weight by 600% to 210 g each. The total weight of a litter of six at emergence is 80% of the normal weight of the mother. Apart from nursing there is no obvious parental care. Up to 900 g, weight gain is essentially linear (10 g/day), so body weight can be used to age rabbits under 900 g using the equation age (days) = weight (g) ÷ 10 (Parer 1977; Daly 1979; Wheeler and King 1980). The most accurate method of estimating the age of a rabbit is from the weight of the dried eye lens which grows throughout life (Myers and Gilbert 1968; Wheeler and King 1980).

3.3 Shelter

In Australia, wild rabbits live in a variety of situations which can be classified broadly by the amount of surface cover that is available to them. Where cover is dense and abundant rabbits tend to dig only small warrens and live mainly on the surface (Section 3.3.2). Large warrens occur mainly in open country such as cleared land, grazed pasture and arid areas. Vegetation in the parts of Australia occupied by rabbits ranges from (1) shrub (scrub and bracken thickets), either with or without an overstorey of trees; (2) patches of dense scrub interspersed with patches of grassland in various proportions; (3) savanna woodland with extensive grassland; (4) grasslands of varying vegetation density; through to (5) short or sparse grass with varying extents of bare ground (Figure 6). This variation in vegetation cover can be viewed as a continuum in which the range or abundance of surface cover varies. As surface cover gets less, warrens become larger and the rabbits depend increasingly on underground shelter (Figure 6).

3.3.1 The warren

'Although the rabbit makes the warren, it is the warren that makes the rabbit' (Andrewartha and Birch 1984).

Contrary to popular opinion, rabbits do not readily dig new warrens, except on sandy soils (Parer 1977; Cowan 1987a). In newly colonised areas without warrens a rabbit will generally live in what is called a *squat* — a shallow depression in long vegetation or under fallen timber. A squat-dwelling pregnant female will dig a shallow burrow, a *stop*, in which to have her litter. The entrance to the stop is covered with soil and is difficult to detect. Separate tunnels may be dug within a stop for successive litters and the stop is then called a warren (Mykytowycz et al. 1960).

Warren complexes are generally larger in more open country, with a greater proportion of rabbits living underground (as indicated in Figure 6). *Source: CCNT*

	Forest Dense shrubs	Woodland Open shrubland	Grassland with patches and verges of shrubs	Grassland	Sparse grassland and frequently bare terrain
Habitat use	Low	Low–moderate	High	High	High
Shelter type	Breeding burrows, logs squats	Breeding burrows, logs squats	Breeding burrows, squats, some warrens	Warrens, breeding burrows, squats	Warrens, squats if available
Surface shelter type	Fallen timber, logs, roots, shrubs, grass clumps, rocks	Fallen timber, logs, roots, shrubs, grass clumps, rocks	Understorey, grass clumps, rocks	Grass clumps, rocks	Grass clumps when present, rocks
Warrens	Very few, used rarely, rabbits on surface mainly	Few, usually small, used infrequently	Some, medium size, used often in grassland	Many often large, used often	Many, usually large, used most of the day
Squats	Some, used frequently	Many, used frequently	Many, used frequently	Few, used occasionally	Few, used infrequently

Figure 6: Surface rabbits, shelter types, squats and warrens. Rabbits remain above ground more where surface shelter is abundant. Warrens are more common and larger where surface shelter is sparse. *(Figure drawn by Fleur Sheard)*

The warren enables the rabbit to survive in semi-arid areas, where there are extremes of temperature and little surface cover from predators. *Source: CCNT*

Nestlings in stops are often dug out by foxes (Lloyd and McCowan 1968; Mulder and Wallage-Drees 1979; Cowan 1987a), but as the warren develops and becomes deeper the nestlings are safer. Females do most of the digging although males may assist. Bursts of digging occur after rain and in relation to pregnancy (Myers and Poole 1962). Rabbits dig with the forefeet and throw soil back with the hind feet. Soil is bulldozed out of the warren with the forefeet and chest. Incisors are used to dislodge stones or gnaw through roots.

In areas with little rabbit harbour, rabbits spend most of the daylight hours in warrens. However a few subordinate rabbits may live in squats (Myers and Schneider 1964; Gibb 1990).

The ideal location for a warren is on elevated, deep sandy soils adjacent to a floodplain (Chapuis 1980; Myers and Parker 1975a, b; Rogers 1981; Rogers and Myers 1979). Here rabbit kittens are unlikely to be drowned or dug out by foxes, the vegetation responds quickly to rain and the adjacent floodplain vegetation remains nutritious after the vegetation on the sand has deteriorated.

Warrens are usually easy to detect because of different vegetation in their vicinity. Nitrophilous weeds, which take advantage of nutrients brought to the surface by digging, nutrients deposited by defecation and general soil disturbance, are common.

The main factor affecting the regional and local distribution of warrens is soil depth, soil hardness and permeability to water. Because rabbits are born with little fur, they thermoregulate poorly until 12 days of age (Poczopko 1969). In badly drained warrens, nestlings may die from hypothermia if the belly hair and the grass which is used to construct the nest become wet and loses its insulating properties. Drowning and hypothermia are significant causes of mortality in badly drained soils or in high rainfall areas (Myers 1958; Stodart and Myers 1966; Lloyd and McCowan 1968; Parer et al. 1987; Robson 1993). In contrast, adults appear to survive in warrens with water running out the entrances.

Soils with a high clay (greater than 40%) content or high silt plus clay content (greater than 50%) are not suitable for warrens as these soils become waterlogged in winter and are too hard to dig in summer. The absence of warrens on cracking clays is due partly to waterlogging but it is also due to burrows collapsing as the soil shrinks and swells with changing water content.

'The dependence on the warren is the weak link in the rabbit's armour. In those areas where rabbits extensively use warrens, destroying the warrens will virtually eliminate rabbit populations.'

The size of warrens is related to soil type and human activities. Warrens on sandy soils are smaller and have fewer underground interconnections than warrens on hard soils; it is probably easier for rabbits to extend a warren on hard soils than to start a new one (Kolb 1985; Cowan and Garson 1985). In areas where warrens are ripped, warren size tends to be small (Parer and Parker 1986) and restricted to rocky areas and cover. A warren may have 1–160 entrances; the average number tends to be from 3–15, but on calcareous soils it may be more. A six-year-old warren in an enclosure in Canberra

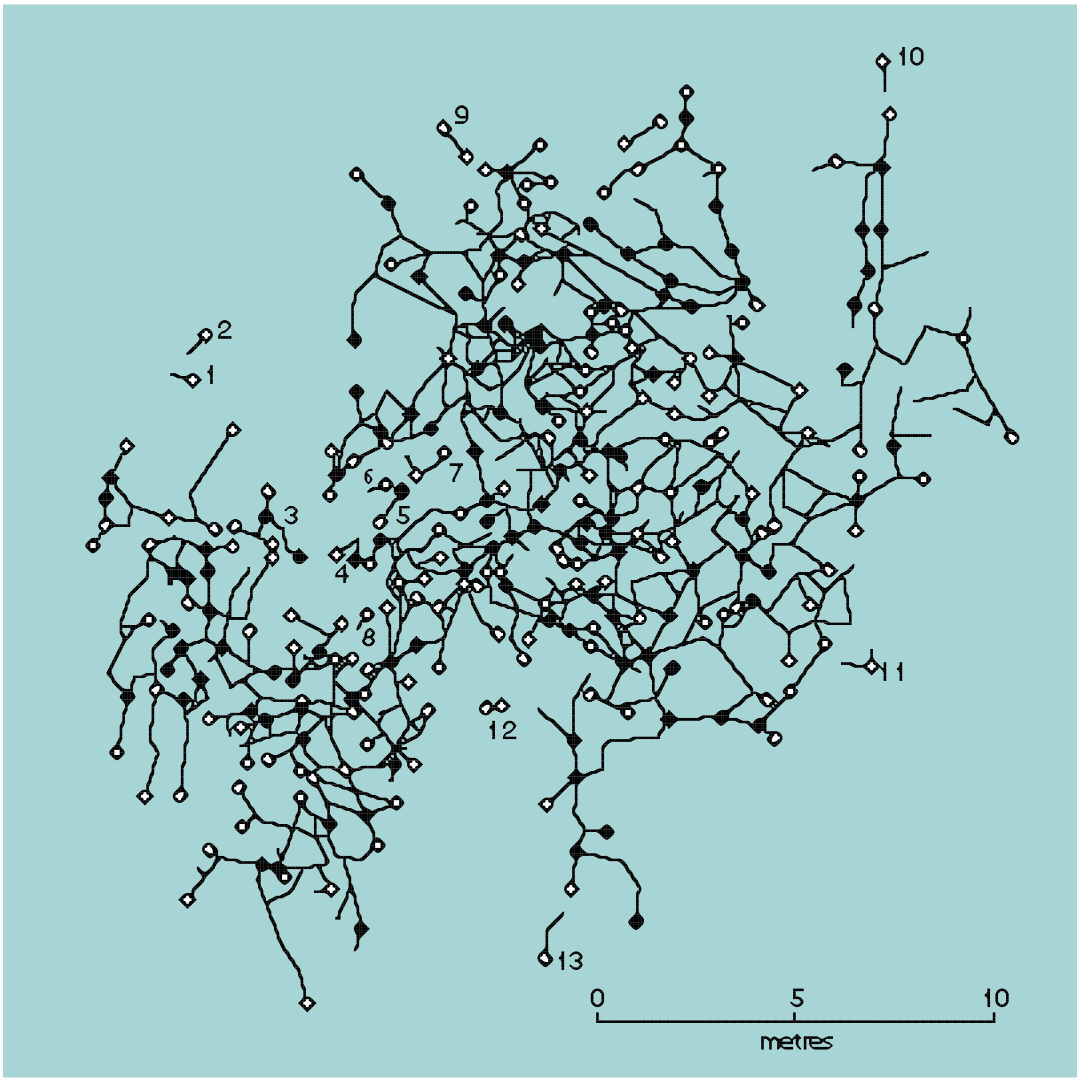

Figure 7: Diagrammatic representation of a six-year-old warren at Canberra. • represents entrances; ○ represents underground chambers. Numerals refer to burrow systems not connected to the main warren (Parer et al. 1987).

had 150 entrances, the total tunnel length was 517 metres and an estimated 10.35 m^3 of soil had been excavated (Figure 7) (Parer et al. 1987). There are usually 2.4–3.4 metres of tunnel for each entrance, except in very sandy warrens where tunnel length is greater. Almost all tunnels are contained within an area defined by a line joining the outermost entrances, but sometimes they may extend to more than three metres outside this (Kolb 1985).

Because of its warren, the European rabbit is the only rabbit species that can colonise open grassland. Because young are protected by the warren they can be born blind, deaf and hardly able to move (Myers and Poole 1962). The short gestation period of 30 days contributes to the rabbit's high reproductive rate. The highest recorded densities of the European wild rabbit (200 per hectare) is much higher than the highest recorded densities of other leporids — 3.5, 4.0 and 9.0 per hectare for the brown hare (*L. europaeus*), the mountain hare (*L. timidus*) and the cottontail rabbit (*S. floridanus*) respectively (Flux 1993). The reason that other leporid species do not attain such high densities is not because of low reproductive rates but possibly because of predation on surface nestlings and social intolerance to high densities.

Besides providing protection from predators, the warren also provides protection from climatic extremes (Hall and Myers 1978; Cooke 1990). However, in northern and central Australia even warren environments can become too severe. Relative humidities in warrens in summer are often below 40% (Cooke 1990) and warren temperature can exceed 33°C (Parer and Libke 1985). At these temperatures and low humidities rabbits have problems with water balance and thermoregulation in dry periods. Temperatures in excess of 27°C cause problems for lactating females because they need to dissipate large amounts of metabolic heat (Cooke 1977a). In its northern range the rabbit cannot live in sandy soils during hot dry years. Sand has a high thermal conductivity and is less favourable than heavier soils in hot environments (McDole and Frostberg 1974).

The dependence on the warren is the weak link in the rabbit's armour. In those areas where rabbits extensively use warrens, destroying the warrens will virtually eliminate the rabbit population.

3.3.2 Surface-dwelling rabbits

'Where there is abundant surface harbour, a high proportion of rabbits may live above the ground.'

Radio tracking has shown that where there is abundant surface harbour, a high proportion of rabbits may live above ground during the day (Boyce 1984; King et al. 1984). On river flats in New Zealand where the soil (shingle) is unsuitable for permanent warrens, rabbits live wholly above ground, sheltering in the scrub by day and feeding on the open river flats by night (Gibb 1993). Kolb (1991) found that all rabbits with warrens more than 70 metres from the dense cover in a forest moved into the forest and lived on the surface during the winter. During the remainder of the year, 80% of the daylight radio fixes were in the forest. Unsatisfactory results from fumigating warrens may be due to surface-living rabbits (Ross 1986).

Dense vegetation such as scrub or bracken, and fallen timber and rocks are suitable surface harbour. Surface-dwelling rabbits are especially abundant in the variable but frequently benign climate of southern Australia where they need little surface cover for daytime shelter.

3.4 Behaviour

Typically, rabbits emerge 1–3 hours before sunset and move back into their warrens at about sunrise. Disturbance, predator activity, rabbit density and the amount of surface cover available can modify this pattern. In New Zealand, rabbits emerge several hours earlier than in Australia. This may be due to the lower levels of diurnal predation in New Zealand (Fraser 1992). After emerging, rabbits have a period of grazing, then loaf or socialise on or near their warrens until dusk, when they move further away. Most rabbits remain above ground all night although a hunting fox may send them back to their warrens (Fullagar 1981). For 2–3 weeks after first emergence young rabbits remain very close to their warrens (Fullagar 1981; Vitale 1989) and consequently may not encounter poison bait (Meldrum et al. 1957).

Like many wild animals, rabbits are initially wary of new food items and new aspects of their environment such as baits or poison trails (Carrick 1957; Poole 1963; Rowley 1963). When threatened, rabbits crouch and freeze or they try to sneak away with the tail down. If these responses fail they sprint for the warren with the white underside of the tail showing. This display may be a visual warning to other rabbits. Near the warren rabbits initially respond to a perceived threat by assuming an upright alert posture and thumping the ground with their hind legs. This may warn young rabbits

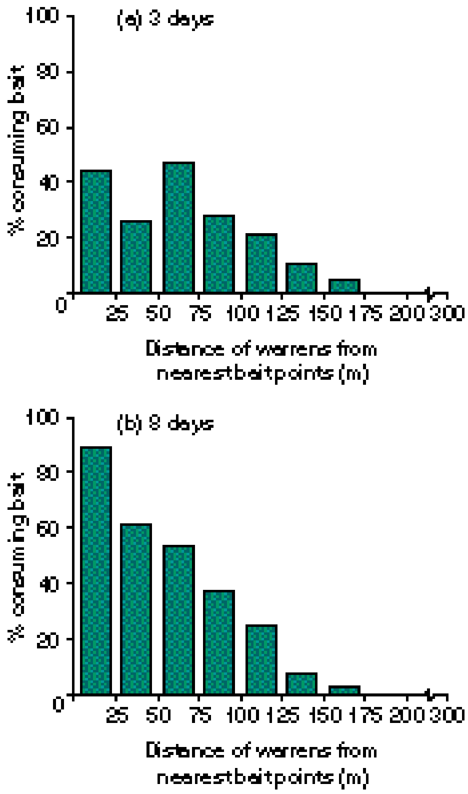

Figure 8: Percentage of rabbits consuming bait placed at different distances from warrens: (a) three days after baiting commenced; and (b) eight days after baiting commenced (after Cowan et al. 1987).

in the warren. Rabbits in low densities may be more vulnerable to predators as they do not have the benefit of warning signals from other rabbits. Rabbits in small groups spend more time in vigilant behaviour than rabbits in large groups (Burnett and Hosey 1987).

Home range size depends on rabbit density, food availability, sex, age and surface cover. Home range size in Canberra was 0.22 hectares for adult males and 0.16 hectares for females; in western New South Wales it was 0.67 hectares for males and 0.39 hectares for females (Fullagar 1981). In a forested river valley in New Zealand, home ranges were large (more than two hectares), possibly because the rabbits' daytime shelter in the scrub was not adjacent to their feeding grounds (Gibb 1993). When high-quality food is scarce rabbits move further than 300 metres from their warrens (Parer 1982b) and in severe droughts a few rabbits may move up to 1500 metres to drink (Newsome 1989). Cooke (1974, 1982a) found that during a drought, some rabbits which were living only 180 metres from a water trough, failed to find it whilst other rabbits which were living 600 metres from the trough did find it. The centre of activity is the warren and the time spent in an area is inversely proportional to its distance from the warren. This is reflected in the amount of biomass consumed in a year; 800 kilograms per hectare at 12 metres from the warren; 220 kilograms per hectare at 25 metres; 150 kilograms per hectare at 100 metres (Wood et al. 1987), and also in the percentage of rabbits eating bait placed at different distances from warrens (Figure 8) (Cowan et al. 1987). When many warrens are clustered, as on a rocky knoll, or when feeding areas are clearings in forests, there may be communal feeding of rabbits from different social groups on the lower slopes or in the clearings (Gibb et al. 1969a, b; Gibb 1993).

3.5 Dispersal

Rabbits have high rates of dispersal. Even when enclosures are open to predators, rabbit populations in enclosures increase much more than outside the enclosures (Gibb et al. 1969a; Parer et al. 1987), indicating that dispersal may be an important factor in population regulation (Henderson 1981). On small islands where rabbits cannot disperse, they tend to become extinct because overpopulation leads to overgrazing and consequent lack of food (Armstrong 1982; Cooper and Brooke 1982; Watson 1961).

Studies of long-distance dispersal have probably underestimated its importance. Young rabbits disperse throughout the breeding season with numbers peaking as pastures deteriorate in early summer in Australia (Parer 1982b; Daly 1981a, b) and

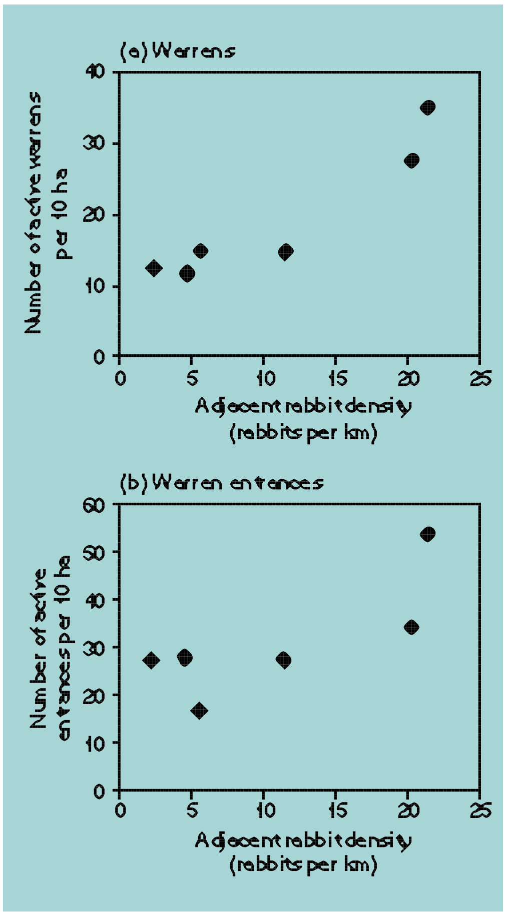

Figure 9: Effect of adjacent rabbit densities on the number of (a) warrens, and (b) active entrances in areas cleared of rabbits and warrens two years previously (Parer and Milkovits 1994).

in autumn in England (Cowan 1991). Very young rabbits (1–2 months old) are the most common dispersers in Australia, whereas in England older rabbits (2–4 months old) are the most common dispersers. Up to 60 days of age, males and females disperse with equal frequency; after 60 days males predominate. A second peak of dispersal occurs mainly among subadult males during the period of social reorganisation at the commencement of the breeding season in autumn or early winter. Rabbits older than eight months rarely disperse (Parer 1982b; Gibb 1993).

Dispersing rabbits move from warrens with a high rabbit density to warrens with a low density (Cowan 1991), and from areas with high production of young to areas with low production (Henderson 1981). After dispersal a rabbit will take up residence in a vacant warren if one is available, or it will shelter in surface harbour and try to become incorporated into the social system of adjacent warrens. Most dispersal is to adjacent social groups, but movements in excess of 20 kilometres have been recorded (Douglas 1969). Even newly emerged kittens may move 1.5 kilometres (Parer 1982b). Between 36–72% of males and 8–30% of females breed in warrens in which they were not born (Mykytowycz and Gambale 1965; Dunsmore 1974; Parer 1982b; Daly 1981b; Cowan 1991).

There are numerous anecdotal reports of mass movements of rabbits from high density populations when food becomes limited (Ratcliffe 1938, 1953; Pick 1942; Rolls 1969). While dispersal can be a hindrance to long-term control, in some situations it is beneficial. If rabbits can be split by control measures into small, isolated populations then emigrants from a population are likely to outnumber immigrants into a population as emigrants will mostly die because of the hazards faced when moving long distances between populations. Snowshoe hares build up to high numbers only where they live in large unbroken habitats (Wolff 1981).

'Rabbits have high rates of dispersal.'

Some movements appear to be directional, as illustrated when rabbits pile up on only one side of a rabbit-proof fence. As recently as 1969 rabbits had to be removed with a bulldozer from the South Australian side of the New South Wales–South Australian border fence. It is possible these directional movements are triggered by rain many kilometres away (Parer 1982b).

While recolonisation from outside is often suggested as the reason for the failure of control programs, it is usually impossible to distinguish between that and on-site reproduction of rabbits not killed in the control operation. Parer and Milkovits (1994)

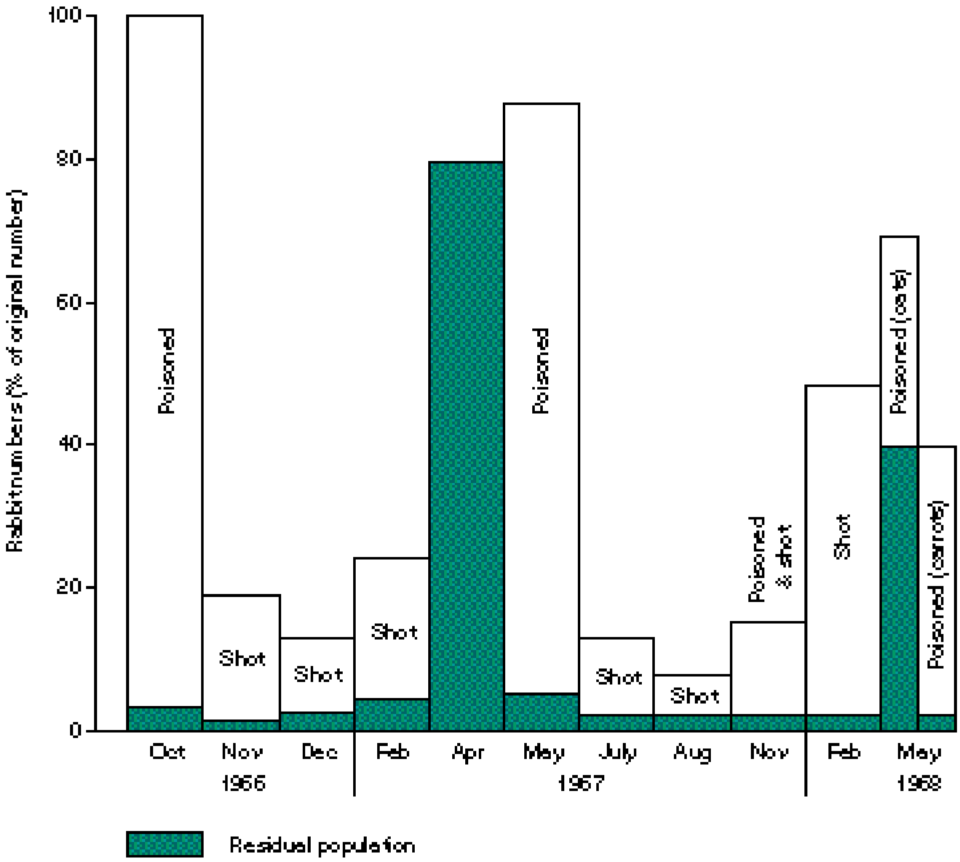

Figure 10: Rabbit numbers on a small property at Margaret River in Western Australia (after Gooding 1968a).

completely eliminated rabbits and warrens from six areas (ranging from 54–78 hectares) by fumigating, ripping, dogging and shooting. Two years later the number of rabbits was 26–81% of pre-control numbers. The number of warrens, and the number of active warrens two years after eradication, was related to rabbit densities on adjacent uncontrolled properties (Figure 9). Adjacent rabbit density was measured by counting rabbits on the perimeters of the experimental sites during late afternoon walk counts.

'Effective rabbit control is difficult on small properties with high adjacent rabbit densities.'

Effective rabbit control is very difficult on small properties with high adjacent rabbit densities. On a small property in Western Australia bounded on three sides by uncleared scrub, control efforts were ineffective because recolonisation from the scrub caused large population increases each autumn (Gooding 1968a) (Figure 10). These increases were not the result of breeding on-site as breeding ceases in that area in November or early December. In the rangelands, rabbits can rapidly recolonise even a large property (21 000 hectares) in high rainfall years if there are high rabbit densities on adjacent properties (Figure 11) (Parer and Parker 1986). The main routes of recolonisation appear to be along sandy creeks and drainage channels.

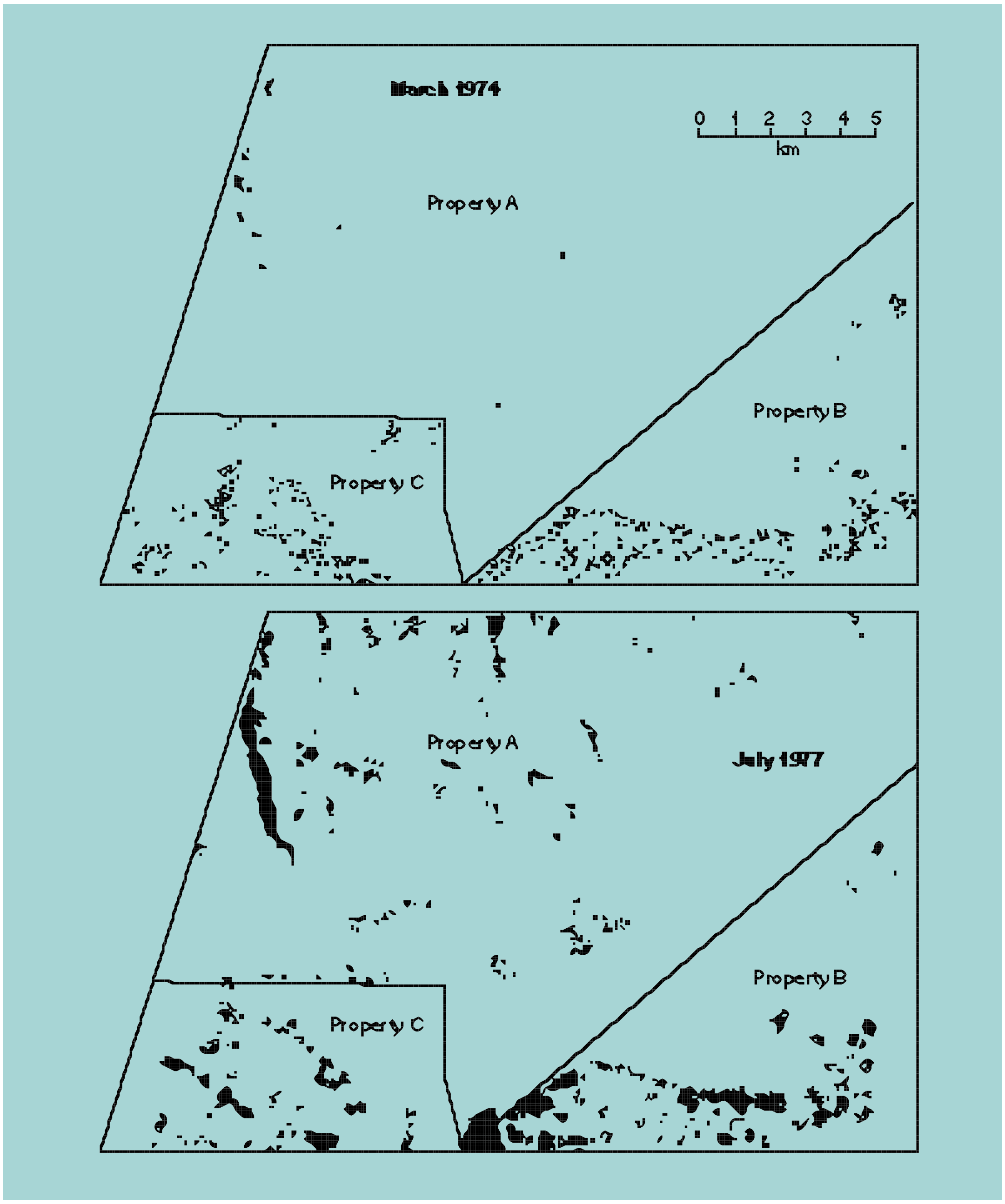

Figure 11: Recolonisation after warren ripping of a 21 000 hectare property in western New South Wales during the high rainfall years of the mid-1970s. No warrens were ripped on this property in 1974–77. Each dot represents a warren (Parer and Parker 1986).

3.6 Social organisation

Social groups of adults vary in size from 2–10 with a slight predominance of females. Within each group there are separate dominance hierarchies for males and females. Males typically defend the territory. The boundary of the territory is the boundary of the home range of the dominant male. On very large warrens with many rabbits, there may be several social groups (Parer 1977; Fullagar 1981), while at low densities one social group may use a number of warrens (Wood 1980). Aggression and territorial defence is greatest during the breeding season. During the non-breeding season, territorial boundaries are less clearly defined.

Males fight to defend access to females and females defend access to nesting sites. Most male aggression occurs in the vicinity of females and most female aggression occurs within five metres of a warren (Cowan 1987a). Males and females do not fight amongst each other as they are defending different resources. As food is not usually concentrated in a small area it is not able to be defended. In enclosures there is less aggression near food and water containers than in the rest of the enclosures (Lehmann 1991). The mating system varies from no long-term association between the sexes (Boyce 1984) through 'monogamous' territorial pairs to harem polygamy. The system operating depends on the dispersion pattern of females which is determined by population density relative to the size and dispersion of warrens (Cowan and Garson 1985; Cowan 1987a, b; Roberts 1987).

The number of entrances in a warren is related to the number of potential nest sites (Kolb 1985). There is a strong correlation between the number of entrances, female group size and the number of young produced (Cowan 1987a; Cowan 1991). In large warrens with many females and limited nest sites, females may kill nestlings of other females (Cowan 1987a). Dominant females give birth to more young than subordinate females. This is mainly due to dominant females being older, and older females start breeding earlier in the breeding season than younger females. Density itself does not greatly affect pregnancy rates (Myers et al. 1971) but when there are many adult rabbits in a warren few of the young born to subordinate females survive to emergence (Mykytowycz and Fullagar 1973). Females living in single female groups live longer and produce more weaned young with higher survival rates than females in multi-female groups (Cowan 1987b). Warren space is a valuable resource to females and they attack foreign young rabbits trying to establish residence on their warren (Parer 1982b). As more males than females disperse, the warren is a heritage passed on by the adult female to her female offspring.

Dominant males guard and apparently have undisputed access to oestrous females. However, Daly (1981a) found that dominant males sired only about 60% of the litters. As females tend to come into oestrous synchronously (Myers and Poole 1962; Parer and Fullagar 1986) the loss of the dominant male's prerogative may be due in part to his inability to guard two females simultaneously.

Rabbits have three major scent glands — the inguinal, chin and anal glands, the last producing the rabbity smell. In experimental pens, the presence of an individual's own odour allows it to dominate an individual whose odour is not present (Mykytowycz et al. 1976). Urine is used for marking inanimate objects and is sprayed onto other rabbits by males during fighting and courtship. The odour of all the glands of all the rabbits in a group gives a 'group odour' which enables them to recognise non-group members.

Rabbits deposit about 350–400 faecal pellets daily (Wood 1988). These are distributed throughout the home range but there are concentrations at locations commonly known as 'dunghills'. Dunghills are visited mainly by adult males and the pellets deposited there have a higher concentration of anal gland secretions than pellets deposited elsewhere (Sneddon 1991).

3.7 Parasites, predators and diseases

3.7.1 Endoparasites

Some endoparasites found in British rabbits did not come with rabbits to Australia. The anoplocephalid cestodes (*Cittotaenia* *pectinata, C. denticulata, C. ctenoides, Andrya cuniculi*) have not been recorded in Australia. Also lacking are the two most pathogenic forms of intestinal coccidiosis, *Eimeria intestinalis* and *E. flavescens* (Coudert 1979), and the nematode lungworm (*Protostrongylus rufescens cuniculorum*). The nematode lungworm was imported by the CSIRO to be evaluated for biological control. Contrary to results reported from France, CSIRO found it was not specific to rabbits and could develop in sheep. Rabbit venereal spirochaetosis (*Treponema paraluis-cuniculi*) is closely related to *Treponema pallidum*, the causative agent of syphilis in humans. It occurs in wild and laboratory rabbits in England but has not been reported in Australia (Graves et al. 1980).

Rabbit endoparasites in Australia

Infestations with coccidia *(Eimeria* spp.) are greatest in the high rainfall areas of eastern Australia and least in the arid zone (Stodart 1968a, b, 1971). Coccidiosis, especially liver coccidiosis (*E. stiedae*), can be lethal to young rabbits, and in moist coastal environments it is an important factor in juvenile mortality (Dunsmore 1971). In the southern tablelands of New South Wales it is more prevalent in wet than dry years (Parer and Libke 1991).

Coccidial oocyst counts are lower in young born into breeding groups containing a single adult female than in those born into groups having more than one female. These lower counts are associated with higher survival (Cowan 1985).

High infestations of stomach (*Graphidium strigosum*) and intestinal (*Trichostrongylus retortaeformis*) nematodes are found in rabbits in high rainfall areas, particularly in adult females (Dunsmore 1966a, b). Experimental infestations with *T. retortaeformis* reduced milk production by 27% (Dunsmore 1981). Rabbits with high infestations of *G. strigosum* have eroded, transparent stomach walls which often burst open when handled at autopsy (Boag 1989; Parer and Libke 1991). Perforation of the stomach wall and peritonitis due to *G. strigosum* infestations have been recorded in rabbits dying unexpectedly early in experimental myxoma infections (Mykytowycz 1956). Rabbits with myxomatosis have a depressed immune system and develop high infestations of endoparasites (Boag 1989; Parer and Libke 1991).

Dog tapeworms, *Taenia pisiformis* and *T. serialis*, are often found in rabbits (Dunsmore 1981). The metacestode of *T. serialis* develops in muscles and the cysts are sometimes so large that they can indirectly lead to death. These cysts resemble hydatid cysts (*Echinococcus granulosus*), which have not been recorded in rabbits. The liver fluke, *Fasciola hepatica*, is found in rabbits in wet areas and may be maintained by passage through rabbits when sheep are absent from a pasture (Dunn 1969).

3.7.2 Ectoparasites

The principal ectoparasites of rabbits in Australia are two mites (*Listrophorus gibbus, Cheyletiella parasitivorax*), three fleas (*Echidnophaga myrmecobii, E. perilis, Spilopsyllus cuniculi*) and one louse (*Haemadipsus ventricosus*). The stickfast fleas (*Echidnophaga* spp.) are a native species commonly found on a variety of marsupials (Shepherd and Edmonds 1978). The European rabbit flea (*S. cuniculi*) is limited to areas with a rainfall greater than 200 mm (Cooke 1984). After its introduction in 1968 as a vector of myxomatosis there were substantial reductions in rabbit

Table 2: Relative importance of young and older rabbits (expressed as a percentage) in the diet of foxes and feral cats (after Catling 1988).

Age of Rabbit	Fox	Cat
Less than 80 days	40	91
More than 80 days	60	9

densities on the tablelands in New South Wales and in Tasmania, Western Australia and South Australia (Cooke 1983b). It is thought to be the only significant ectoparasite vector of myxomatosis, but there have been numerous outbreaks of myxomatosis where there were no European fleas and no flying vectors (Dunsmore et al. 1971; Williams et al. 1972; Newsome 1989).

3.7.3 Predators

The most significant predators of the rabbit in Australia are: the cat (*Felis catus*); fox (*Vulpes vulpes*); dingo (*Canis familiaris dingo*); wedgetail eagle (*Aquila audax*); little eagle (*Hieraaetus morphnoides*); brown goshawk (*Accipiter fasciatus*); brown falcon (*Falco berigora*); and goanna (*Varanus* spp.) (Baker-Gabb 1984; Calaby 1951; Newsome et al 1989; Parer 1977; Ridpath and Brooker 1986).

The two major predators of the rabbit throughout its range in mainland Australia are the feral cat and fox; dingoes are regionally important. Cats tend to eat more young rabbits, and foxes more older rabbits (Table 2).

The proportion of older rabbits taken by cats may be underestimated as cats consume only 15–20% of an adult rabbit and do not eat the parts of the rabbit that can be aged, the ears and bones, and foxes may scavenge these. Both feral cats and foxes take a wide variety of vertebrate and invertebrate prey, but mammals are their staple diet in all

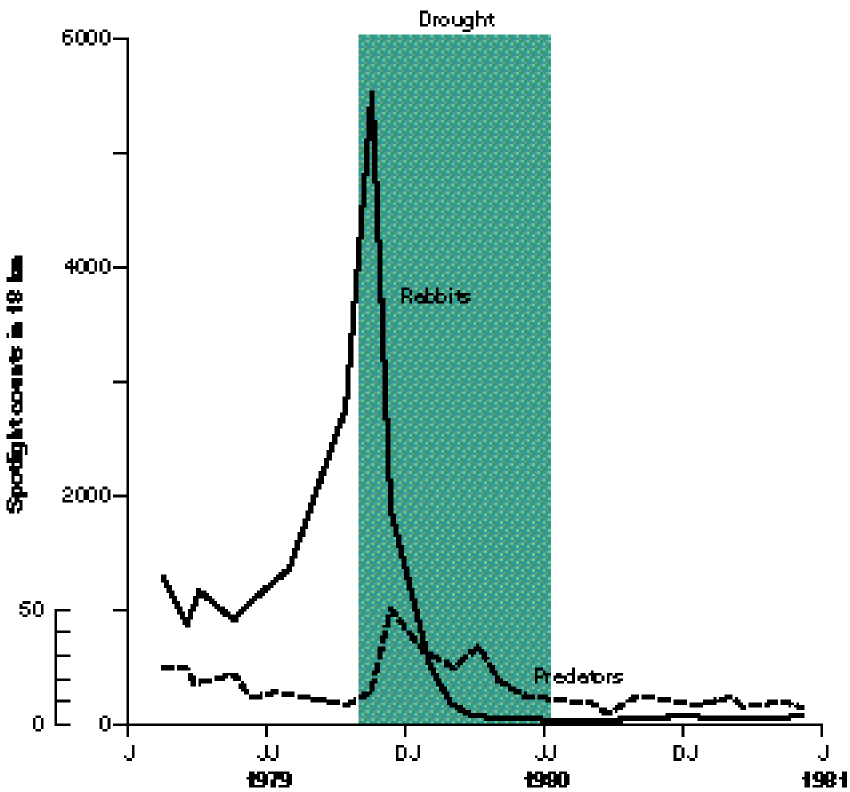

Figure 12: Variations over time in the number of rabbits and predators at Yathong Nature Reserve in central-western New South Wales (after Newsome et al. 1989).

environments. Rabbits, and to a much lesser extent other small mammals, are their main diet in pastoral districts (McIntosh 1963; Coman and Brunner 1972; Coman 1973; Ryan and Croft 1974; Croft and Hone 1978; Jones and Coman 1981; Catling 1988; Seabrook 1991). House mice (*Mus domesticus*) are a major prey item only in some areas and at infrequent intervals.

When rabbit populations crash, fox and feral cat populations also collapse after a

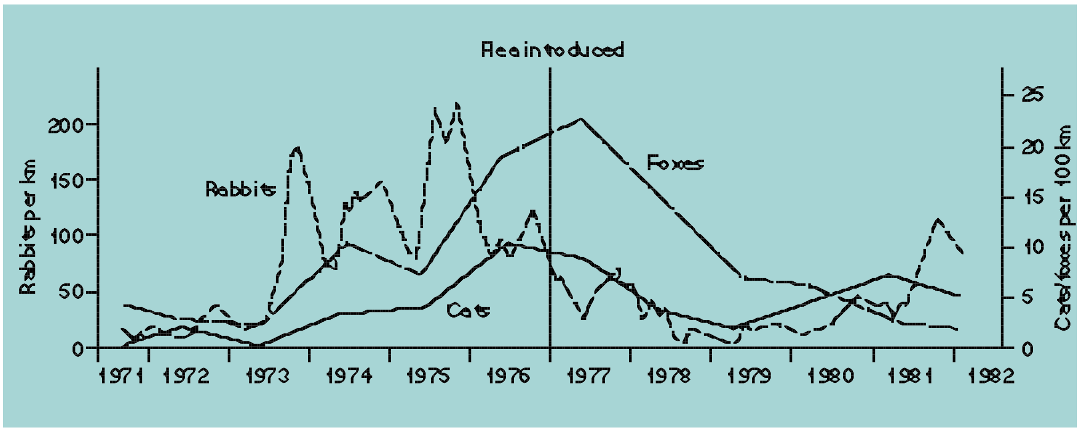

Figure 13: Variation in fox and feral cat populations in relation to changes in rabbit populations in south-western Western Australia (after King and Wheeler 1985).

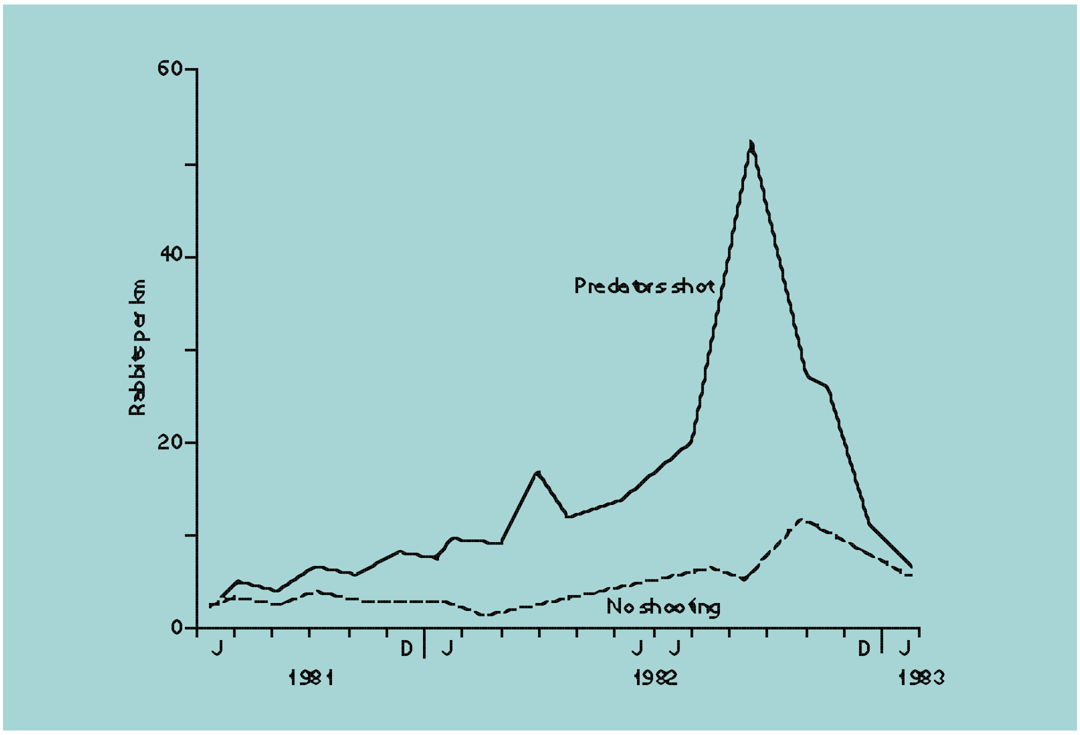

Figure 14: Recovery of rabbits after drought in an area where predators (feral cats and foxes) were shot (solid line), and where they were not shot (broken line) in central-western New South Wales (after Newsome et al. 1989).

time lag (Brooker 1977; Myers and Parker 1975a, b; Newsome et al. 1989; King and Wheeler 1985; Redhead et al. 1991) (Figures 12 and 13). During the time lag there is heavy predation on the remaining rabbits and on many native species of vertebrates and invertebrates.

Young feral cats and foxes usually become independent in summer when there are few very young rabbits. As a result, the survival of these young predators is often low; in mid-summer young emaciated foxes are often found dead or dying (Lugton 1992). As foxes kill larger rabbits than cats and eat more carrion, fox numbers might be expected to be less dependent than cats on the length of the rabbit breeding season and rabbit abundance (Pech et al. 1992). However, fox distribution and abundance appears to be associated with rabbit distribution and abundance (Mitchell 1982; Christensen et al. 1985; Lugton 1992; Wilson et al. 1992b). Both Catling (1988) and Lugton (1992) suggest that foxes could not persist in the rangelands if it were not for rabbits. In the Petermann Ranges in central Australia, rabbits were the only mammal in fox scats and they were present in 97% of dingo stomachs (Foulkes and Kerle 1989). In pastoral districts with rabbits, the densities of foxes and feral cats are about 1–2 and 0.5/km^2 respectively (Lugton 1992; Newsome and Catling 1992). In a forest area in coastal south-eastern Australia with few rabbits, fox density was 0.25/km^2 (Newsome and Catling 1992). In western New South Wales, feral cats were at much lower densities than foxes and were concentrated around run-on areas (Myers and Parker 1975a). Beyond the range of rabbits, feral cat numbers are very low, about 0.02/km^2 at Kapalga near Kakadu (Ridpath 1991).

In shallow warrens on sandy soils, Wood (1980) found that foxes dug out 30% and 73% of the annual production of young rabbits in wet and dry years respectively. He suggested that lower predation in wet years was due to alternative prey being more abundant. In deep sandy soils and on heavy soils few nests are excavated. Rabbit numbers increased much faster following a drought in western New South Wales in an area of stony soils, compared to adjacent sand dunes where fox predation on nestlings was common (Myers and Parker 1975a) (Figure 4). After a drought in central-western New South Wales, rabbit numbers increased four times faster where feral cats and foxes were shot than where they were not shot (Newsome et al. 1989) (Figure 14). Pech et al. (1992) calculated that foxes and feral cats in central-western New South Wales could regulate rabbit populations when rabbit numbers were less than 9–15 per spotlight kilometre (equivalent to 1–2 per hectare). At higher densities, rabbit populations can escape predator regulation. Wherever rabbits co-exist with cats or foxes, they are a major or dominant food item for these predators.

In England, rabbit numbers fell by 95% after myxomatosis. Fox numbers remained high as did their predation on rabbits, which still made up 50% of their diet. Even though foxes increased their predation on voles (*Microtus agrestis*) after myxomatosis, rabbits still contributed more by volume than all other dietary items (Sumption and Flowerdew 1985). This high predation on rabbits, even when they were scarce, indicates that foxes fed preferentially on rabbits.

Both Brunner et al. (1975) and Seebeck (1978) concluded that foxes preyed selectively on rabbits in low density rabbit populations in Victorian forests. After the introduction of myxomatosis in Australia, bounty payments for fox scalps in Victoria dropped significantly over three years; payments then increased to slightly above premyxomatosis levels for the next 13 years (Redhead et al. 1991). On an island with an abundance of nesting short-tailed shearwaters (*Puffinus tenuirostris*), rabbits were still the major food item for foxes (Norman 1971).

The pattern is similar for feral cats. In the forested Orongorongo Valley of New Zealand, rabbits contributed up to 40% by weight to the diet of feral cats, even though rabbit densities were low and alternative prey was available (Fitzgerald and Karl 1979). On islands without rabbits, rats were present in more than 70% of scats and stomachs of cats; on islands with rabbits, rabbits were the main dietary item and rats were usually found in less than 5% of the cat scats and stomachs (Fitzgerald 1988).

The low proportion of native mammals found in diet studies of foxes and feral cats in pastoral districts, does not indicate

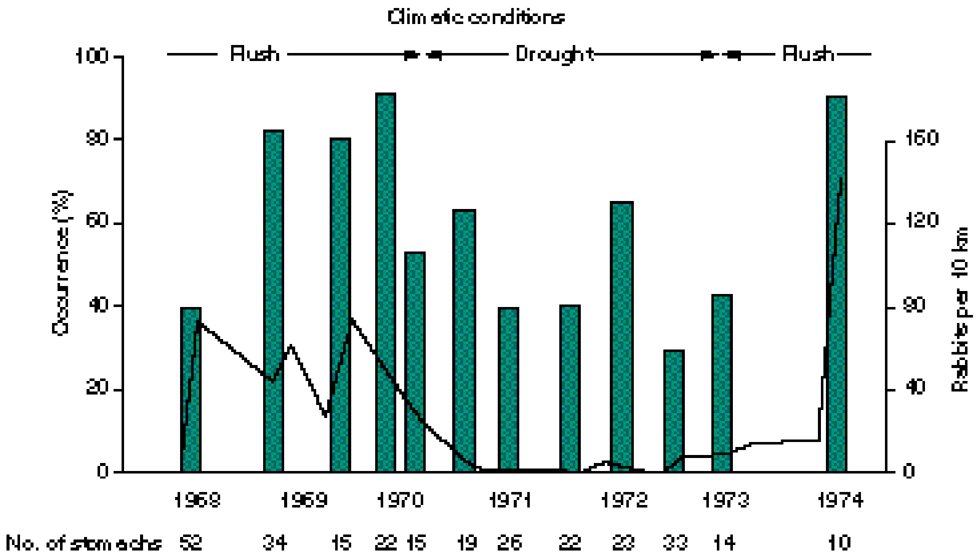

Figure 15: Abundance of rabbits (line graph) and the frequency of occurrence of rabbits in dingo stomachs (bar graph) (after Corbett and Newsome 1987).

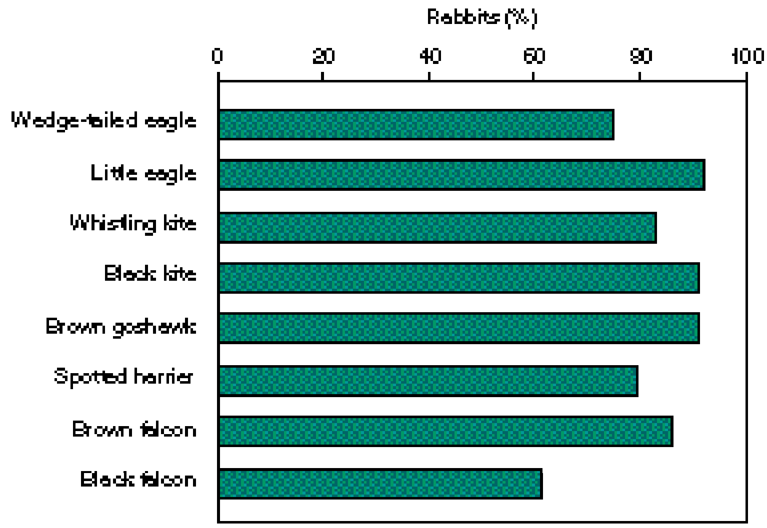

Figure 16: The percentage of rabbit in the spring diet of eight species of raptor in the Mallee region of Victoria (adapted from Baker-Gabb 1984).

whether or not their impact on native fauna is significant in these areas; it simply reflects the virtual absence of small and medium-sized native mammals in many pastoral districts (Kinnear 1991).

Foxes tend to be displaced by dingoes and are at low densities in areas where there are dingoes. Rabbits are 6–29% of the diet of the dingo in coastal and tableland forests and heaths (Newsome et al. 1983), and 61% in southern Northern Territory (Corbett and Newsome 1987). On the southern tablelands, dingo abundance was correlated with rabbit abundance (r = 0.98). In the Northern Territory, rabbits were the preferred prey of the dingo; even at very low densities during a three-year drought rabbits were still 30–60% of the diet of the dingo (Figure 15).

Rabbits are the staple diet of the medium and large diurnal birds of prey in pastoral districts (Figure 16) (Debus 1984; Baker-Gabb 1984; Aumann 1988). The wedgetail eagle mainly kills rabbits which are over four months old (Brooker and Ridpath 1980); other diurnal birds of prey kill mainly kittens (Dunnet 1957; Debus 1984). Baker-Gabb (1984) estimated that hawks and eagles consumed 7–14% of the annual production of young rabbits. Richardson and Wood (1982) found that birds of prey kill 9%, and cats and foxes 18% of young rabbits in the 14 days after their first emergence from the warren.

The diet of the wedge-tailed eagle is 97% rabbits in habitats where alternate prey is scarce. In these habitats eagles are obligate

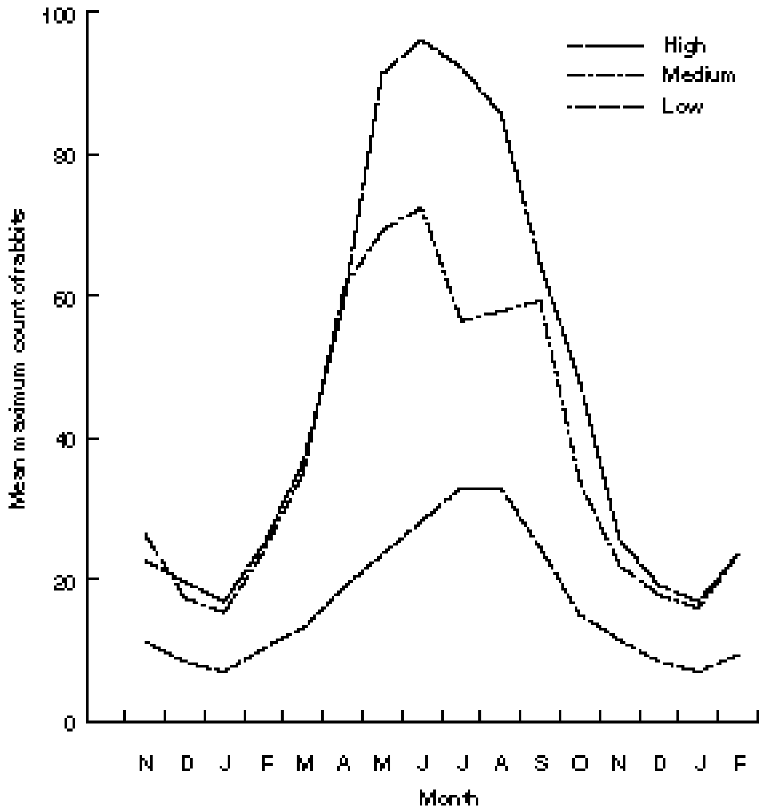

Figure 17: Rabbit abundance indices for areas in England where predator removal effort was measured. High, medium and low levels of predator control (after Trout and Tittensor 1989).

predators on the rabbit and do not breed if rabbit density is less than 0.6 per hectare (Ridpath and Brooker 1986). After myxomatosis reduced rabbit populations, the clutch size of wedge-tailed eagles, brown goshawks and whistling kites (*Haliastur sphenurus*) decreased in southern Australia (Olsen and Marples 1992). The little eagle is a specialist predator with 87% of its diet being young rabbits; when young rabbits are seasonally scarce some birds move elsewhere (Calaby 1951; Parer 1977; Debus 1984). During outbreaks of myxomatosis, birds of prey, including ravens (*Corvus coroniodes*), may kill a high proportion of infected adult and young rabbits (Williams et al. 1973). Rabbits do not live in forests, so it is surprising that rabbits are an important component (38%) in the diet of the forest-dwelling Masked Owl (*Tyto novaehollandiae*) (Mooney 1993).

As rabbits are the staple diet of most birds of prey and mammalian carnivores, high numbers of rabbits keep the populations of these predators high. This may lead to increased predation on rare native mammals and other fauna. This impact is likely to be more intense during and after a crash in rabbit numbers. Keeping rabbits at low densities may be an effective long-term way of reducing the impact of introduced predators on native birds and mammals, though research is required to test this hypothesis.

In both Spain and Australia, small native mammals are not abundant (Delibes 1975), and the rabbit is the principal source of energy for most large predators. If those species for which rabbits comprise 40% or more of the biomass consumed are considered specialists, then Spain has six mammal and eight bird species which could be considered specialist predators of the rabbit (Delibes and Hiraldo 1981). Australia has three mammal and eight bird species which could be considered rabbit specialists. Five of the six specialised mammalian predators in Spain take nestling rabbits. Predation on nestlings is a very effective form of predation as four to six individuals are removed from the population at once. One of the main reasons for the success of the rabbit in Australia is probably the paucity of mammalian predators, and in particular the absence of predators such as mustelids, which kill rabbits in warrens. In New Zealand, ferrets kill 38–58% of nestling rabbits (Robson 1993).

After reviewing all available evidence on the effects of rabbit predators (canids, felids and mustelids), Trout and Tittensor (1989) came to five main conclusions: (1) predators do not have any regulatory effect on high density populations; (2) rabbits rapidly become more abundant and widespread if natural predatory pressure is suddenly reduced; (3) when rabbits are expanding into new areas predation can slow down the rate of spread; (4) rabbits are more abundant in areas where predators have been controlled consistently, for example in estates with gamekeepers (Figure 17); and (5) predators exert a regulatory pressure on low density rabbit populations, particularly those that have suddenly been reduced by a process (drought, myxomatosis, warren ripping) which does not immediately affect the predator numbers.

3.7.4 Myxomatosis

Myxomatosis is a benign disease in two species of cottontail rabbits in the Americas. Scientists became aware of the disease when it almost wiped out the stock of laboratory rabbits at the Institute of Hygiene in Montevideo in 1896. In his account of this outbreak, Sanarelli named the disease ‘infectious myxomatosis of rabbits’ and he suggested that myxomatosis was caused by a member of the newly defined group of infectious agents, the ‘filterable viruses’ (Sanarelli 1898). It was the second animal disease to be attributed to a virus; foot and mouth disease being the first.

The first field trials with the myxoma virus in the arid zone of South Australia in 1938–42 showed that although it killed many rabbits it did not spread far (Bull and Mules 1944).

Another introduction in 1950 in the Albury district, where there were suitable mosquitoes to carry the virus, resulted in its spread over virtually the whole of the rabbits' distribution by 1954. Some groups, such as trappers, did not want myxomatosis and the Tasmanian Government legislated against its introduction. The effects of myxomatosis in the first few years are not well documented except for a few sites in the Riverina in New South Wales. Myers et al. (1954) show that at Corowa, 99% of rabbits that contracted the virus in the first year of release died while in the second year the death rate was 85%.

'Myxomatosis did not solve the rabbit problem.'

Myxomatosis did not solve the rabbit problem. In 1955–56, four years after the introduction of myxomatosis, 45 million rabbits were harvested commercially in Australia (Fennessy 1959); present day harvests are valued at around $9 million (Ramsay 1991), which is about nine million rabbits. At Corowa in the Riverina, rabbit numbers recovered to approximately half premyxomatosis levels only two years after the first outbreak (Figure 3) (Myers 1962). This would not happen in that district today because the country has become less suitable for rabbits; perhaps due to the clearing of harbour and the lack of abundant empty warrens. It was not until the very high rainfalls of 1954–56, possibly causing warrens to collapse, that rabbit numbers fell and remained at very low levels on the clay soils of the plains. In the high rainfalls in 1973–74 rabbits abandoned warrens in clay soils at a site in the Riverina (Daly 1981a).

The innate resistance of rabbits to myxomatosis increased rapidly in the first few years after its release (Marshall and Fenner 1958; Fenner and Ratcliffe 1965) but appeared to reach a plateau by 1958 and remained there for about 20 years. Rabbits from different localities in Australia have very different levels of resistance to myxomatosis. Rabbits from temperate climates are less resistant than rabbits from hot climates (Fenner and Ross 1994; Parer et al. 1994). Recent evidence suggests that rabbits in Victoria developed an increased resistance to the myxoma virus between 1975 and 1985, and by 1990 even the highly virulent Lausanne strain was killing only 50% of rabbits from the Mallee and Wimmera districts (Nolan et al. 1991). This increase in resistance may be related to the introduction of the European rabbit flea or possibly to the widespread introductions of the Lausanne strain of myxoma virus. In England there was a sudden and unexpected increase in the genetic resistance of rabbits in the late 1970s (Ross and Saunders 1977, 1984), which was followed by an upsurge in rabbit populations (Trout et al. 1986). No reliance should be placed on the continued effectiveness of myxomatosis.

There was a rapid decrease in the virulence of myxoma virus field strains in the first few years after the highly virulent Standard Laboratory Strain was introduced (Fenner and Ratcliffe 1965). From 1955 to 1975 there was little change in the virulence of field strains. Since 1975 there has been a trend towards increased virulence of the field strains of myxoma virus (Dwyer et al. 1990). These two trends — increased resistance by rabbits to the disease and increased virulence of the virus — are compensatory so it may be that the capacity of the disease to kill has not been significantly affected.

The percentage of rabbits that die after contracting myxomatosis in the field varies with the age of the rabbit, the time of the year and the strain of the virus. Where mortality rates have been estimated in the field, they were 40–60%. Mortality rates are higher in winter than in summer (Marshall 1959).

Soon after the introduction of myxomatosis into Australia, three species of mosquitoes were identified as the main vectors in semi-arid eastern Australia (Fenner and Ratcliffe 1965). Identification of the main vectors elsewhere proved to be more difficult.

The introduction of the European rabbit flea in 1968 was followed by substantial reductions in rabbit populations in areas where vectors were previously deficient — Western Australia, Tasmania and the tablelands in New South Wales; only in South Australia were the results closely monitored (Cooke 1983b, 1991b). At one site, prior to the introduction of the flea in 1974, myxomatosis killed 24% of young rabbits. From 1975–81 the kill was 84% and from 1983–89 44%. The reason for these changes is not known as there were no changes in the timing of the annual outbreak of the disease and little change in the percentage of rabbits that contracted the virus. These changes in mortality rates indicate that benefits from the introduction of the arid-adapted Spanish flea (*Xenopsylla cunicularis*) may be short-lived.

The highly virulent Lausanne strain of myxoma virus has been used successfully to eliminate rabbits from several islands, but results of its use have been disappointing on the mainland (McManus 1979; Martin and Sobey 1983; Parer et al. 1985).

The very limited spread of myxomatosis after the first releases of the myxoma virus on the Australian mainland was attributed by Bull and Mules (1944) to a high density of foxes and cats which preyed on the sick rabbits before they had infected other rabbits. This interpretation is supported by the data of Flux (1993) which show that when either cats or the myxoma virus were introduced onto islands, the proportion of islands on which rabbits were eradicated was 10% and 11% respectively. When cats and the myxoma virus were introduced together onto islands eradication occurred on only 2.5% of islands.

Due to concerns about the declining effects of myxomatosis, experiments were conducted in Australia and England to investigate whether myxomatosis was still exerting a significant effect on rabbit populations. In Australia, two populations were immunised with a weak strain of myxoma virus. Within two years the two rabbit populations had increased to levels eight and twelve times higher than they were before immunisation (Parer et al. 1985). In England, insecticide was used to reduce the numbers of fleas, the principal vector. During two periods of flea control rabbit numbers increased by 128% and 232% and fell when fleas were not controlled (Trout et al. 1992, Parer 1991). These experiments show that myxomatosis is still important in preventing explosive increases in rabbit numbers. There is no way of predicting how much longer this will continue.

Paradoxically, myxomatosis is one of the most important factors in both assisting and discouraging effective control. Because myxomatosis kills many rabbits, land managers tend to rely on it instead of pursuing a program of effective control.

A newly discovered virus which causes high mortality in rabbits, rabbit calicivirus disease (RCD), shows considerable promise as a biological control agent, and preliminary tests on it have commenced at the CSIRO Australian Animal Health Laboratory (Section 7.4.13).

3.8 Nutrition

Food retention time is the most important factor determining fibre digestibility. Relative to their respective metabolic rates (i.e. body weight$^{0.75}$), the rabbit's fermentation chamber, the caecum, is 20% of the size of the cow's fermentation chamber, the rumen (Hoppe 1977). Consequently, the rabbit retains food for shorter periods than large ruminant animals. As the rabbit ferments its food in the hindgut, the main products of fermentation, microbes, cannot be fully digested in the transit time between the caecum and anus. Hence rabbits, in common with other leporids, produce two very different types of faeces, hard and soft. There is a diurnal cycle in the production of the two types of faeces, with hard faeces being produced at night when the rabbit is grazing and soft faeces being produced during the day when the rabbit is normally in its warren. Soft faeces, which are low in fibre and high in protein (28%) and B vitamins, are eaten directly from the anus, a practice called coprophagy. Hard faeces, which are high in fibre and low in protein (9%), are dropped on the ground. The concentration of vitamin B12 in soft faeces is 221 times that in the diet (Kulwich et al. 1953). About 50% of the food is recycled through coprophagy (Jilge 1974). Rabbits digest fibre only about half as well as cows; protein digestibility is slightly superior (Wallage-Drees and Deinum 1986; Monk 1989).

Rabbits require a high-quality diet of less than 40% fibre with 10–12% protein for maintenance and 14% protein for reproduction (Cooke 1974). Little is known about the rabbit's requirements for specific amino acids. Because of its small size, a rabbit can be very selective in what and how it eats. For example, with thorny plants, it bites carefully between the thorns, bites off the twig and then manipulates it so that the twig is consumed from the base (Belovsky et al. 1991). Although a selective feeder, it spends only about 15% of the day grazing (Mykytowycz and Rowley 1958; Fullagar 1981). When high-quality food is limiting, it grazes for longer periods at greater distances from the warren (Gibb et al. 1969a).

Hard faeces are quite dry, containing 48% water, even when rabbits are eating succulent food. Rabbits can concentrate urine to 2000 osmol per litre which is low compared to desert adapted rodents (Schmidt-Nielsen et al. 1948; Wood and Lee 1985). Because of this, they require a diet with a water content of more than 55% (Cooke 1982a, b). Nevertheless, they do relatively well in dry habitats by selecting a diet with the highest available water content, by being mainly nocturnal and by burrowing to avoid temperature extremes.

There is a seasonal cycle in the composition of the plant material on which rabbits feed. Quality is very high in the first flush of growth, then slowly declines until the vegetation dries out with a pronounced drop in moisture, energy and protein. This sudden change at the end of the season affects lactating females first and nestlings die through lack of milk. Lactating females have very high energy and water requirements (Reyne et al. 1977; Richards 1979). Emerged young are the next to be affected as they are growing rapidly and also have high energy and water requirements. In dry years, subadults die in summer, and in severe droughts even adults die. Adults can lose 40% of their weight, mainly muscle, before dying (Cooke 1982a, b). Sometimes energy and water may be the main deficiencies in the pastures. At other times protein is limiting. Myers and Bults (1977) recorded protein levels in stomach ingesta as low as 5.4% in the subtropics and 6.3% in western New South Wales. In more favourable environments such as the southern tablelands, protein levels in ingesta can be as high as 20% and do not fall below 12% (Parer and Libke 1991).

'There is most competition for food between sheep and rabbits during and coming out of drought.'

Usually some green food has to be selected to satisfy water requirements, but other factors are important in food selection. Many green chenopods are not eaten because they are too salty and contain oxalates, a plant toxin. Green perennial tussock grasses are mostly too low in protein and too high in fibre. A shortage of minerals may limit reproduction in some areas; for example sodium in subalpine environments (Myers 1971) and phosphorus in the tropics (Parer 1987). Henderson (1981) found that pregnancy rates in rabbits were correlated with the phosphorus content of the pasture.

In arid environments, sheep and cattle survive droughts when most rabbits die because stock browse higher, digest fibre more efficiently and have access to water. In high rainfall areas, water and pasture quality are rarely limiting to adult rabbits and they can thrive when stock are losing weight because they graze very close to the ground, dig for roots and eat fallen seeds. During and coming out of drought is when there is most competition for food between sheep and rabbits (Dawson and Ellis 1979).

3.9 Reproduction and survival

Rabbits have an endogenous reproductive cycle (Lin and Ramirez 1991) which is mainly modulated by day length and nutrition (Boyd 1986; Bell and Webb 1991). Spring is the high point of the reproductive cycle and autumn the low (Myers and Poole 1962; Boyd 1986). Rabbits in Australia commence breeding when pastures green up after rain and the last litters are conceived as soil moisture becomes limiting and pastures mature and dry out (Myers and Poole 1962; Myers et al. 1989; Wheeler and King 1985; Wood 1980; Cooke 1981b).

'Survival of rabbits in the wild to nine months of age may be as low as 0.25% or as high as 12%.'

Specific chemicals present in rapidly growing or in drying-out plant tissues may be important agents in initiating and terminating breeding (Boyd and Bray 1989). High protein food (more than 15%) is necessary for reproduction and protein level is correlated with litter size and mortality to weaning (Stodart and Myers 1966; Omole 1982). The reproductive pattern for rabbits at four sites in Australia and one in New Zealand is shown in Figure 18. Female rabbits can mate within hours of giving birth. As a result, a high proportion (up to 100%) can be pregnant in successive months. Rabbits are induced ovulators; ovulation occurs ten hours after copulation as a result of the stimulation of mating. The average number of young produced per year by an adult female varies from 15 in subalpine Australia to 53 at a New Zealand site. Of 11 Australian sites, 18–30 young were produced per female per year on eight of the sites. Females as young as three months can breed, but adult pregnancy rates are not attained until seven months, and adult litter size until ten months (Gilbert et al. 1987).

A high rate of reproduction does not necessarily result in high population densities. Rabbits are not a problem at some New Zealand sites as there is high mortality of young caused by predation and flooding of stops (Robson 1993). In New Zealand, young born outside the main breeding season when predation is high have only a 1% chance of surviving to maturity (Figure 19). Few offspring born to young females survive because they are born at the end of the breeding season when juvenile survival is low.

Expectation of life at emergence is about three months (Parer 1977; Cowan 1987c) and mean generation time is 1.5–2.0 years. Survival rate of young varies according to when they are born relative to the beginning and end of the breeding season. Young born early or late in the season have low survival rates. Both are subject to high predation pressure, and late young also face declining food quality (Figure 19). Survival of young varies between years depending on seasonal conditions (Parer 1977) and the incidence of myxomatosis (Cowan 1987c). Survival to nine months of age may be as low as 0.25% or as high as 12% (Wood 1980). In the arid zone, a breeding season can be so brief that no young reach the age where they can survive the ensuing dry season (Cooke 1983a).

Annual survival rate of adults is 40–60%. Rabbits rarely survive past six years of age in the wild. In the arid zone, the age structure of a population alternates between being dominated by old rabbits during prolonged droughts to being dominated by young animals during periods of rapid population increase. The proportion of rabbits more than two years old in shot samples was more than 17% in arid New South Wales and subtropical Queensland, and less than 7% in the Riverina and in coastal and subalpine New South Wales (Myers 1971).

When there is abundant unused warren space, the rate of population increase can be rapid. In a 33 hectare rabbit-proof enclosure open to predators, a winter outbreak of myxomatosis reduced a population from 260 rabbits to 2 rabbits, a male and a female. Eighteen months later the population peaked at 184 before being

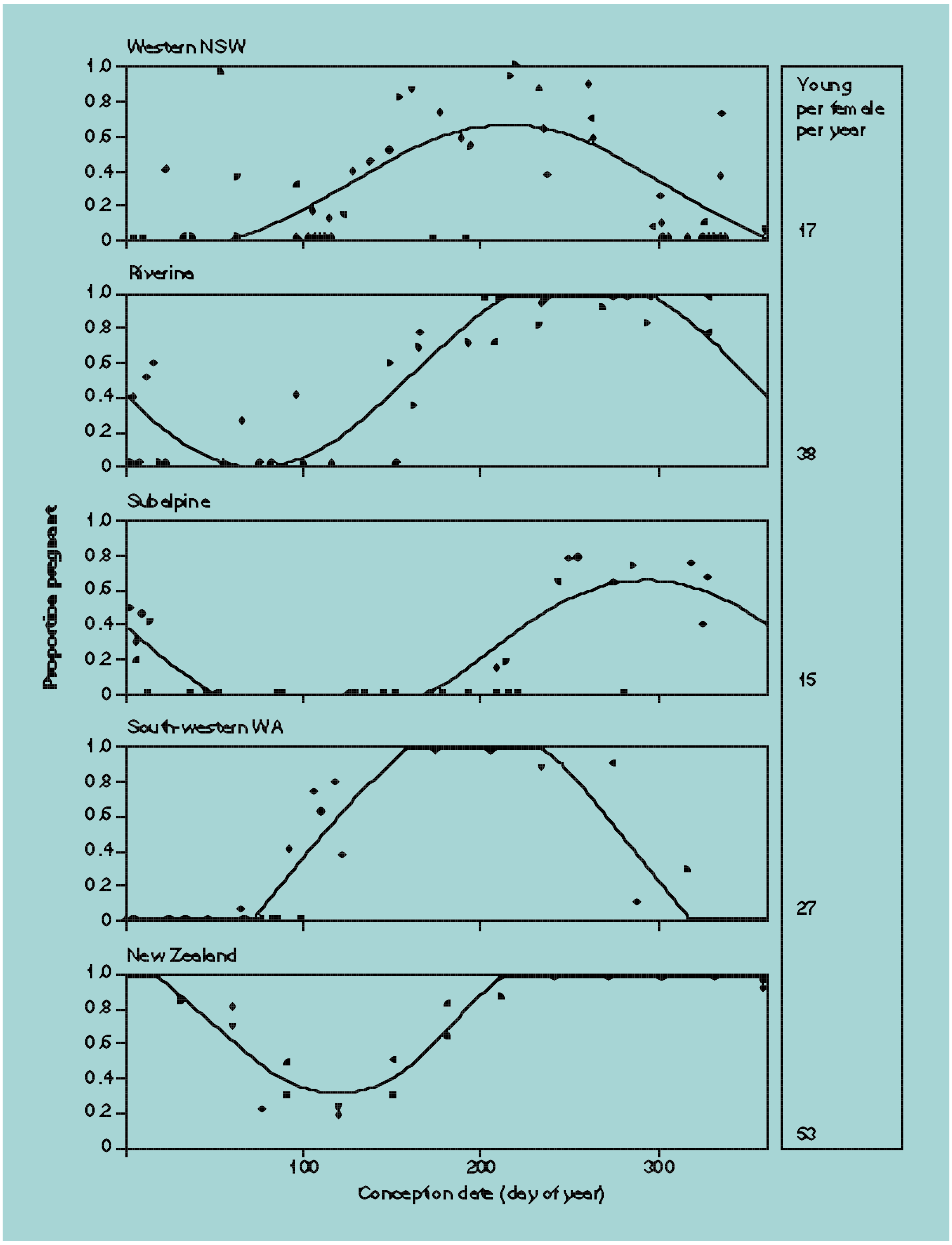

Figure 18: Seasonal variation in the percentage of adult (older than nine months) females pregnant at five sites in Australasia (after Gilbert et al. 1987).

reduced by another episode of myxomatosis (Mykytowycz and Fullagar 1973). In the Tierra del Fuego in South America, four introduced rabbits increased to 20 million within 17 years (Jaksic 1983). Rabbit populations may rebound to pre-control levels within 12 months of poisoning (Rowley 1968; Martin and Atkinson 1978). In contrast to rabbits, populations of animals with low rates of reproduction, such as the possum (*Trichosurus vulpecula*) in New Zealand, take more than 11 years to recover from imposed population reductions of 80–85% (Green 1986).

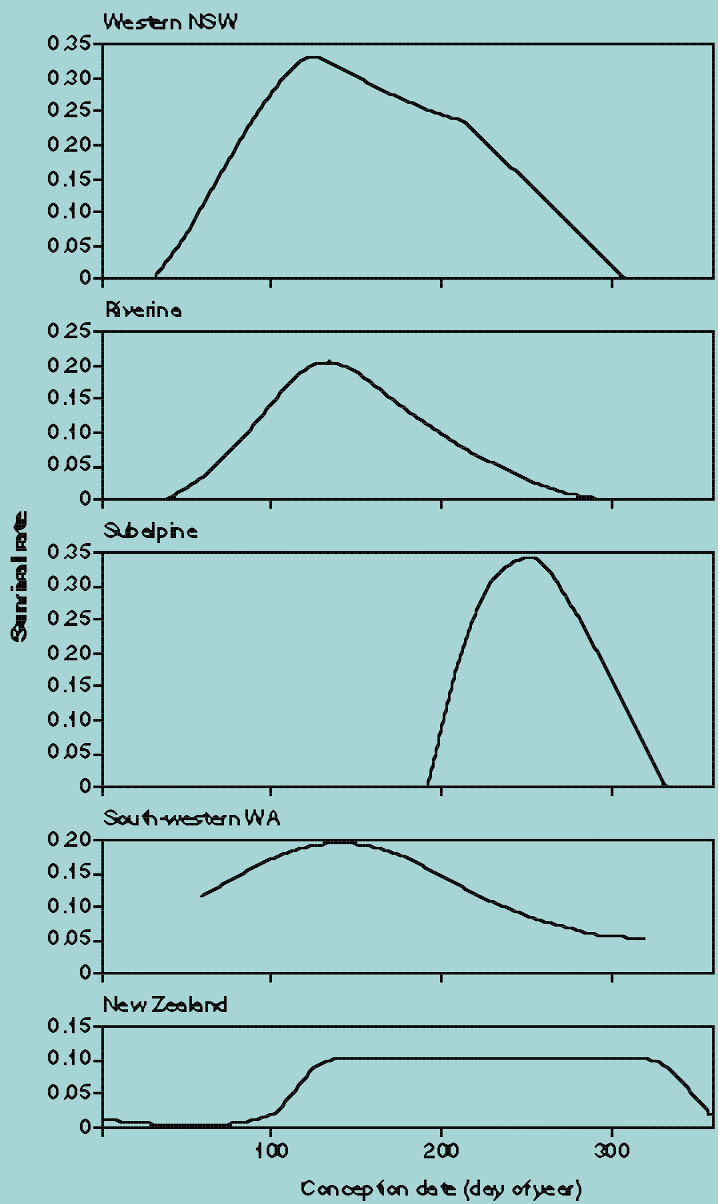

Figure 19: Seasonal variation in the survival rate to 24 weeks of young born at different times of the year (after Gilbert et al. 1987).

3.10 Population dynamics

3.10.1 The rangelands

The most important factors influencing population dynamics are myxomatosis, predators and rainfall. Rainfall often has a dominant role as it influences both reproductive rate and juvenile survival. The year for the rabbit can be partitioned into two parts, the breeding season and the season during which they must survive (Andrewartha and Birch 1984). The relative lengths of these two seasons determines the rate of increase or decrease in numbers.

Breeding season	Survival season	Effect on population
Very long	Very short	Major increase
Long	Short	Increase
Average	Average	Increase or static
Short	Long	Slight decrease
Very short	Very long	Sharp decrease

The sequence of these seasons determines whether a population will attain high densities. Two favourable breeding and survival seasons in succession will result in high densities (Cooke 1981b). If the probability of favourable seasons can be predicted, for example using models that predict the probability of El Niño events, then it may be possible to moderate the potential increase in rabbit density through some form of intervention, such as the introduction of appropriate strains of myxomatosis (Foran et al. 1985) (Figure 20).

'Conventional control techniques, such as warren ripping, would be more effective if applied during dry periods before rabbit populations start to increase.'

Conventional control techniques, such as warren ripping, would be more effective if applied during dry periods before the population started to increase (Figure 20).

Rabbits can reach extremely high numbers which are then dramatically reduced when vegetation and water become limited in summer or a drought, or with an outbreak of myxomatosis.

Source: Unknown

The relative length of rabbit breeding and survival seasons also influences predator numbers. A very long rabbit breeding season increases the survival of young foxes and feral cats. After a sudden decrease in rabbit numbers, predator numbers slowly decline, but their continued pressure on rabbits can prevent any sudden increase in rabbit numbers. When predator numbers finally fall to low levels, the stage is set for a major increase in rabbit numbers when seasonal conditions permit. Myxomatosis is highly seasonal with a peak in the summer months (Parer and Korn 1989) and the interval between outbreaks is 1–3 years.

3.10.2 Higher rainfall areas

Areas of New Zealand with high rainfall have the highest rate of rabbit reproduction in the world (Figure 18) but rabbit densities are relatively low. The reasons for this apparent anomaly are obscure but include predators, flooding of warrens, high parasite burdens, hypothermia of young due to wet nests, and long, dense improved pastures which rabbits dislike (Robson 1993). Where populations are low and stable in New Zealand, the rabbits have a long breeding season and provide a reliable supply of young rabbits to predators throughout the year (Gibb and Williams 1990). Because of this reliable supply of young rabbits, young predators survive well and predator numbers fluctuate little, exerting a constant pressure on the rabbit populations. Contrary to the situation in the Australian rangelands, drought years in the wetter parts of New Zealand provide good conditions which cause a rapid increase in rabbit populations.

In Australia, important mortality factors are predators, myxomatosis, flooding, hypothermia and parasites, with predators possibly being the most important factor in wetter areas. If rabbits are breeding in most months of the year, not only do young foxes and cats have high survival rates, but specialist birds of prey that rely on young rabbits do not have to leave the area to search for food, as they must in districts with pronounced seasonal rabbit breeding. As a

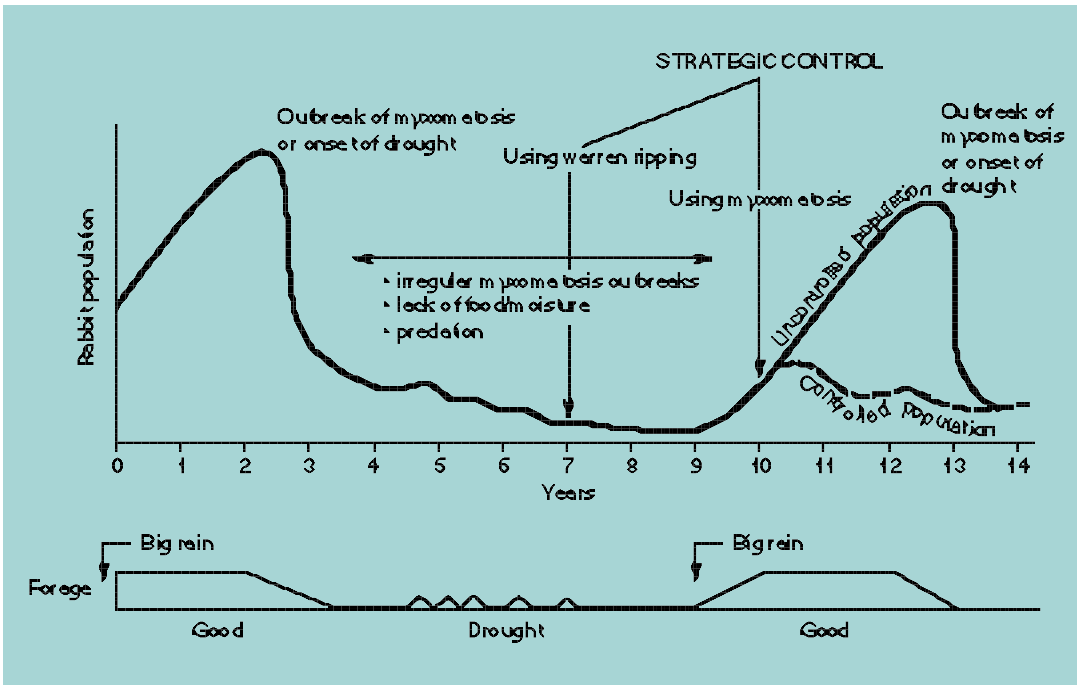

Figure 20: Hypothetical model of central Australian rabbit populations and suggested strategic application of control measures (after Foran et al. 1985).

result, they can maintain a high predator pressure on the rabbit population.

Also in wetter areas, higher parasite infestations may kill rabbits (Dunsmore 1971, 1981) or weaken them, making them susceptible to predation. Rabbits with myxomatosis are often present in a population throughout the year, providing a consistent source of food for predators (Parer and Korn 1989; Parer and Libke 1991). Predators can exert their greatest effect on low density, scattered rabbit populations, if these predators can maintain their own numbers on alternative food when there is a reduction in the rabbit population due to seasonal effects or myxomatosis. Alternative food is more abundant in high rainfall than in other areas.

3.10.3 Intermediate rainfall areas

The most favourable climate for rabbits in Australia is in the sheep–wheat intermediate rainfall zone, where severe droughts are not common, parasite burdens are low, and the survival of young predators is low. In addition the breeding seasons of rabbits, although not as long as in higher rainfall areas, result in higher annual productivity per female (Myers 1971; Gilbert et al. 1987) (Figure 19).

Although the intermediate rainfall zone is biologically the most favourable area for rabbits, they are less of a problem in this area compared to the higher and lower rainfall areas because: (1) the land is mostly flat and warrens are easily ripped; (2) there is little surface harbour due to extensive clearing and the burning of fallen timber to facilitate cultivation; (3) a high proportion of the area is cultivated; and (4) there are more frequent outbreaks of myxomatosis affecting a higher proportion of the rabbit population, compared to higher and lower rainfall areas.

PART TWO

IMPACTS AND USE

4. Economic and Environmental Impacts

Summary

Before the introduction of myxomatosis, rabbits greatly reduced stock productivity and caused profound direct and indirect damage to soils and to native plants and animals. Today, rabbit damage is worst in the rangelands, where a whole suite of plant species and their dependent animals are threatened with severe range contraction or extinction.

The effect of the rabbit in preventing regeneration of native plants is not always obvious. Many of these plants are long-lived but the populations are reaching a stage where many individuals are dying from old age. If rabbits are not controlled before the remaining plants reach the end of their reproductive lives, there will be a long-term decline of the tree and shrub populations in many parts of the rangelands. The extent of the ecological consequences of this are unknown. Significant changes in bird communities and increased soil erosion are likely to be two of the main consequences. There may be no safe rabbit density for some tree and shrub seedlings particularly within 200 metres of rabbit warrens.

As well as causing detrimental habitat change, rabbits threaten native mammals directly through grazing competition and indirectly through intensified predation by cats and foxes after rabbit numbers crash during droughts or myxomatosis outbreaks. Unfortunately it is probable that reducing rabbit numbers will reduce numbers of native birds of prey as rabbits are the main food of many raptors during their breeding seasons.

The extent to which rabbits reduce the carrying capacity for livestock is not well quantified, although there are numerous anecdotal accounts of increased carrying capacity for sheep following rabbit control. Competition between sheep and rabbits is likely to be most significant when pasture biomass falls below about 250 kilograms per hectare, especially during and coming out of drought. The value of lost production due to rabbits is estimated to be $20 million a year for the pastoral districts of South Australia and $115 million annually for the wool industry over the whole of Australia. In addition to this are the costs of stock deaths and destocking in droughts which could be reduced if there were fewer rabbits. Besides these short-term production losses, rabbits, in combination with other wild grazers and livestock, cause damage to the long-term sustainable use of rangeland for nature conservation and pastoralism. Rabbits cause changes in the quality of forage and damage to the flora and habitat of native fauna. Rabbit damage is most severe during and coming out of drought.

There has not been a properly designed study to demonstrate the cost-effectiveness of rabbit management in the rangelands, although several retrospective studies indicate that rabbit management can be highly profitable. For example, there is an estimated 30% return on investment for rabbit management in the southern Flinders Ranges of South Australia.

Rabbit management, particularly in the rangelands, is central to the success of a number of natural resource conservation programs on which the Commonwealth Government has recently embarked. These programs include Ecologically Sustainable Development (ESD), Endangered Species Program (ESP) and the Decade of Landcare, which incorporates the National Resource Management Strategy, National Landcare Program (NLP), One Billion Trees and Save the Bush Programs. In New Zealand the rabbit was declared a pest of national importance under the Agricultural Pest Destruction Act 1967. Rabbits need to be effectively managed in rabbit-prone reserves and national parks to ensure the conservation values of these areas are protected.

It has been demonstrated in the high rainfall areas of New Zealand that control of low density rabbit populations is unnecessary because numbers remain low if control is relaxed. This is, however, not true in the drier areas of Australia and New Zealand, or in areas with unreliable rainfall.

Rabbits are commercially harvested, used as subsistence food by some Aboriginal groups, farmed for food and raised as pets. Wild rabbit harvesting is worth about $10 million annually. Unlike the harvesting of some other pests such as feral goats, the commercial use of rabbits appears to have little value for managing rabbit damage mainly because wild harvesting is opportunistic and does not reduce densities to a level where damage is effectively managed.

4.1 Introduction

The economic and environmental impact of the rabbit is not well quantified. Much information consists of anecdotal reports or results of experiments where there have been no non-treatment controls or replication of experimental sites. Consequently the reliability of the information presented here is uncertain. Scientifically designed studies to demonstrate the relationship between rabbit density and damage are necessary so that farmers and governments can be made more aware of rabbit damage and give appropriate priority to rabbit management.

4.2 Economic impact

4.2.1 Public costs

The main public costs are:

1. Environmental degradation. These costs are discussed in Section 4.3.

2. Cost of rabbit control on public lands. The Victorian Department of Conservation and Natural Resources

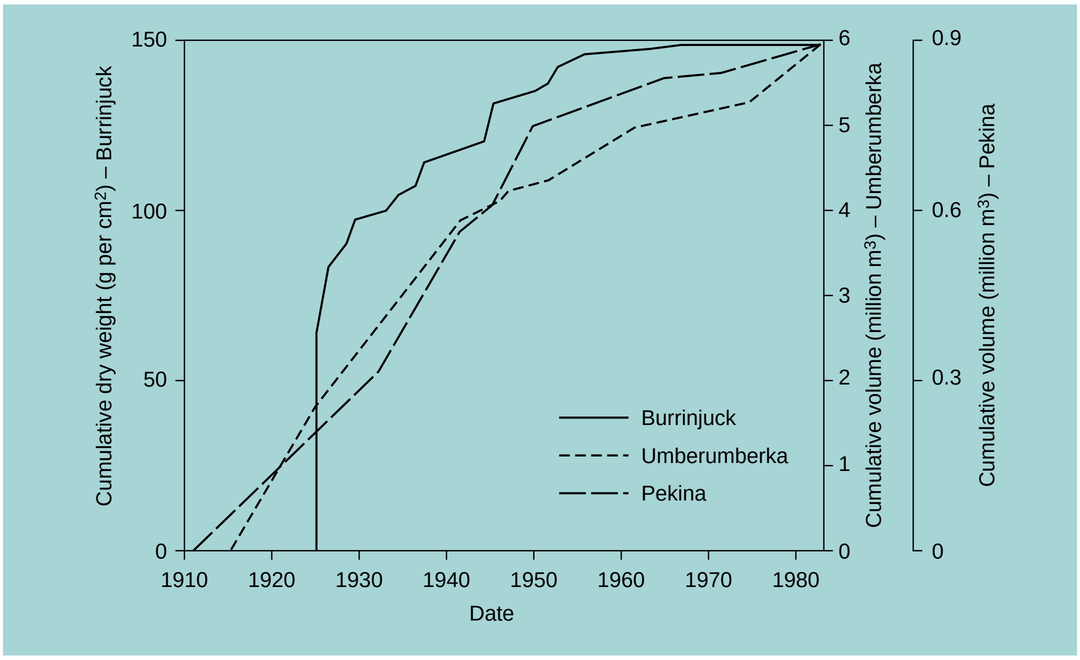

Figure 21: Cumulative sedimentation in Burrinjuck (southern tablelands, New South Wales), Umberumberka (western New South Wales) and Pekina (near Peterborough, South Australia) Reservoirs. Burrinjuck first filled in 1925 (after Clark 1990).

(DCNR) spends more than $4 million a year on rabbit control (Begg and Davey 1987). Similar relative expenditures can be expected for other states with substantial rabbit populations.

3. Siltation of dams. The effect of rabbit density on siltation is illustrated by the rate of deposition of sediments in Burrinjuck Reservoir before and after the advent of myxomatosis in 1951 (Figure 21). In the more arid areas (Pekina and Umberumberka), the decline in the rate of siltation is less pronounced due to the reduced effectiveness of myxomatosis in the arid zone and overgrazing by domestic stock which continues to the present day.

4. Forestry and tree plantation losses. Rabbits can cause extensive losses to both introduced pine and native eucalypt plantations (Griffith and Dolman 1985). For example, in Tasmania prior to myxomatosis and the use of 1080 poison, most *Pinus radiata* seedlings had to be protected with rabbit-proof netting (Tasmanian Forestry Commission 1960). Rabbits can prevent regeneration of native *Callitris* spp. and other species, damage tree plantings, and significantly increase the cost of public tree planting programs due to the need to erect tree guards.

5. Research, extension and administration costs associated with rabbit control.

6. Reduced tax revenue due to the reduced income of primary producers.

4.2.2 Private costs

The main private costs are:

1. *Reduced stock production*. Direct use of forage by rabbits results in fewer livestock, lower wool clip per sheep, lower lambing percentages, lower weight gain, breaks in the wool, and earlier stock deaths during droughts. On a grazing property at Robe in South Australia, stock numbers were able to be increased by approximately 40% after rabbit control, and these increased stocking rates were maintained during the worst drought on record in 1967 (Table 3).

The cost of lost production has been estimated as $115 million for Australia (Sloane, Cook and King Pty Ltd. 1988) and $20 million for the pastoral district of South Australia (Henzell 1989). The effect on related industries and the community has not been examined.

There are also indirect losses to stock production. Increased areas of bare soil due to rabbits causes dirty fleece. Lamb losses can result from the higher fox numbers maintained by rabbits (Lugton 1987, 1991).

'On a grazing property at Robe in South Australia, stock numbers were able to be increased by approximately 40% after rabbit control, and these increased stocking rates were maintained during the worst drought on record in 1967.'

The rabbit is the intermediate host of two canid tapeworms (*Taenia pisiformis* and *T. serialis*). Rabbits are a reservoir of liver fluke (*F. hepatica*) on spelled paddocks

Table 3: Comparison of stocking rates on a mixed grazing property in the south-east of South Australia before and after rabbit control (J. Burley, Animal and Plant Control Commission, pers. comm. 1992).

Stock carried	Years	Sheep	Cattle
Before	1962	2400	63
rabbit control	1963	2280	97
	1964	2433	92
	1965	2926	76
After	1966	3787	107
rabbit control	1967	3800	100

2

(Dunn 1969). High rabbit numbers could also increase the prevalence of hydatids (*Echinococcus granulosus*), parvovirus, toxoplasmosis, distemper, brucellosis and leptospirosis (Mulley et al. 1981), due to augmented fox and cat numbers. Rabbits with toxoplasmosis were collected from Mud Island in Port Phillip Bay even though there had been no sighting of the cat, the primary host for *Toxoplasma gondii*, for 10 years before the rabbits were collected (Cox et al. 1981).

2. *Higher costs during drought.* During droughts rabbits graze on the reserve forage in the rangelands. This results in the earlier consumption of perennials by livestock, leading to stock transport and agistment costs during droughts, or forced sale of stock at low prices and purchase at higher prices. These costs can be crippling to individual landholders. Rabbits are most abundant on the drought resistant sections of a property, the deep soils in run-on areas (Mutze 1991). Planning and managing for drought can reduce the losses and damage to the land but at the cost of less stock and/or extensive pest animal control.

3. *Land and vegetation degradation.* Rabbit grazing leads to pasture degradation and lack of regeneration or destruction of important fodder trees, shrubs and perennial grasses, particularly during and coming out of droughts. Grazing and warren building by rabbits causes more extensive areas of bare and disturbed soil (Leigh et al. 1987; Cochrane and McDonald 1966) which leads to soil erosion and consequent loss of soil fertility, and siltation of dams. There is no hard data on the contribution of rabbits to soil erosion at low densities. The effects at high densities are obvious but have not been measured.

   There are also costs associated with the restoration of degraded lands and reduction in land values.

4. *Forestry and tree plantation losses.* Rabbit control costs in private forests can be as high as $80 per hectare during the period when trees are vulnerable to rabbit damage. Damage from browsing rabbits can approximate one year's loss of growth, equivalent to $800 per hectare, at clear-felling (Griffith and Dolman 1985). Farmers also bear the costs of losses of planted trees and the cost of protecting them from rabbits.

5. *Reduced crop yields.* Wheeler and Nicholas (1987) estimated that rabbits inhabiting scrub alongside the boundary of a crop took one-third of the crop within 50 metres of the boundary. In a similar situation in South Australia, Burley (Animal and Plant Control Commission, pers. comm. 1992) recorded a loss of 58% in the first 70 metres of a crop paddock. Annual crop losses to rabbits in South Australia are an estimated $6.5 million (Henzell 1989).

6. *Direct costs to farmers of rabbit control operations.* Henzell (1991) estimated that rabbit control in South Australia for cropping and grazing land costs $1.7 million a year, $0.5 million by landholders and the rest by government. In addition there are levies paid to control boards and the erection and maintenance of rabbit-proof fencing.

4.2.3 Vegetation degradation

In the rangelands, intense rabbit grazing results in a reversal of the usual direction of succession — biomass and cover are reduced as perennial grasses and shrubs are replaced with annual species and then an increasing component of unpalatable weeds. With sustained high grazing pressure the result is an increasing cover of moss and ultimately lichens that supports few stock and few rabbits (Farrow 1917; Tansley 1939; Fenton 1940). Legumes are the first to decline because they are selected for their high nutrient quality. Rabbits eat the leaves, the developing flowers and the fallen seeds (Myers and Poole 1963; Wood et al. 1987). After three years of high rabbit densities, the cover of subterranean clover (*Trifolium subterraneum*) was reduced from 75% to 20% on the southern tablelands of New South Wales (Croft 1990).

The change in vegetation composition due to changes in the occurrence of unpalatable plant species is detectable 300 metres from a warren (Leigh et al. 1989). On a reseeded pasture in England, rabbits reduced the biomass of sown grasses and clovers by 77–84% and increased weeds by 70% (Phillips 1953). Rabbits make many shallow scrapes which are ideal germination sites for weeds. Rabbit warrens are often dominated by weeds because of soil disturbance, high nutrient status and higher grazing pressure.

It is difficult to measure the current impact of rabbits on the composition of Australia's natural pastures using short-term studies because variations in rainfall have profound short-term effects and change now is relatively slow compared with the initial impact of stock and rabbits. Nevertheless, some changes have been recorded. Foran et al. (1985) found that the density of *Enneapogon* spp., the most valuable component of the herbaceous layer for rangelands stability and domestic animal forage in the Alice Springs district, decreased at rabbit counts of over 20–27 rabbits to the spotlight kilometre, equivalent to four rabbits per hectare.

It would be desirable for land managers to spell grazing areas more frequently from stocking to encourage their rehabilitation. Most land managers are unwilling to take this action because they believe, probably correctly, that rabbit and kangaroo numbers will build up due to invasion or breeding and the increased numbers will prevent recovery of the spelled areas (Norbury and Norbury 1992).

4.2.4 Impact on stock production

The impact of rabbits on domestic stock production can be estimated by various methods: stock equivalents; exclosures; before and after method; farmer questionnaires; direct experimental measurements; and whole-farm comparisons.

Stock equivalents

One way to estimate the production loss due to rabbits is to estimate both the food consumption of rabbits and rabbit numbers and then convert rabbit numbers to sheep equivalents. From enclosure studies, Short (1985) found that 16 rabbits eat as much as one sheep. However, there is some evidence that competition between sheep and rabbits in the western division of New South Wales is low until pasture biomass is less than 250 kilograms per hectare (Short 1985; Williams 1991). Therefore it is not necessarily valid to assume that all

Table 4: Estimated relative grazing pressures in dry sheep equivalents (DSE) by sheep, goats, kangaroos and rabbits on different land types in the Broken Hill district (after Tatnell 1991).

Grazing pressure	Calcareous soils	Sandy soils	Stony hills	Saltbush plains
Sheep (DSE)	650	580	400	800
Goats (DSE)	20	42	400	20
Kangaroos (DSE)	250	375	240	200
Rabbits (DSE)	800	1000	150	50
Rabbit grazing (as a % of total grazing pressure)	47	50	13	5

Table 5: Pasture biomass consumed (kg/ha/yr) by rabbits. Data derived from exclosure studies (Wood et al. 1987).

Location	Years	Biomass consumption (kg/ha/yr)	Rabbits per hectare
Subalpine	1978–85	210–710	9
Southern Tablelands	1972–73	330–440	1–16
Western Plains (NSW)	1979–85	126–200	1–60
Alice Springs	1981–83	300	4

the feed taken by rabbits would be taken by sheep.

When pasture biomass is greater than 250 kilograms per hectare there are other reasons why results from this method should be interpreted with care. Rabbit density estimates are very imprecise, and rabbit densities vary throughout the year as well as between years and between parts of the one property. Rabbit densities are highest in late spring and early summer, and much of the abundant ephemeral vegetation rabbits eat then will, if not eaten, dry out and blow away rather than be eaten by stock. Conversely, relatively low rabbit grazing pressure may have particularly adverse effects when rabbits concentrate on the most nutritious and green components of the pasture, particularly in summer. Small amounts of out-of-season green feed are immensely valuable for livestock nutrition (Wilson and Hodgkinson 1991). An indication of the palatability of some relatively small components of the pasture to stock is shown by the observation that a species of grass was 80% of the diet of sheep when it was less than 1% of available forage (Graetz and Wilson 1979). Rabbits are not the only competitor with sheep on rangelands. Sheep also compete with kangaroos but this competition is mainly for the less nutritious perennial grasses (Wilson 1991a, b).

Table 6: Estimates of pasture biomass loss from various densities of rabbits, using exclosure techniques in Western Australia (after Gooding 1955).

Estimated rabbit density	Pasture eaten by rabbits(%)
Light and moderate	10–47
Heavy	62–77
Very heavy	86–100

Wood et al. (1987) collated 27 estimates of post-myxomatosis rabbit densities from all over Australia and calculated the herbage loss for these densities; the range was 1–847 kilograms per hectare per year with an average of 87 kilograms per hectare per year. This would be equivalent to a lowering of carrying capacity by one sheep for every five hectares although, as stated earlier, it is not valid to assume that all feed not taken by rabbits would be available to sheep. Rabbit numbers on individual properties can be high. During 1965–66, six million rabbits from Innamincka Station were processed at a chiller which is 375 000 sheep equivalents (South Australia, Department of Lands 1986).

Tatnell (1991) estimated rabbit densities by counting warrens and then assuming that a limestone warren had an average of eight rabbits and a sandy warren had an average of four rabbits, and used a conversion factor of 16 rabbits = one dry sheep equivalent (DSE). From this he estimated the total grazing pressure in the Broken Hill district and showed that rabbits accounted for 5–50% of the total grazing pressure (Table 4).

Rabbits were an even greater component of the total grazing pressure in the calculations of Mutze (1991). Using the conversion factors of two active entrances = one rabbit, and 12 rabbits = one sheep, he estimated that grazing pressure from rabbits was seven times the average stocking rate on the study site in South Australia.

Exclosures

In this method areas of pasture are fenced in such a way that one area has no grazing and another is fenced using a mesh size which allows rabbits but no other grazers into the plot. The difference in biomass measurements between the grazed and ungrazed plots can be assumed to be the amount of feed lost to rabbits. Assuming that one sheep requires say 1.25 kilogram per day, the production loss can be calculated. Again the assumption is that sheep would have consumed all the biomass eaten by the rabbits, and this, as mentioned earlier, may not be valid.

Wood et al. (1987) presented estimates of biomass consumption by rabbits from four Australian exclosure studies. He found a range of 200–400 kilograms per hectare per year, which would be equivalent to lowering carrying capacity by 0.5–1 sheep per hectare if sheep would have eaten the additional pasture (Table 5).

In a national park the biomass inside a rabbit exclosure grazed by kangaroos alone was 460 g/m^2; outside the exclosure in the area grazed by both kangaroos and rabbits the biomass was 118 g/m^2 (Cochrane and McDonald 1966). Results of another exclosure experiment on a pastoral property in the mallee showed that in 11 of the 13 years studied, rabbits ate more pasture than did sheep (Zaller 1986).

Based on exclosure studies in Western Australia, Gooding (1955) estimated the percentage of pasture taken by rabbits at different densities of rabbits (Table 6), concluding that rabbits consume a significant proportion of the available pasture in the rangelands, often selecting the most nutritious components. However, the extent to which rabbits reduce the carrying capacity for livestock is not well quantified. Competition between sheep and rabbit grazing is likely to be most significant when pasture biomass falls below a critical level (approximately 250 kilograms per hectare for western New South Wales) and especially during and coming out of drought (Short 1985).

Before and after method

This method compares stock production before and after a reduction in rabbit density. Other factors such as seasonal weather, changed management practices and changes in density of other wild herbivores can influence the result and so reduce the reliability of conclusions drawn from this method. For example, Plant et al. (1984) found changes in seasonal weather, feral pig predation and ram management caused changes in lamb marking percentages in different years.

A comparison of the five-year averages before and after myxomatosis showed that in New South Wales: (1) wool production and the numbers of (2) sheep and (3) cattle slaughtered (assuming slaughter percentages were constant) increased by 26, 25 and 26% respectively (Waithman 1979). In Western Australia, sheep numbers increased by 33% during 1954–57 (Tomlinson 1959). Reid (1953) estimated that the value of increased wool and meat production due to the effects of myxomatosis in 1952–53 alone, was 34 million pounds ($590 million in 1990 dollars). Most of this increased production came from New South Wales (21%), South Australia (18%) and Victoria (12%). Queensland (10%) had a relatively small

Table 7: Increase in production after rabbit control on a 650 hectare property in the northern Midlands, Tasmania (after Meldrum 1959).

Year	Wool clip (kg)	Rabbits killed	Control costs ($)
1952	5 338	16 000	9 080
1953	8 175	3 000	1 080
1954	9 668	1 200	720
1955	9 289	900	520
1956	10 452	600	330
1957	11 629	450	240

amount of country seriously infested by rabbits, and Tasmania (7%) and Western Australia (2%) were little affected by myxomatosis at that time.

In England and France, following the successful introduction of myxomatosis, the yield of cereal crops increased by up to 1018 kilograms per hectare (Sumption and Flowerdew 1985). The annual damage cost to wheat, field crops and grassland in Britain before myxomatosis was estimated to be around $A1 billion (Flux et al. 1990). The Ministry of Agriculture, Fisheries and Food estimated losses in 1986 to be in excess of $A330 million (Mills 1986).

Meldrum (1959) showed that wool production on a Tasmanian property more than doubled following rabbit control (Table 7). More recently a 247 km^2 property in South Australia carrying 4500 sheep when a rabbit control program began in 1985, was carrying 7500 sheep six years later with plenty of reserve fodder, whilst neighbouring properties were reducing sheep numbers due to lack of feed (Hunt and Rasheed 1991).

Effective rabbit control on a property near Colac in Victoria resulted in an increase in carrying capacity from 1.75 DSE per hectare in 1975 to 7.75 DSE per hectare in 1990. Composition of the pasture improved, bare ground was revegetated and there were fewer weeds (Nolan 1991).

A rabbit control program on a property in 1988–89 in the Ivanhoe district resulted in a 180% increase in gross income compared with the district average increase of 25% (R. Wynne, Soil Conservation Service, NSW, pers. comm. 1991).

Farmer questionnaires

Farmers were asked to estimate loss of production due to rabbits. Respondents from western New South Wales and northern South Australia estimated production losses due to rabbits to be about 30%; respondents in higher rainfall districts seldom nominated loss rates above 10% (Sloane et al. 1988). Total loss for Australia's wool industry was estimated to be $140 million. This may be an underestimate as farmers generally do not admit to problems on their own farms and they usually underestimate rabbit numbers on their properties, sometimes by as much as 90% (Tatnell 1991). For example, in a survey of the Darling Downs, 88% of respondents to the questionnaire thought that land degradation was a serious problem on the Downs and 47% thought it serious on their neighbours' land, but only 11% thought they had a problem on their own property (Rickson et al. 1987). This result shows that data from this form of questionnaire need to be interpreted with caution.

Direct experimental measurements

Scientifically designed experiments, with appropriate non-treatment areas, and aimed at determining the relationship between rabbit density and damage, provide unequivocal evidence of rabbit damage. These studies require livestock to be run at a set rate in similar paddocks with zero rabbits in some paddocks and a known rabbit density in others. The difference in livestock production between the treatments can then be inferred as being due to rabbit grazing. However, few such experiments have been conducted to measure rabbit damage. Appropriate experiments can be technically difficult, expensive and difficult to interpret, particularly if grazing by other species such as kangaroos occurs on the treatment sites. They need to continue for long periods to sample different seasonal conditions and it is difficult to simulate broadacre conditions if small experimental exclosures are used.

In an experiment run over 18 months in the far west of New South Wales, there was no difference in wool production between treatments with 0.1 and 4 rabbits per hectare (Williams 1991). Due to good seasons during the experiment, biomass of forage was not limiting and wool production is one of the last physiological factors affected by poor food (Stock et al. 1976).

In the southern tablelands of New South Wales blocks free of rabbits returned $68.70 per hectare more from wool sales than blocks which had 72 rabbits per hectare (Croft 1990). Sheep liveweight was 7.23 kilograms higher in the blocks free of rabbits than in blocks with extremely high rabbit density, 72 per hectare. Thus, in this experiment, the cost in lost production per rabbit each year was about one dollar. In England rabbit densities of eight per hectare lowered weight gains in sheep by 20% in the first year and 64% in the second year (Thompson and Worden 1956).

Whole farm comparisons

The basis of this method is to scientifically study the management system. The productivity of farms which are starting long-term, large-scale rabbit management are compared with matched farms not practising rabbit management. Rabbit management costs, farm inputs and outputs are monitored for at least ten years. This is the basis of the adaptive management approach advocated by Walters and Holling (1990). Results from this method would provide the most convincing evidence for land managers. A long-term study of this type, partly funded by the National Soil Conservation Program, is in progress in the Northern Territory (Low et al. 1992).

4.3 Environmental impact

4.3.1 Europe

'The rabbit has been for so long a feature of the countryside that we take its biotic effects for granted; but, next to man and his domestic animals, rabbits are the prime architects of our landscape. They feed on one type of seedling and its dies; they avoid that of another species and it thrives' (Thompson and Worden (1956) on the effects of the rabbit in England).

Rabbits are the pivotal species in many ecosystems in western Europe. They are a filter that germinating plants have to go through if they are to reach maturity. All trees have a seedling stage where they are vulnerable to rabbit grazing. The effect of rabbit grazing on grass height and density has had profound effects on species as diverse as butterflies (Thomas 1980), rodents and lizards (Sumption and Flowerdew 1985). Rabbits are the basis of the diet of most carnivores because, under most circumstances, they are by far the highest biomass of the small to medium-sized herbivores.

In his monumental work on the vegetation of the British Isles, Tansley (1939) considered rabbit grazing to be the most important factor modifying the (semi-natural) vegetation of that region. However, the real impact of the rabbit was evident only after myxomatosis was introduced to Britain. Thomas (1956) recorded ash (*Fraxinus excelsior*) seedlings on a previously bare forest floor. In Breckland, pine *(Pinus sylvestris)* seedlings were seen for the first time in 35 years. In Scotland the amount of natural regeneration of conifers and deciduous trees prompted calls for changes in management policy (Kennedy 1956). Shrubs such as gorse (*Ulex* spp.), hawthorn (*Crataegus* spp.) and bramble (*Rubus* spp.) became a problem (Hodgkin 1984). Grass heath reverted to a heather (*Calluna* spp.) heath. Reafforestation without rabbit-proof netting became possible for the first time in 100 years. The major forests of England were established before the rabbit became abundant in the middle of the nineteenth century.

After myxomatosis was introduced in the Netherlands, the area covered by scrub on the sand dunes expanded. Previously, almost all seedlings of *Crataegus* had been eaten by rabbits (Wallage-Drees 1988). Dr Armand Delille introduced myxomatosis into France in 1952 and was awarded a special medal in 1956 by the National Federation of Foresters in recognition of his valuable service to the forest industry (Fenner and Ratcliffe 1965).

Not all rabbit impact is seen to be negative. Rabbits are now regarded as necessary to maintain some degraded 'natural' communities in Britain. In the Breckland Environmentally Sensitive Area, rabbits are being encouraged in order to help maintain the grass heath subcommunities rich in lichens and ephemerals (Dolman and Sutherland 1992). At Newborough Warren at Anglesey in Wales, the immediate consequence of reduction in rabbit numbers by myxomatosis was scrub invasion which increased the soil pH, organic matter content, water holding capacity and the nutrient supplying capacity. *Pinus* spp. are now invading the area and Hodgkin (1984) considered that the increase in soil fertility would lead to a forest dominated by exotic conifers rather than the diverse native flora previously found on the dunes (Boorman and Fuller 1982).

4.3.2 Australian rangelands

'What is the difference between chainsaws, bulldozers, sheep and rabbits? Not much really. Though chainsaws and bulldozers are the preferred tool for clearing land, sheep and rabbits are just as effective. They eat tree seedlings so that when the adult trees die there are no young ones to replace them. The net effect is identical, only the time scale differs' (Pickard 1991).

Time scale is important when considering the fate of rangeland vegetation. When a drought breaks the annuals germinate and the perennials grow new shoots. There is an illusion of stability because many rangeland shrubs and trees live for 100–400 years (Hall et al. 1964; Crisp 1975, 1978). Natural mortality of these plants is a slow, inconspicuous process, even if it is occasionally accelerated by drought and rabbits. The extent to which it is happening is difficult to appreciate because of the long time scale. Because the downward trend tends to be in discrete episodes and is highly variable across the rangeland, it is masked by the short-term patterns of growth and decay in response to rain. Even when there is some successful regeneration, it is usually not enough for long-term replacement of the species. The current replacement rate of many of the trees and shrubs in the southern rangelands is not sufficient to prevent their disappearance in the long term (Lay 1979; Lange and Graham 1983). The relative contributions of sheep, cattle, goats, kangaroos and rabbits have not been properly investigated, but studies by Auld (1990), Cooke (1991a) and Henzell (1991) indicate that rabbits by themselves are capable of preventing the regeneration of many species.

'Rabbits need to be kept at low densities for many years to permit successful regeneration of some plants which are highly palatable to them.'

Conditions suitable for germination and establishment of vegetation in the rangelands occur at time intervals of 5–50 years, depending on species and rainfall patterns. Even an apparently successful germination can be wiped out by rabbits up to 15 years after the event (Henzell 1991). Rabbits can ringbark shrubs and even fell small trees. The time necessary to grow beyond the reach of rabbits depends on seasonal conditions and the growth rate of the species. Rabbits need to be kept at low densities for many years to permit successful regeneration of species that are highly palatable to rabbits. Paradoxically, in western and central New South Wales, the interaction of grazing, reduced rabbit numbers, changed fire regimes and fluctuating climates has encouraged massive regeneration of some native shrubs and trees that are unpalatable to stock, the so-called 'woody weeds' (Tatnell and March 1991).

The rains that promote germination and establishment of native trees and shrubs are also likely to result in high rabbit populations through the increased availability of pastures (Cooke 1981b). The most obvious damage done by rabbits is during a subsequent drought. In their search for succulent vegetative material they can ringbark small trees and shrubs and 'strip off the leaves, and snip off the smaller twigs, reducing plants four or five feet high to a bundle of leafless twigs about 12 in [30 cm] high' (Hall et al. 1964). These episodes can occur once every 6–7 years in South Australia (Cooke 1977b; Oxley 1987).

Grasses and herbs

The initial impact of sheep and rabbits on Australian grasses and herbs was profound. Many plant species have disappeared along with their seed banks; and we do not know what has been lost in many areas. In ten years (1979–88) at Yathong Nature Reserve in central New South Wales, no species of grasses or herbs were lost where exposed to rabbit grazing and no new species were gained in grassland plots protected from rabbits (Leigh et al. 1989). This suggests that many years of intensive grazing have permanently changed some grasslands, so that only those few species able to withstand the extremes of grazing and climate now persist, and seed stores of the other species have disappeared (Robertson 1986).

'Whilst rabbits are a major problem in the rangelands, attention must also be given to damage due to grazing by other species, namely livestock and other wild herbivores.'

In the mallee in western Victoria, 17 indigenous species of ground layer plants, including one undescribed *Sida* species, recorded inside two-year-old rabbit-proof exclosures were not recorded outside the exclosures. Kangaroos grazed freely over both areas and sheep were absent (Cochrane and McDonald 1966). The density of the native grass *Enneapogon* declined at moderate rabbit densities in central Australia (Foran et al. 1985). In a study area near Cobar in central New South Wales, grazing-induced mortality of seedlings of native perennial grasses was as high in plots grazed by kangaroos and rabbits as it was in plots grazed by sheep, kangaroos and rabbits in seven out of 15 comparisons (Grice and Barchia 1992). In this study grazing did not affect the mortality of established plants (Grice 1989). Rabbit populations of less than three per hectare can maintain the dominance of introduced annual herbage but when rabbits are excluded native perennial grasses such as *Stipa* and *Danthonia* can rapidly replace the exotics (Mallet and Cooke 1986).

Acacias

While rabbits appear to selectively browse seedlings of certain shrubs and trees (Lange and Graham 1983), sheep select older plants, possibly because seedlings are too small and isolated (Lange et al. 1992). A recent study (Lange and Graham 1983) examined selective browsing by rabbits at low population density (less than 0.5 per hectare) on seedlings of arid zone acacias including *A. papyrocarpa* (western myall), *A. kempeana, A. oswaldii* and *A. burkittii*. After 15 months, only seedlings totally protected from rabbit and sheep showed good growth. All others, including those protected from sheep but available to rabbits, were severely damaged. There may be no safe rabbit density for some tree and shrub seedlings. For practical and economic reasons, as well as for nature conservation, sustained reduction of rabbits to very low densities should be the aim of management strategies, as well as monitoring to assess whether trees and shrubs do regenerate under this strict control regime.

Lack of regeneration of acacias has been observed close to warrens (within 200 metres), but not at 700 metres (Lange and Graham 1983). In South Australia, western myall is the dominant tree in the arid zone, providing soil cover, animal shelter and fence posts (Lange and Purdie 1976). It is not regenerating on the Nullarbor Plain, where there are rabbits but no domestic stock (Johnson and Baird 1970). Conditions suitable for the establishment of western myall seedlings occur only about once every 20 years (Ireland and Andrew 1992). Even mature acacias of species considered unpalatable to domestic stock such as sandhill wattle, *A. ligulata* show a browse line due to rabbits (Jessup 1951).

On the property used by Lange and Graham (1983), Woodell (1990) investigated why *A. burkittii* regenerated on some sites and not on others. There were two peaks of regeneration. One coincided with high rainfall and the advent of myxomatosis in the mid-1950s, and the other with very high rainfall in 1973–74. There were however, considerable differences between sites in the survival of seedling acacias. The only three sites with seedlings that survived were in very broad watercourses which flood only with exceptional rains. Woodell (1990) suggested that flooding of the watercourses eliminated rabbits long enough for the trees to grow beyond the size at which they are most vulnerable. Near Wentworth, New South Wales, Chesterfield and Parsons (1985) observed the only known regeneration of belah (*Allocasuarina cristata)* from seed. This followed 120 mm of rain in one day in 1961, which flooded the site for five days.

Mulga (*Acacia aneura*), which lives to 250 years, is very palatable to rabbits and stock. It is the most important drought fodder tree in Australia. Estimates of the frequency of occurrence of seasons favourable to germination and establishment of mulga range from 9–30 years (Brown 1985). In South Australia, where rabbit densities are high, mulga regeneration is rare now, and was non-existent prior to myxomatosis (Ratcliffe 1938; Crisp 1978; Greenwood et al. 1989). By comparison, in Queensland, mulga is regarded as a woody weed in places because of extremely high densities. Many of these Queensland stands were established in the early 1950s in cattle country after myxomatosis reduced already low rabbit densities. In parts of the Northern Territory, where mulga grows in areas without rabbits, the high density of regeneration is a problem for some pastoralists (Friedel 1985). We conclude from this that rabbits, not domestic stock, are preventing regeneration of mulga.

Sheep grazing causes more damage to mulga seedlings and inhibits the growth of mulga more than cattle grazing (Pressland 1976). After the seedling stage, sheep grazing does not appear to kill mulga, but even the lightest sheep grazing prevents mulga from growing (Brown 1985). Mulga more than 40 years old can be less than a metre tall (Everist 1949) and therefore still susceptible to ringbarking and browsing by rabbits.

In 1977, Henzell and Lay (1981) established (1) goat-proof; (2) goat and rabbit-proof; and (3) unprotected control plots in the Gammon Range National Park, South Australia. Very few mulga seedlings survived for more than a few years in the plots with rabbits, even when they were at low densities (Henzell 1991). Only in the plots without rabbits was regeneration sufficient to replace deaths among mature mulga. There were three major mulga germinations — 1979, 1984 and 1989. Only the 1979 germinations resulted in survivors.

Table 8: Number of trees and shrubs per hectare at different rabbit densities (after Friedel 1985).

Vegetation type	Rabbits per hectare*	Trees and shrubs per hectare by height		
		Less than 1 m	1–2 m	More than 2 m
Calcareous shrubby	0	808	97	59
grassland	50	0	2	13
Open woodland	0.2	553	84	21
	3–9	150	48	9
	10	21	11	10

* Rabbit density was assessed as one rabbit for every two active warren entrances. This provides a measure of historically high abundance rather than abundance at the time of the survey.

Apparently competition from established grasses and ephemerals prevented successful regeneration in 1984 and 1989.

In the central arid woodlands of the Northern Territory, several species of Acacia and Cassia had mass successful germinations in the mid-1970s in areas where there were stock but no rabbits (Foran 1984). In open woodland in the Northern Territory, Friedel (1985) found no regenerating shrubs or trees on a site with high rabbit density, but good regeneration on sites without rabbits (Table 8). On calcareous shrubby grassland the number of regenerating trees and shrubs was inversely related to the number of warren entrances per hectare. She concluded that in the acacia-dominated calcareous landscapes of the Northern Territory trees and shrubs will disappear in the long term without rabbit control.

If rabbit control to very low densities is not implemented soon in some areas, it is likely that when the remaining mature trees and shrubs die, there will be no seeds available for regeneration and some species may disappear. In the Alice Springs district, *Acacia kempeana* seedlings were almost absent in areas open to rabbit grazing but were dense in exclosures (Foran et al. 1985). From studies in Kinchega National Park, Auld (1990) concluded that rabbit control will be necessary to prevent the extinction of *Acacia carnei*, a threatened species with a limited distribution.

Chenopods

Seedlings of bluebush (*Maireana sedifolia*), a major component in one of the major plant communities in the southern rangelands, rarely survived for more than a few months in a reserve from which sheep had been excluded since 1925. Although rabbits do not often eat the seedlings, the poor survival was probably due to lack of water in the root zone as a result of low infiltration into an eroded soil denuded of mulch by rabbits (Hall et al. 1964).

In a five-month dry spell near Broken Hill, it was observed that rabbits largely depended

Table 9: Percentage basal cover of three vegetation groups and the percentage of bare ground 12 years after erection of rabbit enclosures (after Zaller 1986).

	Not grazed	Rabbits only	Stock and rabbits
Grasses	33.1	21.5	19.9
Forbs	30.2	25.9	25.5
Chenopods	7.2	2.0	3.1
Bare ground	29.5	50.6	52.5

on perennial species including sandhill canegrass (*Zygochloa paradoxa*) and black bluebush (*Maireana pyramidata*) for food (Stanly and Milthorpe 1977). *M. pyramidata* is a long-lived, drought resistant plant which grows on coarse-textured soils susceptible to wind erosion. Rabbits reduced establishment and survival of *M. pyramidata* on coarse-textured soils. Although *M. pyramidata* leaves are unpalatable, rabbits snipped off the leaves and ate the stems. They also killed plants by digging at the roots and scratching out seedlings. Rabbits rather than sheep may also have been responsible for the disappearance of *Maireana* spp. in areas of western New South Wales (Beadle 1948).

Rabbits have indirect effects on saltbush and bluebush communities. Consumption of annual plant species by rabbits may be of little direct consequence as the plants usually have time to set seed. But by eating these plants, rabbits force stock to graze the perennial shrubs more heavily than they would in the absence of rabbits (Ratcliffe 1938). In the Mallee, the cover of chenopods did not increase where rabbits were present (Table 9) (Zaller 1986). In the Chilean mattoral, analogous to Australia's chenopod shrubland, grazing by European rabbits on the seedlings of palatable shrubs is halting the secondary succession process (Fuentes et al. 1983).

Cypress pine

White cypress pine (*Callitris columellaris*) was thought to be in long-term decline but mass germinations occurred in many areas in the 1950s after myxomatosis was introduced. This may indicate that rabbits and not stock were preventing regeneration. In state forests, according to Lacey (1972), 'Prior to 1952, when very little regeneration could be obtained, there was no possibility of providing for a second rotation. Management was orientated towards an organised and gradual liquidation. This problem has now been replaced by the difficulty of removing the bulk of the seedling numbers'. In 1950, however, when myxomatosis was introduced to wild rabbits, a 60-year period of below average rainfall ended in central New South Wales. Over the next 30 years rainfall in this region was well above the long-term average (Bureau of Meteorology). So the improved tree regeneration may equally well be attributed to the improved rainfall as to the introduction of myxomatosis, or to a combination of both.

Some of the effects of rabbits are more subtle. In a state forest near Goondiwindi, southern Queensland, where there had been no white cypress pine regeneration for 30 years, an area was protected in 1952 from sheep and rabbits and another protected from sheep alone. Sixteen years later there were 27 seedlings per plot on plots protected from both sheep and rabbits; one per plot on the rabbit-grazed plots; and none on the sheep and rabbit-grazed plots. There was no build-up of ground cover on the rabbit-grazed plots. The lack of regeneration was due partly to rabbit grazing but mainly to the increased heating of the ground due to lack of ground cover (Johnston 1969). Changes in the composition and cover of the vegetation are also likely to influence populations of ants, termites and topsoil micro-arthropods. Vegetation changes may have long-term effects in maintaining soil structure as macropores in the soil are a major avenue for deep water penetration (Tongway et al. 1989).

Woody weeds

The suppression of fires, favourable rains and the lack of perennial grasses facilitated the proliferation of woody weeds after the introduction of myxomatosis. In the Broken Hill district the land systems with the highest warren densities also have the highest densities of woody weeds (Tatnell and March 1991). Both woody weeds and rabbits appear to favour light soils so the correlation of rabbits and woody weeds may not be causative. Reduced rabbit numbers may be desirable, however, to allow vigorous grass growth during favourable seasons, thereby providing competition against the spread of woody weeds, and more importantly, allow fuel build-up for prescribed burning of the weeds. Hence, rabbit management may be an essential first step to economic control of woody weeds.

Cassia eremophila, which is regarded as a woody weed in some areas, successfully regenerated in areas with low rabbit densities on Koonamore Vegetation Reserve but not in areas with high rabbit densities (Silander 1983). Although *C. eremophila* is unpalatable to stock, it is locally extinct outside the reserve where there are sheep and rabbits. Sheep and rabbits seem to be a particularly destructive combination.

Other species

Only one seedling of *Alectryon oleifolium* (also known as *Heterodendrum oleifolium*) has ever been seen. This species produces root suckers which are grazed by stock and rabbits. Even in the absence of stock the suckers can disappear 'almost overnight' as the annual herbage dries up in summer (Newsome 1993). Chesterfield and Parsons (1985) comment: 'Thus it joins the long list of palatable perennial plants destined for severe decline or extinction over large areas of the southern arid zone'. In a dry summer in western New South Wales, 25% of rabbit diet was large shrub and tree species, including *Acacia* spp., *A. oleifolium*, *Capparis mitchellii* and *C. cristata* (Dawson and Ellis 1979).

The regeneration of even unpalatable trees such as *Myoporum platycarpum*, which are untouched by stock, can be prevented by moderate to high rabbit numbers (Chesterfield and Parsons 1985). There has been virtually no new seedlings of *M. platycarpum* in the last 100 years (Boreland 1983; Westbrooke et al. 1988).

Less common and rare species are also at risk, but the effect of rabbits on most of the less common species has not been studied. Anecdotal evidence suggests that many of the short-lived or palatable species became locally extinct in the first few decades after rabbits and sheep were introduced (Peacock 1908). Trees such as Kurrajong (*Brachychiton populneum*) face local extinction wherever there are rabbits as they are very palatable at all stages. Rabbits have been known to fell and almost entirely consume, trunk included, kurrajong trees 18 cm in diameter (Peacock 1908). Rabbits burrow along and consume the roots of even larger kurrajongs (D. Wood, CSIRO Division of Wildlife and Ecology, pers. comm. 1989). Rabbit-proof fences had to be erected around groups of bell-fruit trees (*Codonocarpus pyramialis*) to prevent the extinction of the species in the Flinders Ranges National Park (South Australia, Department of the Environment and Planning 1983).

Unstocked areas

On the Nullarbor Plain, where there are rabbits but no domestic stock, large areas of bluebush (*Mariana sedifolia*) have been destroyed and the dominant woody shrubs and trees (*Acacia papylocarpa, Myoporum platycarpum*) are slowly dying without regenerating (Johnson and Baird 1970; Beard 1975). A survey of 47 000 km^2 of the Nullarbor Plain found no accelerated erosion (Mitchell et al. 1979). However, 40% of the area was in poor condition with the pastures degraded to annual species, due to the combined effects of rabbits, fire and drought.

Rabbits may strip bark from woody vegetation. The plant will die where such ringbarking is complete. *Source: CCNT*

Ratcliffe (1938) observed that rabbits burrowed under most of the sandhill canegrass (*Zygochloa paradoxa*) clumps on the crests of dunes and reduced their viability in droughts. *Z. paradoxa* is important in maintaining the stability of dune crests. Pech and Graetz (1982, page 7) are optimistic this will not destabilise dunes: '… rabbits pose the most significant present-day threat to the integrity of the Simpson Desert … it appears that overgrazing by rabbits to the extent of precipitating remobilisation of the dune crests is unlikely to occur due to the lack of permanent water supplies'.

A dietary study of wild rabbits in a 30 km^2 paddock in north-eastern South Australia that has had no stock since 1912 identified rabbit consumption of bark high up in shrubs and trees during dry times (Catling and Newsome 1992). This paddock has only isolated pockets of regeneration of mulga and white cypress pine (P. Catling, CSIRO Division of Wildlife and Ecology, pers. comm. 1994). Unmanaged rabbit and kangaroo populations in rangeland national parks have resulted in native flora and fauna being in little better condition with no more regeneration than surrounding properties (Greenwood et al. 1989; Bridgewater and Potter 1993).

The only large vegetation zone in the rangelands that has not suffered significant degradation is the Mitchell grass (*Astrebla* spp.) grasslands which is also the only zone that does not support rabbits.

The rangelands, although far from being undisturbed, constitute the largest remaining area of trees and shrubs in Australia. Extensive tracts of woodland and shrubland are under threat from high total grazing pressure, including that due to rabbits. Effective rabbit management is essential, but improved grazing systems with conservative stocking levels that not only increase financial returns, but also prevent further degradation and possibly encourage rehabilitation of the rangelands, are needed when this is achievable (Purvis 1986; Morrissey and O'Connor 1988; Friedel et al. 1990). Cheal (1993) noted the almost total lack of regeneration of trees and shrubs in grazed areas in semi-arid Victorian woodlands. Whilst rabbits are a major problem in the rangelands, attention must also be given to damage due to grazing by other species, namely livestock and other wild herbivores, the impact of which can often be more easily managed (Reid 1992; Tiver 1992).

4.3.3 Higher rainfall areas

Rabbits, at three per hectare in the Coorong National Park on the coast of South Australia, prevent regeneration of *Acacia longifolia* and the sheoak, *Allocasuarina verticilliata* (Cooke 1987; Cooke 1993). Only a brief period of regeneration following the introduction of myxomatosis has prevented the sheoak population from consisting of 'scattered, senescent trees' (Cooke 1987). Rabbits are present in and behind most coastal dunes in southern Australia. Their effect in this situation has not been measured, although Douglas (1981, page 827) commented: 'Many of the Victorian coastline dune floras have been reduced to dangerous levels, sometimes solely by rabbits'. Rabbits have threatened the success of some marram grass (*Ammophila arenaria*) plantings used to control erosion on coastal dunes.

After a fire, rabbits can suppress regeneration of snowgum (*Eucalyptus spp.*) from lignotubers and seedlings (Wimbush and Forrester 1988). In a subalpine site in Kosciusko National Park the presence of rabbits resulted in the loss of nine palatable forbs in seven years. Where rabbits were excluded there was a net gain of two species. The presence of rabbits increased the risk of soil erosion due to reduced ground cover and there was reduced seed set because of the rabbit's propensity for eating seed heads (Leigh et al. 1987). Even low density rabbit populations can be damaging in these predominantly tussock (*Poa spp.*) grasslands as it is only the forbs and minor grasses, 2% of the biomass, that are nutritionally adequate for rabbits (Leigh et al. 1991). This is significant, as it is not the absolute density of rabbits that is important, but their density relative to the palatable and nutritious components of the ground layer.

'Rabbits can suppress regeneration of snowgums after a fire.'

In a Victorian forest, neither rabbits nor sheep grazed eucalypt seedlings. Rabbits, at a density of about four per hectare, selected plants that were low in fibre and high in protein and within three months had eaten out the favoured grasses and herbs, and had stripped the palatable shrubs of their foliage and ringbarked them (Farrington and Mitchell 1966). In many remnant woodland reserves and in forests, the proportion of the ground layer vegetation that is palatable and nutritious to rabbits is very low. Even apparently insignificant rabbit densities could be having major effects on the minor palatable components and tree regeneration. This has not been investigated. After the introduction of myxomatosis, the survival of the exotic *Pinus radiata* improved and it began invading native forests near Canberra (Dawson et al. 1979).

On pastoral lands, domestic stock appear to be preventing the regeneration of trees in many areas. How much rabbits are contributing to this is unknown. Rabbits are probably preventing regeneration on many roadsides, which are important vegetation reserves as well as corridors for wildlife (Breckwoldt 1990).

4.3.4 Islands

The ecological effects of rabbits on islands can be immense, but have rarely been fully documented. Rabbits introduced onto Laysan Island in 1903 had by 1936 eliminated three endemic bird species and 22 of the 26 plant species (Watson 1961). In 1923 the island was a barren waste of sand with a few stunted trees. Philip Island, off Norfolk Island, was reduced almost to bedrock by firstly goats and rabbits and then rabbits alone. Prior to the eradication of rabbits in 1986 it was almost devoid of vegetation. The endemic parrot (*Nestor productus*) became extinct, even in the absence of introduced predators. Two endemic plant species had become extinct and one, the Philip Island hibiscus (*Hibiscus insularis*), was on the brink of extinction (Coyne 1982). Since 1986, the island has become extensively revegetated. The Norfolk Island abutilon (*Abutilon julianae*), last seen in 1912, has recolonised patches on the island (Bridgewater and Potter 1993).

'Rabbits introduced onto Laysan Island in 1903 eliminated three endemic bird species and 22 of the 26 plant species.'

Fullagar (1978) lists 48 Australian islands with rabbits. Many of these islands are important for seabirds, the nesting sites of which are affected by rabbits (Gillham 1963; Coyne 1981; Martin and Sobey 1983). The Gould's petrel (*Pterodroma leucoptera*) nests on only one island, and its long-term future is in doubt because of vegetation changes due to rabbits (Clough and Werren 1980; Davey 1990; Werren and Clough 1991). On Manana Island rabbits have been observed displacing sitting brown noddy terns (*Anous stolidus*) and then rolling their eggs until they break on stones (Brown 1974). On some islands where they prey on rabbits, populations of cats and skuas are maintained at high levels, thus increasing predation on native fauna. Winter nesting seabirds no longer nest on Macquarie Island because of this predation pressure (Brothers 1984). Here the shooting of cats was found to be ineffective and now rabbit control is the major form of cat control (Brothers et al. 1985). It is doubtful that foxes and cats could persist on some islands during the six-month absence of nesting seabirds if rabbits were not present (Norman 1971).

'It is doubtful if foxes and cats could persist on some islands during the six-month absence of nesting seabirds if rabbits were not present.'

Rabbits were eliminated from Rabbit Island off Wilsons Promontory in 1966. Between two botanical surveys in 1959 and 1978, 39 plant species were gained but ten were lost (Norman 1988). The shrub, *Rhagodia baccata*, first recorded in 1968 has now developed to the extent that shearwater (*Puffinus tenuirostris*) colonies are being restricted. On Citadel Island, west of Wilsons Promontory, the extensive plant cover that supported grazing by Cape Barren Geese (*Ceropsis novae-hollandiae*) was almost destroyed by rabbits and so much soil lost that Gillham (1961) could find only eight species of flowering plants. When rabbits were exterminated, the number of plant species increased from eight in 1959 to 25 in 1978 (Norman 1988). After rabbits were eliminated from Carnac Island off Western Australia in 1969, the marked recovery in the island's vegetation was evident from comparisons of aerial photographs taken in 1969 and 1972 (Abbott 1980). Cabbage Tree Island (30 hectares), the only island off southern Australia with rainforest, will eventually lose both the rainforest and the cabbage tree palm (*Livistona australis*) from which the island derives its name (Clough and Werren 1980; Davey 1990). Even though there are only 30–40 rabbits on the island the density is high relative to available food.

Rabbit eradication on some islands has resulted in the proliferation of some exotic plant species, boxthorn (*Lycium ferocissimum*) on Monunau Island (Taylor 1968) and 'kikuyu' (*Pennisetum

The impact of rabbits can be dramatic. Rabbits stripped vegetation from large areas of Philip Island near Norfolk Island.

Source: M. Hallam, ANCA

clandestinum) on Bowen Island (M. Braysher, Bureau of Resource Sciences, pers. comm. 1994), and this has made parts of the islands less suitable for nesting penguins and sea birds. Habitat modification by rabbits at Macquarie Island appears to have benefited Antarctic prions (*Pachyptila desolata*) but disadvantaged white-headed petrels (*Pterodroma lessoni*) and sooty shearwaters (*Puffinus griseus*) (Brothers 1984).

4.3.5 Impact on native animals

Observations obtained incidentally at the CSIRO Division of Wildlife and Ecology suggest that the effects of rabbit aggression on native mammals could be significant. Despite the size difference, rabbits (1.5–2.0 kg) in enclosures will attack yellow-footed rock wallabies (*Petrogale xanthopus*, 8–10 kg) (Poole et al. (1985). When rabbits and burrowing bettongs (*Bettongia lesueur*) were kept in adjacent enclosures, a female rabbit climbed the rabbit-proof fence and had a litter in the bettongs' warren. Although a bettong is about the same size as a rabbit and bettongs are reported as being 'exceedingly pugnacious' (Jones 1924), the female rabbit evicted the bettongs and one died with deep scratches to the lumbar and posterior region (Myers and Libke, CSIRO Division of Wildlife and Ecology, unpublished observations, 1980).

In communal feeding areas rabbits (1.5 kg) were dominant to hares (4 kg) in 45 out of 55 encounters (Flux 1981). Rabbits could have evicted burrowing native mammals from their burrows and excluded other mammals from the best feeding areas (Calaby 1969). The decline of burrowing rufous hare-wallaby (*Lagorchestes hirsutus*) in the western deserts in the 1930s (Short and Turner 1992) coincided with the first major eruption of rabbits in those areas (Kerle et al. 1992). Rufous hare-wallabies are now found in only two colonies in the Tanami desert and a section of one of these colonies was being colonised by rabbits in 1977 (Bolton and Latz 1978). The burrowing bettong is now extinct on the Australian mainland and the bilby (*Macrotis lagotis*), a burrowing animal, is now found only north of the rabbits' distribution or where rabbits and foxes are rare (Watts 1969; Southgate 1990).

'Rabbits have been seen five metres up trees.'

Jones (1924, page 211) predicted the extinction of the tungoo, the burrowing bettong:

'In good seasons there is enough juicy herbage for cattle and rabbits as well as Rat Kangaroos but in bad seasons the rabbits and the marsupials perish in large numbers. Such losses among the rabbits are soon made good, but with the marsupials this is not the case, and probably the end of the Tungoo is not far off … In the more cultivated districts of the South, where food is plenty, the wholesale scattering of poisoned pollard has led to their complete extinction'.

'Even animals as large as the red kangaroo may be vulnerable to competition from rabbits as they rely on refuge areas in droughts where there is some green pasture.'

Most of the mammals that have become extinct or had their ranges contract to small areas have been the small to medium-sized herbivores in the arid zone, where rabbits compete for the last remaining high-quality food in drought. Extinctions and contractions of range have occurred in both pastoral and unoccupied country (Burbidge and McKenzie 1989; Morton 1990; Stafford-Smith and Morton 1990). The soils in arid Australia are highly leached and infertile; plants growing on these soils tend to be poorly digestible because they have developed chemical and structural defences. The fertile and productive areas tend to be run-on areas where both water and nutrients channelled (Morton 1990).

The response of rabbits at moderate to high densities to drought is to eat virtually everything accessible and edible. Populations then crash to low levels. The few survivors live on fallen leaves and seed pods, the roots of herbs, the slightest sprouting from perennial grasses and shrubs, and even termites. They have even been seen five metres up trees. Immediately prior to and during the crash there is a major dispersal of juveniles and subadults (Parer 1982b). These rabbits stop their dispersal in any slightly favourable area, such as water run-on areas. Any native mammals using these favourable habitats as drought refuges have to compete with both resident and immigrant rabbits. Local extinctions of rabbits and native mammals may result. With the breaking of drought rabbits have the potential to increase at a faster rate than the

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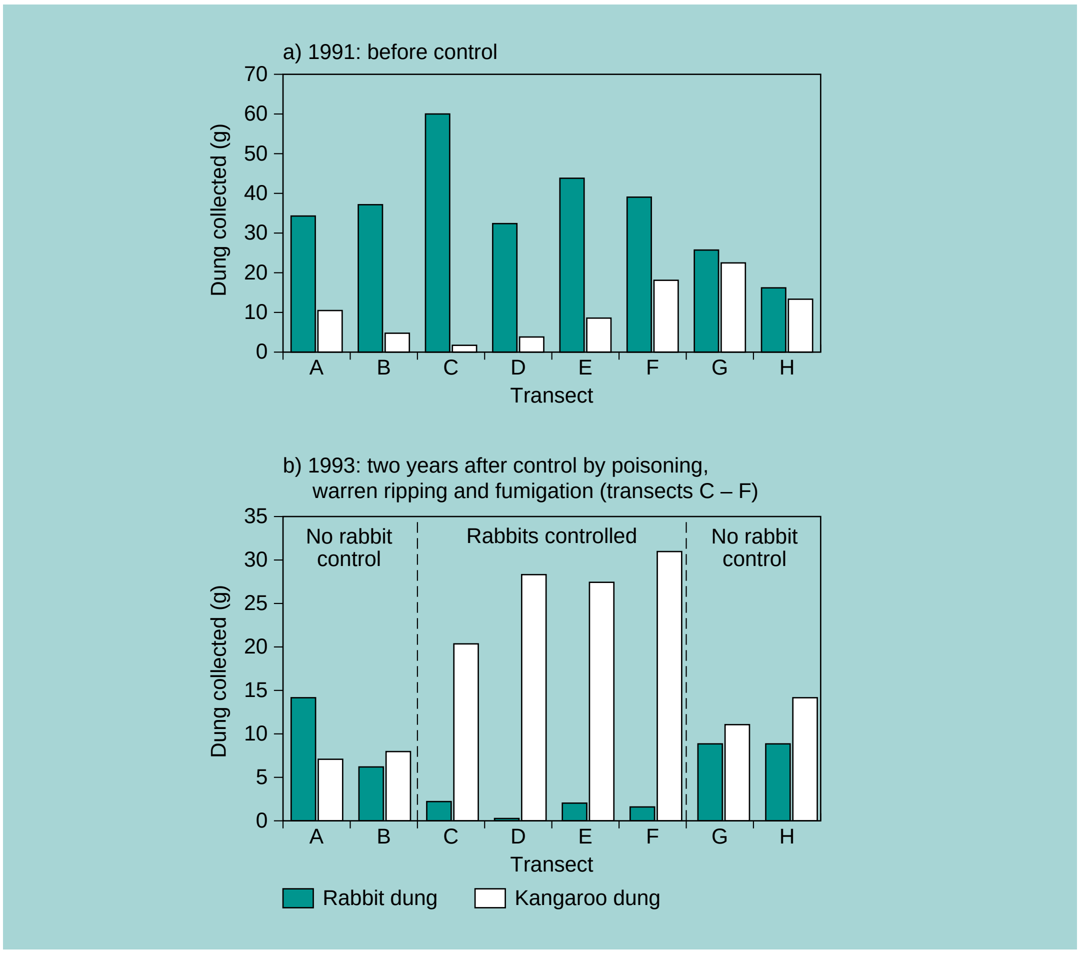

Figure 22: Dung collected from points on eight transects in Coorong National Park in South Australia, a) 1991 — before control; and b) 1993 — two years after control by poisoning, warren ripping and fumigation (Cooke 1993).

Table 10 Approximate mean LD_{50}* of 1080 poison (sodium monofluoroacetate) for different groups of native animals with known past and continuing exposure to naturally occurring fluoroacetates, and for introduced animals and those native animals with no known past exposure to this toxin (after McIlroy 1992)

Groups of animals	Known exposure		No exposure	
	Number of species	Mean LD50 (mg/kg)	Number of species	Mean LD50 (mg/kg)
Introduced placental carnivores	–	–	3	0.2
Marsupial herbivores	10	42.0	10	0.3
Introducted placental herbivores (includes rabbits)	–	–	5	0.4
Marsupial carnivores	12	8.3	9	2.7
Rodents	10	21.6	10	3.1
Pigs	–	–	1	4.1
Bandicoots	4	13.2	4	5.9
Birds	14	28.4	45	7.8
Reptiles	2	525	5	163.0

* LD_{50} represents the number of milligrams of 1080, per kilogram of body weight, which will kill 50% of the test animals.

native mammals. The rabbits then spread out from their survival areas and soon recolonise vacated areas. Medium-sized native mammals do not have such high dispersal rates (Morton 1990). Long dispersal distances have been recorded for large but not for medium-sized marsupials (Friend 1987; Johnson 1989). With successive droughts and local extinctions the probability of recolonisation by native mammals becomes less until regional extinctions result.

The diets of rabbits and yellow-footed rock-wallabies (*Petrogale xanthopus*) become similar in droughts (Dawson and Ellis 1979). Sticknest rats (*Leporillus* spp.), which are extinct on the mainland require succulent vegetation (Robinson 1975; Watts and Eves 1976). They almost certainly lost the competition with rabbits for this scarce resource in droughts. The nutritional requirements of the spectacled hare-wallaby for the seasonally scarce green grass and herbs put it in direct competition with the rabbit (Ingleby and Westoby 1992). Although the species is still relatively common, it has disappeared from those parts of central Australia where there are rabbits (Ingleby 1991). Even during spring in an excellent season, Foulkes and Kerle (1989) found considerable dietary overlap, particularly for the more nutritious species, between brushtail possums (*Trichosurus vulpecula*) and rabbits in central Australia. Competition is more intense in dry periods and it would be necessary to implement and maintain a rabbit management program in areas where possums are reintroduced.

Even animals as large as the red kangaroo may be vulnerable to competition from rabbits as they rely in droughts on refuge areas where there is some green pasture (Newsome 1975, 1977). For example, there were significant increases in kangaroo numbers after rabbit control in Hattah-Kulkyne National Park, Victoria and in the Coorong National Park, South Australia (Figure 22) (Bridgewater and Potter 1993; Cooke 1993). The rabbit has probably been responsible for the range contraction of the common wombat (*Vombatus ursinus*) in South Australia (Mallet and Cooke 1986).

Table 11: Comparative toxicity of 1080 to various animals (after O'Brien and Korn 1991).

Species	LD50* (mg/kg)	Relative tolerance compared to a dingo
Dingo	0.11	1
Fox	0.13	1
Common wombat	0.19	2
Red-necked wallaby	0.21	2
Eastern grey kangaroo	0.23	2
Rabbit	0.37	3
Cattle	0.39	4
Horse	0.41	4
Goat	0.50	5
Sheep	0.50	5
Brushtail possum	0.67	6
Crimson rosella	0.88	8
Southern bush rat	0.13	1
Tiger cat	1.85	17
Human (estimate)	2.0–5.0	17–45
Red kangaroo	3.20	29
Eastern rosella	3.45	31
Feral pig	4.11	37
Australian raven	5.10	46
Galah	5.53	50
Kookaburra	6.00	55
Domestic fowl	7.95	72
Wedge-tailed eagle	9.49	86
Australian magpie	9.93	90

* LD_{50} represents the number of milligrams of 1080, per kilogram of body weight, which will kill 50% of the test animals.

On a large island off Washington State, the density of deer in areas with European rabbits was only 10% of that in areas without rabbits (Stevens and Weisbrod 1981) and rodents were rare in areas with rabbits. However, 20 raptor species were observed in rabbit areas, an unusually high number for an island.

Birds can be affected indirectly by rabbits. The destruction of sandhill canegrass by rabbits will reduce populations of birds such as the Eyrean grasswren (*Amytornis goyderi*), which are dependent on canegrass (Parker 1980). Frith (1962) considered that sheep and rabbit grazing and not fox predation was the principal cause for the decline of mallee-fowl (*Leipoa ocellata*) populations. Overgrazing by rabbits modifies habitats making them unsuitable for the endangered plains-wanderer (*Pedionomus torquatus*) (Baker-Gabb 1990).

Risk of non-target poisoning

The risk of non-target poisoning can be reduced by (1) using a bait which is not attractive to the animals at risk; (2) using the recommended minimum concentration of 1080 in the bait; (3) using the minimum effective number of free-feeds; and (4) removing as many dead rabbits as possible (McIlroy and Gifford 1992). Nevertheless, to reduce the potential risk to non-target animals, it is suggested that poisoning in areas where there may be native animals which are sensitive to 1080 should be a one-off operation to reduce dense rabbit populations prior to maintenance control, principally by warren ripping.

The distribution and abundance of many species of birds and other animals will be seriously affected by the long-term decline in the tree and shrub populations in the rangelands. Reid and Fleming (1992) describe this as a 'biological time-bomb quietly ticking away' and suggest that it will result in unprecedented changes in bird community composition.

Past rabbit management has also had a major impact on native fauna. On many properties there was, prior to myxomatosis, intensive poisoning and trapping of rabbits. Medium-sized mammals would have been vulnerable to traps and all grain and flesh-eating mammals vulnerable to poisoning. Small rodent-size mammals would also have been affected. Even birds were not immune. Sir Frederick McMaster of Cassilis, who eventually exterminated rabbits on his

16 000 hectare property, once had eight poison carts laying bait on a netted paddock of 500 hectares.

'For months we persisted and certainly killed many thousands but we could never get them all. Nature saved sufficient virile stock to re-infest the whole area in a single season. The slaughter of bird life was so tragic that I hate to contemplate it now. Poisoning is the worst of all methods' (McMaster 1935, page 158).

When phosphorised oats were laid on the Riverina Plain, plains turkeys (*Ardeotis australis*) died in their hundreds. Rolls (1969) recalls when he laid his first 500 metres trail of oats and strychnine in 1948 he was shocked to count 32 dead peewits and 17 spur-winged plovers. It was not unusual for rabbit trappers to catch more bilbies (*Macrotis lagotis*) than rabbits (Jones 1924). The laying of 1080 in a Tasmanian forest resulted in a 50% decline in two populations of *Bettongia gaimardi* (Statham 1983).

There has been public concern about the risk that 1080 poisoning may pose to native fauna. The sensitivity of animals to 1080 varies considerably depending on the class of animal and whether it is naturally adapted to the toxin (McIlroy 1992). 1080 is the sodium salt of a naturally occurring form of this toxin, fluoroacetate. This natural form occurs in some native plants in parts of Australia, notably *Gastrolobium* spp. and *Oxylobium* spp. in south-western Australia (King et al. 1981; Twigg and King 1991). Native fauna in these areas are relatively tolerant to it (Table 10). Placental herbivores and carnivores, which include rabbits and foxes, are highly sensitive to 1080; most marsupials and birds are less sensitive and reptiles highly resistant to it.

Details of the lethal dose (milligrams per kilogram) of 1080 and the tolerance of species relative to the dingo are presented in Table 11. The amount of poison necessary to kill an animal increases with body weight so juveniles are more likely to be killed than adults of the same species. Even though eastern grey kangaroos are more susceptible to 1080 than rabbits, it would require about 15 times more 1080 to kill the larger kangaroo.

Even if precautions are taken, poisoning can still kill significant proportions of some native mammals. The burrowing bettong or boodie (*Bettongia leseur*) was eliminated from Boodie Island off Western Australia by a rat poisoning campaign in 1985 (Short and Turner 1992). Oats impregnated with pindone were placed in containers accessible to rats but not to bettongs. It is thought that the bettongs were poisoned by eating grain scratched out of the containers by the rats.

Poison is often used on 'islands' of habitat, such as rocky, timbered knolls, where other forms of rabbit control are difficult to implement. These habitat islands are precisely the type of refuge habitat which might contain small populations of endangered native mammals which could be at risk in a poisoning campaign.

Of the 171 native species for which toxicity data are available, individuals of 50–60 species are potentially at risk from 1080 rabbit poisoning campaigns (McIlroy 1986). However, the actual losses of native fauna due to poisoning campaigns are probably small (McIlroy 1986, 1992). There are usually very few native mammals on farmland where most 1080 rabbit poisoning is done. Although a few individuals of non-target species may have been killed in an experimental poisoning, the populations were not affected (McIlroy and Gifford 1991). McIlroy (1992) concludes that most native animals are not at risk from 1080 rabbit poisoning programs, with the possible exception of some small and medium-sized mammals such as potoroos and some native rodents, especially if a highly palatable bait such as oats is used.

4.3.6 Predator impact on native animals

With high rabbit numbers, the populations of birds of prey, goannas, cats, foxes and dingoes build up. The high numbers of predators impose high predation pressure on the relatively scarce native mammals.

The worst effects happen when rabbit numbers crash during drought. The number of cats, foxes and dingoes decline six months to two years later (Figures 12 and 13) with the cat numbers declining first and dingoes last. During this period the predation pressure on almost all small to medium-sized native mammals is intense. After rabbit populations crash the number of predators may exceed the number of rabbits (Figure 12) and the predators concentrate on the rabbit survival areas (Myers and Parker 1975a, b) which are also the survival areas of native species.

'With high rabbit numbers, the populations of birds of prey, goannas, cats, foxes and dingoes build up.'

Community, governments and conservationists are concerned that effective management of rabbits will severely increase the predation pressure on native fauna. This may happen in the short term, but the increased pressure on native species would be similar to what happens now during drought or after a widespread myxomatosis outbreak. With effective rabbit management the increased predation pressure occurs only once. With repeated ineffective control the increased pressure occurs repeatedly.

'Unfortunately it is probable that reducing rabbit populations will reduce numbers of native birds of prey.'

Ideally, reduction in exotic predator numbers, particularly of the fox, should occur in conjunction with initial rabbit control. Unfortunately, broad-scale practical techniques for fox and cat control are not available. The impact on native fauna by exotic predators following rabbit control needs to be investigated (Chapter 12). Until the studies are completed, available resources for predator control should be concentrated on areas that contain threatened, rare or endangered native fauna susceptible to fox predation.

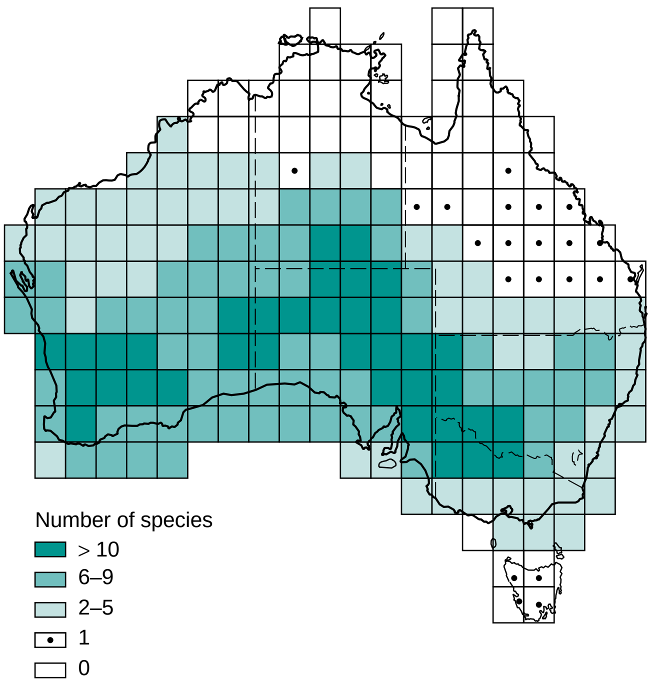

Figure 23: Number of small mammal species extinct or locally extinct since European colonisation (after Woinarski and Braithwaite 1990).

Sustained effective rabbit management is the most potent method available for reducing the impact of introduced predators on native species (Section 3.7.3). Unfortunately it is probable that reducing rabbit populations will reduce numbers of native birds of prey, as rabbits are the main food of many raptors during their breeding seasons (Figure 16) (Baker-Gabb 1984).

4.3.7 Cause of extinctions

No known native mammal has become extinct north of the range of the rabbit since European settlement (Figure 23). In the central deserts of Western Australia extinctions occurred after the rabbit arrived but before the fox became established there (Burbidge et al. 1988). Of the 30 terrestrial mammals that became extinct in the Flinders Ranges, all but three became extinct before the fox arrived in the area. Most of the extinctions occurred in the period from 1880 when the rabbit arrived and 1910 when the fox arrived (Tunbridge 1991). Drought and overstocking at the turn of the century undoubtedly contributed to these extinctions. Many mammals became extinct in areas where there were foxes and rabbits but no domestic stock (Brooker 1977). The common thread is the rabbit. The rabbit may not have caused the extinctions by itself but it appears to be closely implicated. The elimination of rabbits is believed to be 'a prerequisite for the re-establishment of native mammals in the southern parts of central Australia' (Low 1986). Algar (1986) attributed the failure of a program for the reintroduction of quokkas (*Setonix brachyurus*) to overgrazing by rabbits and macropods.

Recovery plans for many threatened species recommend either rabbit-proof fencing or rabbit control (Bridgewater and Potter 1993, page 30). However, as Bridgewater and Potter comment *'We cannot fence every threatened species. We cannot bait and fumigate every habitat of every threatened native animal. We need to find more holistic, integrated approaches in rabbit control and wildlife conservation'.*

4.3.8 Local extinction in progress — a case study

Foulkes and Kerle (1988) studied brushtail possums (*Trichosurus vulpecula*) and rare native plants at Irving Creek in the Petermann Ranges in the Northern Territory. From their study it seems that the path of possums to extinction in central Australia is likely to be hastened by competition from rabbits for rare and declining preferred plant species, and predation by carnivores which are maintained by high rabbit densities.

Brushtail possums are now rare in central Australia, where they were once widespread and common, and the decline continues. They disappeared from Uluru some time after 1962 and from Anamarra, Gillen and Charley Creeks sometime after 1984. They are now known to exist in only three localities — Giles Yard Spring, Atnarpa Range and along the Irving and Armstrong creeks in the Petermann Ranges. All three locations are refuge sites with higher water and soil nutrient status than surrounding areas. The Armstrong Creek population is in decline as tracks were found of only one or two males which appeared to be searching for mates. Along Irving Creek, rabbits were at a density of nine per hectare with warren capacity for peak populations of 19 per hectare. Possum density was about 0.1–0.2 per hectare.

Table 12: Percentage frequency of occurrence of vertebrates and invertebrates in dingo and fox scats collected at Irving Creek in 1989 (Foulkes and Kerle 1989) and the percentage frequency of occurrence in dingo stomachs collected in 1969 in the Petermann Ranges (L. Corbett, unpublished, quoted in Foulkes and Kerle 1989).

Item	Dingo scats	Dingo stomachs	Fox scats
Rabbit	96	97	86
Mus musculus	4	1	–
Pseudomys / Notomys	4	1	–
Birds	15	3	–
Insects	14	–	14

Environmental impact

There is no doubt that rabbits are a very significant threat to the integrity of arid zone ecosystems. The threshold density below which rabbits need to be maintained to conserve native biota for an area needs to be determined. But there is evidence that rabbits can severely damage some native vegetation even at densities as low as one per hectare. In areas where vegetation is vulnerable to rabbits, management should aim to reduce rabbits to very low densities and maintain them at that level and monitor impact to make sure resource damage is being controlled. This type of management is also thought to be the most cost-effective form of rabbit management.

The Commonwealth Government has recently embarked on a number of national programs aimed at conserving Australia's natural resources. They include Ecologically Sustainable Development, the Endangered Species Program and the Decade of Landcare which incorporates the National Resource Management Strategy, National Landcare Program, One Billion Trees and Save the Bush Programs. Effective rabbit management, particularly in the rangelands, is central to the success of these programs. It should be given high priority.

Possums had dens in the fringing red river gums (*Eucalyptus camaldulensis*) along the creek line. Foulkes and Kerle (1989) found that even in spring of 1989, an excellent season, there was a high proportion of browse in the rabbits' diet and the diet of rabbits and possums overlapped considerably (24%). Competition would be more severe during droughts. To obtain high-quality food, possums have to spend time in low shrubs and on the ground travelling between the den trees and the widely spaced preferred feeding trees. One possum was tracked 500 metres from a den tree to a mulga grove.

Analyses of the diets of foxes and dingoes at Irving Creek showed that they depended almost completely on rabbits (Table 12). The diet of the feral cat was not examined but would most likely be almost entirely rabbit.

During dry times, rabbit numbers collapse and possums need to spend more time on the ground travelling between feed trees. At these times, the predator pressure on possums would be very high.

In addition to the increased predation pressure on possums due to rabbits, the possums also face direct competition from rabbits for the most preferred food plants. Even though only three specimens of plumbush (*Santalum lanceolatum*) were found on a 25 hectare site on Irving Creek, it was 11% of the rabbits' diet in the spring of a high rainfall year. Plumbush is also a preferred species for possums as it has high digestibility (67%), moisture (67%), available nitrogen (1.2%) and phosphorus (0.18%). The extinction of plumbush on that site during a dry period seems inevitable. It is perhaps surprising that it has survived so long.

4.3.9 Soil erosion

The effect of rabbits on soil erosion has not been quantified. The Soil Conservation Service of New South Wales (SCS) considered that the elimination of the rabbit was necessary to establish a protected area on the foreshores of Burrendong Dam (Colclough 1960; Graham 1965). The sedimentation rate of reservoirs was greatly reduced after the advent of myxomatosis in 1951 (Figure 21) (Clark 1990). The soils that are most susceptible to wind erosion (desert and mallee sands, podsols, desert loams) have a sand content of greater than 80% and are the soils most favoured by rabbits (Lorimer 1985). In Kosciusko National Park, fire followed by rabbit grazing and scratching for seeds increased the proportion of bare ground to levels greater than those found to result in erosion (Leigh et al. 1991; Costin et al. 1960).

Friedel (1985) found no significant correlation between soil erosion and density of warren entrances. In the Flinders Ranges of South Australia, however, there is a close correlation between dense rabbit populations and soil erosion (Greenwood et al. 1989). Soil erosion, with rabbits as the major cause, continues even in national parks in the Flinders Ranges where there is no compounding influence from domestic stock (Greenwood et al. 1989).

The gradual elimination of perennial grasses, shrubs and trees from parts of the rangelands will cause accelerated erosion during drought, with the eroded areas being less suitable for germination and growing sites. In the mallee in Victoria, where stock were excluded, the percentage of bare ground was 14.4% inside an exclosure open to kangaroos and 62.4% in the area grazed by rabbits and kangaroos outside the exclosure (Cochrane and McDonald 1966). Twelve years after the exclusion of livestock, in another area of the Victorian mallee, the amount of bare ground had not decreased where rabbits were present (Table 9) (Zaller 1986).

'Even at densities as low as one per hectare, rabbits can severely damage some native vegetation.'

On Philip Island off Norfolk Island the effects of rabbits were spectacular, with the sea around the island sometimes turning red with suspended soil particles (Fullagar 1978; Coyne 1982). Before the eradication of rabbits in 1986 the island looked like a moonscape. Since 1986 there has been extensive revegetation. After the eradication of rabbits from Rabbit Island off Wilsons Promontory in 1966, a sand blown eroded area covering 20% of the island had been revegetated by 1979 (Norman 1988). Rabbits were introduced onto St. Helens Island (51 hectares) off Tasmania in 1975 and within two years had extensively damaged the vegetation, and wind erosion was apparent (McManus 1979). Rabbit burrowing and the reduction in the density of the dominant perennials caused landslip on Macquarie Island (Costin and Moore 1960).

Unwise rabbit control techniques, poison trails and warren ripping going up and down slopes, have frequently initiated gully erosion.

4.4 Resource value and use

Prior to the successful introduction of myxomatosis in the 1950s, rabbit harvesting was a significant industry. With the introduction of myxomatosis, the supply of rabbits to the commercial market fell and at about the same time, increased supplies of farmed domestic rabbits in Europe and China provided strong competition for the wild rabbit product from Australia (Ramsay 1991). These two factors led to a steady decline in the scale and value of the commercial harvest of wild rabbits in Australia. By 1991 most processors were selling most of their products to low income consumers, at low margins, with increasing competition in static or declining markets.

Two–three million wild rabbits are harvested in Australia each year, with most coming from the more arid interior (Ramsay 1991). The annual consumption of wild rabbit meat within Australia is about 1800–2000 tonnes, with a wholesale value of about $5.2–5.8 million. There are ten rabbit meat processing establishments, two of which have licences for overseas export. Exports of rabbit meat from Australia have expanded since 1988, when rabbit calicivirus disease (RCD) appeared in Europe, with most going to Western Europe and the USA. Exported rabbit products from Australia in 1990–91 were worth more than $2.5 million. This needs to be put into perspective with other industries. For example, most harvested rabbits came from the Lake Eyre Basin. Cattle production from this area is estimated at $290 million annually (Ramsay 1991).

The commercial rabbit industry in Australia produces about 200 tonnes of dried rabbit skins a year with a wholesale value of about $1 million. Most skins are used to make felt hats while some are used in garment manufacture. White rabbit fur is imported for coloured hats, but recently an Australian felt hat manufacturer had to import coloured rabbit skins in order to maintain production. The annual wholesale value of Australian wild rabbit products, including exports, is about $9 million. In addition, about $2.5 million is invested in capital equipment, and over 300 processing staff and shooters are employed (Ramsay 1991).

The long-term viability of the rabbit market is difficult to gauge. Historically, the rabbit harvesting industry in Australia has been subject to wide variations both in supply and demand. Although the volume of international trade is reasonably stable, a number of factors influence the demand for the Australian product. These include the quantity and price of exports from China (and to a lesser extent Hungary), the veterinary inspection requirements of some countries, and duties and tariffs on imports (Ramsay 1991).

'The annual wholesale value of Australian wild rabbit products, including exports, is about $9 million.'

The Australian industry is flexible and mainly opportunist, being able to shift its operation rapidly to exploit temporarily high rabbit populations. The industry employs relatively few full-time staff but offers an additional source of income for shooters operating mainly in the arid interior.

There are no Australian data on the impact of commercial rabbit harvesting on rabbit populations, but evidence suggests that the reductions achieved are too small and too localised to aid management. Data from New Zealand (Williams and Robson 1985) indicate that short-term reductions in populations averaged 40% after very intensive rabbit shooting campaigns aimed at high-level control. The cost was about $11–39 per rabbit and did not achieve noticeable reduction in rabbit damage or long-term reduction in rabbit numbers even though the high intensity shooting was done each year (Gibb et al. 1969a; Williams and Robson 1985).

In England, commercial rabbit trapping in autumn and winter removed about 35% of the rabbit population and observations of three years of such trapping indicated that there was no decline in the population from year to year (Phillips 1955). During the three years no cats, foxes or stoats were seen or trapped in the area. It appeared that many years of commercial rabbit trapping had eliminated the mammalian predators of the rabbit.

Generally, commercial operators will leave an area once the nightly tally per person falls below 50–150 pairs, depending on the market price of rabbits and alternative shooting areas. Shooters receive $1.60–$2.20 per pair and, with costs taken out, it is clear that a nightly tally of less than 100 pairs will not be commercially viable. Although no data exist to compare nightly tallies with rabbit densities, an area yielding 50–150 pairs/night/operator must have a rabbit density far above the minimum needed to achieve effective management of rabbit damage.

Many of the areas now subject to commercial harvesting, mainly in the rangelands, are those where wide-scale effective management with conventional control techniques such as poisoning, fumigation and ripping are difficult to achieve in the short term, either economically or logistically.

Rabbits are also a significant subsistence food source for some Aboriginal groups providing high-quality fresh food and economic saving to the communities (Wilson et al. 1992a).

PART THREE

COMMUNITY ATTITUDES

5. Attitudes to Rabbit Use, Animal Welfare and New Technology

Summary

Community attitudes will influence the extent to which a national, coordinated approach to managing rabbit damage is successful. Images of 'likeable' rabbits from children's literature, animal welfare issues, the use of rabbits as an economic resource, and ignorance of the damage caused by rabbits in Australia, all determine community attitudes. Those involved in the administration of rabbit management must inform legislators, land managers and the public about the true nature of rabbit damage and ensure these people have sufficient information to make appropriate decisions on rabbit management.

Promoting wild harvesting and other forms of commercial rabbit use may complicate effective rabbit management through, for example, providing a case against the introduction of new biological control agents.

Rabbits are a major part of the diet of some Aboriginal groups and are perceived by them as an integral part of the land. It is important that Aboriginal communities have access to information on the long-term consequences of high rabbit numbers, which may include loss of traditional values as well as ecological impacts. State and territory land management authorities need to work closely with Aboriginal people to assist them to make land-use decisions which meet their needs, and meet the goals of ecologically sustainable land use.

Some rabbit control practices are inhumane. The steel-jawed trap should be banned. The fumigant chloropicrin should be phased out once a more humane alternative is found. While some suffering must be expected with the use of techniques recommended in this report, their intelligent application would minimise suffering by maintaining reduced rabbit populations, thereby minimising the need for repeated treatments.

As a result of the success of myxomatosis in the 1950s, the promise of research on new biological control agents, such as myxomatosis transmission via the arid-adapted Spanish flea, rabbit calicivirus disease (RCD) and virally-borne immunocontraception, could encourage many land managers to become complacent about the need for continuing conventional rabbit management. Even if these research projects are successful, however, the release of such new agents will be several years away. Virally vectored immunocontraception in particular, is very long-term and high risk research, and it is too early to predict whether it will be successful. These new techniques will complement, not replace, conventional control, and the challenge will be to use conventional control techniques to take maximum advantage of lowered rabbit densities following biological control. Maintenance control after the release of myxomatosis was poor and was not encouraged or coordinated by the relevant authorities. Land managers cannot afford to rely on the potential of new agents to save them from action now.

5.1 Community perceptions

5.1.1 Introduction

There are strongly held conflicting views among people interested in the management of rabbits. Some scientists judge rabbits as Australia's most pernicious environmental problem, and wish to see more resources allocated to their management. People involved in commercial or subsistence use of rabbits are alarmed at the prospect of rabbits being managed to levels too low to allow such uses to continue. Economists argue the spending on rabbit management should be fully justified in terms of the economic or environmental returns on such investments, and are concerned that the

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information necessary for this to occur does not exist. People holding strong animal welfare concerns hope to see rabbit management and better control techniques reduce the level of suffering in rabbits subjected to control operations. The following quote is an indication of the strength of feeling about rabbits by some scientists.

'We strongly believe that introduced herbivores have been responsible for massive land degradation and the loss of native species. The primary culprit here is the rabbit. We think it unfortunate that the overwhelming impact of the rabbit seems continually overlooked by a whole spectrum of decision makers, from funding agencies through to environmental activists … the southern two-thirds of the arid zone remains infested with Australia's most pernicious environmental problem' (Morton and Pickup 1992).

5.1.2 Attitudes of governments

Commonwealth issues

Many Commonwealth Government initiatives in areas such as land degradation, ecologically sustainable development and reafforestation have paid little attention to the damage caused by rabbits. The Hon. R.J.L. Hawke (1989) in his statement on the environment proposed the planting of one billion trees by the year 2001 but did not mention rabbits in relation to tree loss. It is likely that rabbits may cause the loss of far more than one billion regenerating trees between now and the year 2001.

'Crawler tractors have greatly increased the speed and cost-efficiency at which warrens can be ripped.'

The Report of the House of Representatives Standing Committee on Environment, Recreation and the Arts, *The effectiveness of land degradation policies and programs* (1989), makes no specific mention of rabbits, yet two of its three terms of reference were (1) ongoing causes of land degradation; and (2) measures required to protect the environmental and productive values of land. *The Report of the National Estate* (1972), commissioned by the Australian Parliament, has an eight-word mention of rabbits. In 1985 the Australian Heritage Commission (AHC) produced its Special Australian Heritage Publication Series No. 1 entitled *Australia's National Estate: the Role of the Commonwealth* (1985). There was one mention of rabbits lumped in with camels, donkeys and goats. A book on environmental policy in Australia (Gilpin 1980), by the first full-time adviser to the House of Representatives Standing Committee on Environment and Conservation, does not even discuss the rangelands, much less the rabbit. The report of the Department of Arts, Heritage and Environment (1985), *State of the Environment in Australia* 1985, proposed six actions to stem land degradation in the arid zone. Rabbit control was not included. Only the report of the Working Group on Ecologically Sustainable Development (1991) gives consideration to rabbits.

Given its limited constitutional role for vertebrate pest management, such initiatives as the Vertebrate Pest Program and the preparation of these guidelines indicate that the Commonwealth Government is becoming more aware of the significance of damage caused by introduced pest animals, such as rabbits, and is determined to assist in improving their management. It is also significant that under the *Endangered Species Protection Act 1992*, the competition and land degradation caused by rabbits is listed as one of five key threatening processes. Consequently, the Australian Nature Conservation Agency will be preparing and implementing, under the legislation, a threat abatement plan for rabbits.

State issues

While it is difficult to identify all the reasons for the unwillingness of state authorities to confront the magnitude of the rabbit damage issue, a number of factors are clearly involved:

- Lack of a national perspective.
- An attitude, arising from the success of myxomatosis in the 1950s, that this disease will keep rabbit numbers in check. Indeed, there is a widely held hope that the problem can be solved by some second generation disease agent and many landholders await the 'new myxo' or 'rabbit AIDS' in the expectation that it will solve all of the problems.
- A view that the rabbit problem has become an accepted nuisance. Certainly, there is one view which sees the rabbit problem as being so vast as to defy any attempt to overcome it. We are psychologically intimidated by the size of the problem (Section 11.3.5).
- Until recently, lack of data on the real costs of rabbit damage. Current data have not been widely promoted or understood and accepted by land managers and the community. Wider agendas have also been set. Once it was sufficient to protect farming interests alone but now conservation interests are recognised.
- A concern that if rabbits are effectively managed by either conventional means or by a biological control agent, predation pressure on native species will be increased. This may be true in the short term, but the increased pressure on native species would be similar to what happens now during droughts or after a widespread myxomatosis epizootic. With effective rabbit management the increased predation pressure occurs only once, without effective management it occurs frequently. If it is considered necessary, a predator reduction program could be carried out in conjunction with the initial rabbit control. Effective rabbit management is the most potent method we have for reducing the impact of introduced predators on native species (Sections 3.7.3 and 4.3.6). The greatest detrimental impact of heavily reduced rabbit populations will be on birds of prey as rabbits are the bulk of the diet of many species during their breeding seasons (Figure 16) (Baker-Gabb 1984).

There is now increasing public concern about environmental issues and the interrelationships between rabbits and land degradation are becoming more obvious. Land managers are now taking a long-term view and looking at the range of factors affecting their production. Improved technology, in the form of crawler tractors, has made warren ripping possible in places where it was previously impossible. Crawler tractors have also greatly increased the speed and cost-efficiency at which warrens can be ripped. Importantly, we are beginning to see better communication between scientists and land managers of the real nature and threat posed by rabbits in Australia.

5.1.3 Attitudes of the general public

Often the first contact that children have with rabbits involves the heavily anthropomorphised characters of fable, fairy tale and legend. The images gained from the Easter bunny, cartoon characters, *Watership Down*, A.A. Milne and Beatrix Potter are vivid, because they portray idealised human values or, in some cases, human failings. Such childhood illusions do not entirely disappear in adulthood. Recently there has been a move to replace the Easter Bunny with the Easter Bilby.

'Often, the first contact that children have with rabbits involves the heavily anthropomorphised characters of fable, fairy tale and legend.'

Those involved in the administration of rabbit management must inform legislators, land managers and the public about the true nature of rabbit damage and ensure these people have sufficient information to make appropriate decisions on rabbit management.

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5.1.4 Attitudes in the rural community

The rural community in rabbit-prone areas also needs to be informed about the damage caused by rabbits. On some of the more productive grazing lands, in particular, there has been a tendency to tolerate increasing rabbit numbers with little attempt to determine the economic and environmental damage this entails. In part, this situation has arisen because of a gradual decline in the effectiveness of myxomatosis, so the problem of rabbit damage has 'crept up' slowly. Gradual increments in rabbit damage are less obvious to the untrained eye. Moreover, rabbit damage can be detrimental, not just to the individual landholder, but to the wider community, which should therefore bear some of the management costs.

5.2 Implication of rabbit harvesting for rabbit damage control

Although wild rabbits are generally accepted by land managers to be Australia's most damaging pest animal, they are also commercially harvested.

People and politicians with a commercial interest in rabbits have always opposed the introduction of biological control agents or more effective legislation (Fenner and Ratcliffe 1965; Hughes 1987). In 1925 David Stead was appointed Special Commissioner to enquire into the rabbit menace in New South Wales (Stead 1928). His massive report and the 22 excellent recommendations were never published because:

'Parliament treated the report with expediency and contempt. Both sides of the House moved to stop it from being printed. One party favoured the rabbiters, the other party the dealers and exporters of skins and carcasses. Both sides wished to nurture the Pastures Protection Boards. The rabbits flourished with Parliamentary sanction' (Rolls 1969, page 186).

Promotion of, or assistance to, what is essentially an 'opportunistic industry' potentially conflicts with a national approach to rabbit management. The future of the commercial industry depends on an adequate supply of wild rabbits, while the national rabbit management strategy is based on the premise of rabbits as a national pest rather than a national resource.

'Motivation is the key factor in the success of any rabbit control program.'

There have been a number of studies which show the severe effects of rabbits upon the regeneration of many species of native trees and shrubs (Section 4.3.2). Even at low densities, rabbits can have a significant impact on plants (Cooke 1987; Bell 1987). Given the extent and severity of rabbit damage, particularly in the rangelands (Chapter 4), the national interest is best served by promoting more effective rabbit management rather than the expansion of the wild rabbit industry.

Henzell (1989) has estimated losses in livestock production due to competition with rabbits to be about $20 million a year in the arid zone of South Australia. By contrast, the annual returns to rabbit harvesting for the whole of Australia are estimated to be about $9 million (Ramsay 1991). Cooke (1991a) cites an example of a single cattle station during a rabbit plague being forced to truck out 7000 head of cattle with a total market value equivalent to that of all the rabbits marketed in Australia in the same year.

The management of rabbits in Australia depends upon clear and consistent policies at all levels of government, to encourage local action, either by individual landowners or groups of landowners. Motivation is a key factor in the success of any rabbit management scheme. The early success of the rabbit 'killer' policy in New Zealand (Fennessy 1958) and the more contemporary success of the Victorian Landcare Program (LandCare) and 'Rabbit Action' groups in Victoria were based upon the clear perception of the rabbit as an unwanted pest. To obtain long-term commitment to a goal of either local eradication or management to low maintenance levels is difficult for any animal that is both a pest and a resource. A single landowner in the midst of a 'rabbit control' group opting for commercial use of wild rabbits as a supplementary source of income would obviously pose a problem.

5.3 Rabbits on Aboriginal lands

Aboriginal communities in Australia control approximately 13% of the land mass (Wilson et al. 1992a) and a high proportion of this tribal land is rabbit-infested and prone to degradation by rabbits. In a recent report to the Senate Select Committee on Animal Welfare (SSCAW), representatives of the Central Land Council pointed out that Aborigines use introduced animals as a source of food, income and employment. In fact, such animals are considered part of the country and many Aborigines speak of the need to manage this resource rather than to eradicate it (Nugent 1988). Nonetheless, there is no one Aboriginal view on this issue (SSCAW 1991). Each community needs to be consulted on the issue before any proposed action on rabbits is taken.

The state, territory and national response to this position has either been to ignore it or, alternatively, to support the harvesting of rabbits by the local Aboriginal communities. As an example, the Mutitjulu and Imanpa communities received funding from the Department of Primary Industries and Energy (DPIE) and the Department of Employment, Education and Training (DEET) to set up a rabbit-harvesting enterprise to supply local communities.

If such projects are successful in supplying local communities with food, then maintenance of high rabbit populations on some of these lands may be seen to be essential for the continued prosperity of the community. Aboriginal communities in rabbit-prone areas need to have access to information on the relationship between rabbit populations, and the likely long-term damage to land and traditional values due to rabbits, which will affect the sustainable use of their lands (Chapter 4). Many of these communities are becoming involved in regional land-use planning through the Aboriginal and Torres Strait Islander Commission regional councils. Under this system Aborigines on pastoral leases in Western Australia are addressing issues such as land rehabilitation. State and territory land management authorities need to work closely with Aboriginal communities to assist them to make land management decisions which meet their needs and enables ecological sustainable land use.

5.4 Commercial farming of rabbits

Commercial rabbit farms have been a controversial issue in Australia for many years. This is reflected by the different regulations related to rabbit farms in different states. As an example, South Australia does not permit the keeping of domestic rabbits for commercial production whereas Western Australia does, under strict controls.

'Few rabbit farms in Australia are profitable.'

There are good arguments in favour of the development of a commercial rabbit farming industry in Australia. Some breeds of domestic rabbits are efficient converters of food into meat or fibre and the food conversion factor, dressing percentage and meat-to-bone ratio of some breeds of rabbits approach those of the broiler chicken. In addition, the rabbit can be fed a lower quality cellulose-based diet than that required for chickens. If, however, lactation and maintenance of the doe is taken into consideration, the conversion ratio for chickens is considerably higher. Rabbits bred for meat production produce a low-quality pelt which is available as a saleable by-product. The meat is also low in cholesterol and is often the first choice of people on strict diets.

In many countries production of rabbit meat is a large industry. Annual production is 300 000 tonnes in Italy, 150 000 tonnes in both Russia and France and 120 000 tonnes in both Spain and China (Lebas and Colin 1992). To put these figures in perspective, lamb production in Australia in 1990–91 was 290 000 tonnes.

In recent years, the price for Angora rabbit fibre has been high. Each Angora rabbit produces over one kilogram of fibre per year. This equates more than favourably with the returns from fine wool merino sheep.

Despite these advantages, few rabbit farms in Australia are profitable. Many farms which began in the last decade are now out of production. One reason for this is the vagaries of the market for fur and meat, plus the existence of a huge production base in other countries. Another factor is poor animal health.

Commercial rabbit farming creates an adverse psychological climate for the attainment of high levels of control in the field. In any areas where management of wild rabbit damage is being attempted, the introduction of commercial rabbit farming may undermine efforts to maintain motivation and vigilance by landholders and local control authorities. While a clear distinction can be made between wild rabbits and their farmed counterparts in relation to their damage potential, such a distinction is often not made by landholders. They may resent the fact that their neighbour can make a legitimate living from the farming of rabbits while they can be prosecuted for harbouring the same species.

If a new industry is at best marginal, it needs careful consideration if it jeopardises existing attitudes to rabbits. In a climate where market forces predominate, it will be these which ultimately determine the fate of the industry. There is also increasing opposition from many animal welfare groups to the intensive 'battery' farming of rabbits. Nonetheless, there are some issues, implicit in commercial production, which impinge upon a national strategy for rabbit management. For example, the commercial rabbit farming lobby in Western Australia has opposed the introduction of biological control agents.

5.5 Animal welfare

A major issue is how to balance the concerns for animal welfare with the need to save whole ecosystems.

In most rabbit populations the vast majority die young. Indeed, it is unlikely that any wild rabbit dies peacefully of old age. In some instances, predation by foxes, cats and raptors will account for a large proportion of the young. In others it may be endemic parasites and diseases such as coccidiosis and myxomatosis or death through thirst or starvation during drought. None of these forms of death are painless and it is therefore

Traps pose a significant animal welfare concern and cause unnecessary stress and suffering. They are not an effective method of rabbit management.

Source: K. Heinrich, APCC

necessary to critically examine the role of human-imposed control as a means of decreasing the total amount of suffering incurred.

This requires some objective measure of the relative degree of suffering associated with the various types of death. Animal suffering must always be associated with some degree of anthropomorphism. We simply cannot experience or grasp, in any objective way, the reality of 'rabbit existence'. The most useful approach is to consider suffering in terms of rabbit populations rather than in terms of individual rabbits. Although pain or suffering is not strictly additive, it is generally considered to be so. There should be more concern about suffering in 1000 rabbits than about the same level of suffering in a single rabbit. This is the central argument of rabbit management authorities for use of human-imposed controls.

'It is unlikely that any wild rabbit dies peacefully of old age.'

It may well be that certain techniques of control, such as gassing with chloropicrin, are far more inhumane than say, being torn to pieces by a predator. However, the point about human-imposed controls is that they can decrease the total amount of suffering in future years by permanently lowering a rabbit population. In this way, the enormous population surpluses are avoided and, with them, the future aggregate suffering of large numbers of rabbits.

There is an important corollary to this approach. It requires that the human-imposed controls are effective and essentially non-repetitive. For instance, where a land manager uses large amounts of 1080 bait each year or every few years, then nothing is achieved by way of preventing large-scale suffering of rabbits in the future. This is a strong argument for doing the job properly, including permanently lowering rabbit populations by warren ripping such that their annual recruitment is severely curtailed. The potential for future suffering is then reduced.

The following is an assessment of the humaneness of poisons and major control techniques used in rabbit management.

5.5.1 Fumigant chemicals

Chloropicrin

Synonyms: Trichloronitromethane, nitrochloroform

Trade names: Larvacide[R] and Chlor-O-Pic[R]

Chloropicrin is a non-flammable, slightly oily, colourless liquid which vaporises slowly at room temperature (Sexton 1983). It is a strong sensory irritant which affects all body surfaces, and it causes watering of the eyes 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). Workers handling chloropicrin report that brief accidental exposure causes intense irritation and distress.

Measurement of sensory irritation has been attempted in mice (*Mus musculus*) 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 necrosis in lung and olfactory epithelium (Buckley et al. 1984). Experiences with chronic human occupational exposure has shown that concentrations of less than one ppm cause similar destructive changes in lung tissues and severe irritation (TeSlaa et al. 1986). A

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concentration of one ppm causes immediate eye irritation in people (Sexton 1983). The correct use of chloropicrin as a rabbit fumigant will not normally lead to chronic occupational exposure for humans. This is particularly so for power fumigating machines where the presence of the marker smoke gives clear warning of gas drift. The human safety aspects of chloropicrin use are dealt with in Appendix A, A4.

Toxicity of chloropicrin is primarily due to its effects on the small and medium bronchi. Death may result from fluid in the lungs (pulmonary oedema), bronchopneumonia or bronchiolitis obliterans (Clayton and Clayton 1981). The speed at which this will occur depends upon the concentration of the gas and the exposure time. Oliver and Blackshaw (1979) observed that chloropicrin was unevenly distributed in a rabbit warren when not introduced by a power fumigator. The gas, being heavier than air, sinks and collects at low spots in the warren.

Gleeson and Maguire (1957) suggest that chloropicrin exhibits a delayed effect on rabbits which have been exposed to sub-lethal but acute doses. This is typically observed in rabbits which escape from fumigated warrens. These are sometimes found dead (apparently due to the effects of the gas) some weeks after initial exposure. An opossum was also observed to die 48 hours after exposure (Andrews 1964). In this case, autopsy results indicated widespread alveolar emphysema as being the probable cause of death.

Chloropicrin is not a humane agent for rabbit control. The symptoms seen in live animals and the pathological changes seen in autopsied animals suggest some suffering over a period which may involve hours or, in the case of animals escaping from warrens, even days. The use of power fumigators, which force the gas through most parts of the warren quite quickly, might decrease the time to death and, therefore, the duration of suffering. Nonetheless, there is a need to investigate more humane alternatives (Section 12.8).

Phosphine (hydrogen phosphide) — H_3P

Trade names: Phostoxin^R, Gastion^R, Magtoxin^R

Phosphine is a colourless gas, and is characterised by a slight garlic odour. It is about 20% heavier than air, and is produced by the action of water on aluminium or magnesium phosphide. Because hydrogen phosphide is a highly flammable gas, it is supplied in a solid tablet with ammonium carbamate which will, upon generation of the phosphine, produce carbon dioxide and ammonia and thus reduce the risk of the phosphine igniting (Sexton 1983).

In humans the gas does not appear to cause sensory irritation. 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 on bone marrow, organ tissues and brain tissue and is perhaps related to the phosphorylation of enzymes (Klimmer 1969).

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

Rabbits can remain immobile during lethal exposures and this may indicate that the chemical is not a sensory irritant to them (Oliver and Blackshaw 1979). The pain and suffering caused in rabbits is not known but in humans the symptoms 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. The time taken to achieve maximum gas concentration in the warren can be many hours and it is largely governed by the availability of moisture.

From the little evidence available, phosphine is probably more humane than chloropicrin. Again, the length of suffering or discomfort will probably depend upon gas concentrations in the warrens and, under moist conditions with sufficient quantity of tablets, the time to death may be quite short.

5.5.2 Poisons used in baiting

Sodium monofluoroacetate (compound 1080) — $C_2 H_2 FO_2 Na$

Sodium monofluoroacetate is a tasteless and odourless (to people) inorganic chemical which is highly soluble in water. It is relatively stable in aqueous solution but the powder will begin to decompose above 200°C. It is rapidly absorbed by the gastrointestinal tract, but only slowly by the skin.

The main responses to 1080 are: (1) a loss of energy; (2) an accumulation of citrate in body cells; and (3) a disturbance of central nervous system activity and of heart function. Death results from progressive depression of the central nervous system, with either cardiac failure or convulsive respiratory arrest as the terminal event.

'There is no evidence that 1080 poisoning of rabbits causes severe or prolonged pain.'

The toxicity of 1080 varies in different species. Cold-blooded vertebrates are less sensitive than warm-blooded ones, as are herbivores less sensitive than carnivores, and avian species less sensitive than mammals.

For one to two hours after ingestion of 1080 rabbits appear normal (Chenoweth and Gilman 1946). This is usually followed by the rabbit sprawling with the head placed flat on its side between the forelimbs. Between two and 12 hours after ingestion, ventricular fibrillation occurs and is immediately followed by an anoxic convulsion. Spontaneous reversion to a normal sinus rhythm may occur during a period of ventricular fibrillation but a second anoxic convulsion soon follows and the animal usually dies in a second bout of fibrillation. Observation of wild rabbits poisoned in the field support these findings. Batchelor (1978) noted that the first rabbit died just under two hours after bait ingestion. Of the first ten rabbits observed, the typical pattern was to continue feeding until collapse, after which the animal died in a brief spasm of kicking. Two of the ten animals squealed for a short period.

The suffering caused in 1080 poisoning of rabbits is difficult to determine. It appears that violent pain, if it is experienced, is short. Our only direct knowledge of the humaneness of 1080 poisoning comes from reports of human ingestion. Gajdusek and Luther (1950) provided the first report of human poisoning in a two-year-old boy who accidentally ingested 1080. They reported nausea and vomiting, with the child becoming comatose and unresponsive to painful stimuli for two days following poisoning. He gradually increased responsiveness and made an uneventful recovery with discharge 11 days after ingestion.

Williams (1948) personally experienced clinical signs consistent with a high but sub-lethal level of ingestion including epileptiform convulsions. He explicitly reported no pain during poisoning. In other accounts of human poisoning with 1080 only one reports pain occurring (Gregory 1991).

Based on these observations of behaviour in poisoned rabbits and upon human cases of ingestion there is no evidence that 1080 poisoning of rabbits causes severe or prolonged pain.

Pindone (2-pivalyl-1-,3-indandione)

Pindone is a yellow crystalline solid with a melting point of 110°C. It is soluble in most organic solvents but largely insoluble in water (calcium and sodium salts are soluble in water). It is odourless and tasteless to people.

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Pindone is an anticoagulant poison and one of many coumarin analogues used for this purpose. The time of onset and the severity of the bleeding can vary depending upon the amount of pindone ingested, the rate of metabolism of the chemical, the disappearance rates of the vitamin K-dependent coagulation factors, and the bio-availability of vitamin K (Jubb et al. 1985).

A broad spectrum of clinical signs occur. Internal bleeding into body tissues and cavities as well as blood loss from body orifices can cause collapse due to low volume of circulating blood (hypovolemic shock). The hypovolemia and the haemorrhage into organ parenchyma and surrounding tissues can cause organ dysfunction. The first clinical signs are usually seen about three days after ingestion. Onset of bleeding may be acute, and on occasion an animal may be found dead with no previous signs of illness (Jubb et al. 1985). In subacute cases, animals may be anaemic with pale mucous membranes and skin, nose and eye haemorrhages. Nose bleeds (epistaxis), difficulty breathing (dyspnoea), weakness, bloody vomit (haematemesis) or bloody faeces may also be evident. Lameness due to swollen or tender joints as a result of blood in the joints (a haemarthrosis) may also be present.

The pain or suffering associated with the above symptoms in rabbits is difficult to gauge. In cases where bleeding into joints is involved, one would expect quite severe pain. On the other hand, some forms of internal bleeding might be much less painful. Each case will differ. It appears, however, that ingestion of massive lethal doses will generally produce a more humane outcome than the ingestion of smaller doses over a longer time.

5.5.3 Other control techniques

Ripping warrens

The technique requires a tractor or bulldozer fitted with single or multiple-tyned rippers (Section 7.4.9 and Appendix A, A2). The rippers need to penetrate at least 0.5 metres (much deeper in sandy country). With single-tyned rippers behind rubber-tyred tractors, it is recommended that the rip lines are no further than 0.5 metres apart and that cross-ripping is performed (i.e. the rip lines run in one direction and then a second series run at right angles to the first).

With a powerful machine operating in reasonably loose soil, complete collapse of the warren occurs and the rabbits are quickly crushed or asphyxiated. Asphyxiation would be hastened by the weight of surrounding soil preventing effective movement of the diaphragm. However, when warrens extend beyond the depth of the ripper, sealed chambers will contain some air, and death under these circumstances will be slower and, one assumes, accompanied by some suffering. Hayward and Lisson (1978) report the survival times for wild rabbits exposed to elevated concentrations of carbon dioxide. At 50% CO_2, mean survival time of wild rabbits was 71 minutes. Although rabbits quickly became unconscious at levels above 40% CO_2, at lower concentrations full unconsciousness was infrequent.

'Ripping is a humane method of rabbit destruction if complete disintegration of the warren is achieved.'

Ripping is a humane method of rabbit destruction if complete disintegration of the warren is achieved. Where rabbits are trapped in blind endings beyond the reach of the implement, some may dig to the surface and escape but, inevitably, others will die of gradual asphyxiation. Burrows must therefore be ripped as deeply as possible and at times of low rabbit density. Where warrens contain large numbers of rabbits, it is a good policy to poison the area before ripping. Warren destruction is essential for effective management of rabbit damage and gives long-term management. It is a means of achieving humane management of rabbits since, if done properly, it obviates the need for repeated control operations in the future.

Shooting

Although not normally regarded as a method of primary control, shooting can be useful as a maintenance control. Both .22 rifles and 12-gauge shotguns are used.

Shooting is a humane technique only when, in the case of rifles, head or chest shots are possible. With shotguns maiming can occur, particularly when light shot is used over longer distances. In general, shooting can be regarded as being one of the most humane techniques for the destruction of rabbits. Death is usually rapid and, even when maiming occurs, the stricken animals can generally be killed quickly and humanely with a second shot.

Myxomatosis

Myxomatosis in Australia today should not be regarded as a control 'tool' but, rather, as a naturally-occurring and endemic disease of rabbits. To this extent, questions of its humaneness are really no more relevant than a discussion on the humaneness of predation, coccidiosis or any other naturally occurring mortality agent. Nonetheless, some deliberate inoculation of wild rabbits with the myxoma virus still occurs in Australia, and to this extent comment upon the humaneness of the technique is required. This should begin with a description of the disease process.

Upon infection of a rabbit with a virulent strain of myxoma virus, there is a typical sequence of pathological events which includes the appearance of the virus in different organs and its subsequent multiplication in those organs. The most prominent abnormalities found in the bodies of rabbits that die of myxomatosis are skin tumours and pronounced swelling, especially in the area of the face and around body orifices. Skin, heart and intestinal haemorrhages may sometimes be observed. No consistent changes have been described for the spleen, liver, kidneys or lungs but various degrees of fluid accumulation will occur in these organs depending on the severity of the disease (Weisbroth et al. 1974).

In myxomatosis resulting from infection by mild strains of virus, the sequence of symptoms is the same, though the maximum levels of virus are much lower and transient. Free antigen does not appear in the blood and the symptoms are less severe (Fenner and Woodroofe 1953). In the severe form of the disease (often associated with highly virulent Californian strains), rabbits may die within a week of exposure to the virus and will often exhibit little more than slight swelling of the eyelids and coma immediately preceding death (Weisbroth et al. 1974).

The symptoms described above say little about the degree of suffering or discomfort in diseased rabbits but, to human eyes at least, the most common forms of the disease seen in the field cannot be regarded as leading to a humane death. Rabbits are usually blinded or partially blinded and many become extremely emaciated. Secondary infections and even flystrike can also occur. Death is not rapid and animals may linger on for many days if not weeks.

If the myxoma virus was not discovered until this decade, it is doubtful whether current public opinion in Australia would allow the deliberate release of the disease. Indeed, this has been a recent outcome in New Zealand where a move by the South Island Land Protection Coordinating Committee to introduce the myxoma virus was defeated largely on the grounds of animal welfare concerns.

Rabbit calicivirus disease (RCD)

This is a relatively new disease (Section 7.4.13) and research on its pathology is still underway. A description of the course of the disease has been given by Lenghaus (1993) and this gives some insight as to the relative humaneness of the process. Following direct inoculation of even small quantities of the virus, most rabbits became progressively quieter from about 24 hours after infection, developed an elevated temperature, then became comatose and died quietly 6–12 hours later. Elsewhere, there have been reports of rabbits with convulsive episodes terminally, or a period of squealing before death (Chen 1986, cited in Xu and Chen 1989). This has not been seen in rabbits infected in Australia.

At autopsy the most consistent findings are a markedly enlarged, dark spleen, a pale and swollen liver, heavy, wet lungs and a wind pipe filled with clear froth. Microscopic examination of tissues indicates that death is generally due to a massive, uncontrolled activation of the blood clotting mechanism, apparently triggered by the virus infection, with extensive coagulation of blood in the spleen, liver and lungs, and less frequently in kidneys and heart.

In his description of the disease process, Lenghaus (1993) has commented that the time-course of infection and seemingly quiet death of rabbits infected with RCD virus compares favourably with many of the methods of rabbit control currently used.

Viral-vectored immunocontraception

Current studies in Australia are attempting to produce a biological control agent which is centred on contraception rather than mortality (Section 7.4.14). As such, the technique must be seen as perhaps the most humane approach available to deal with the rabbit problem in Australia. Nonetheless, some issues of animal welfare may be involved.

The viral-vectored approach to rabbit immunocontraception has centred upon the use of the myxoma virus as the 'carrier' agent and, of course, the humaneness of the approach will depend very largely on the potency of the virus. Ideally, a very mild strain of myxoma might be used which would not result in any serious disease process. The problem here is that very mild strains are probably poorly transmitted from rabbit to rabbit (Section 7.4.12) and it may be necessary to seek a more potent strain. The degree to which a successful, self-propagating myxoma strain (carrying the contraceptive 'message') can be selected or engineered for minimum side-effects (i.e. manifestation of pathology of myxomatosis) is unknown at this stage.

Clearly, the development of a transmissible contraceptive technique free of any associated disease process represents the ultimate humane control technique for rabbits. Research on immunocontraception for rabbits is in the early stages and it is not yet possible to assess the probability of success. A decision regarding whether to release genetically engineered immunocontraceptive viruses will require much public debate and public education and it may be a decade or more before rabbit immunocontraception becomes a technical and socially-accepted possibility.

5.6 Rabbits as a recreational resource

Although not highly regarded as a game animal, wild rabbits are probably the largest hunting resource in southern Australia. There are no published reports on the size and value of sport hunting of rabbits. In general, hunting clubs in Australia support the need to manage rabbit damage. They also often argue that sport hunting can be a useful aid for management. Recreational hunting has value for damage control only after rabbits have been reduced to low numbers by conventional control techniques such as poisoning, ripping and fumigation. Small numbers of survivors in difficult country can be hunted with dogs and guns. Hunters then have the added incentive of knowing that their efforts are of lasting benefit.

5.7 Pet rabbits

The size and value of the pet rabbit trade in Australia is poorly documented. Although some states and territories require permits to keep pet rabbits, there is no evidence that pet rabbits pose a threat to the effective management of wild rabbits. There are few data to support the argument that escaped or released pets will add to the 'fitness' of wild rabbits. Escaped pets will quickly fall prey to predators or die from myxomatosis. Nonetheless, there is likely to be a strong case for excluding pet rabbits from areas where management has reduced rabbits to very low densities, or where local eradication has been achieved.

Domestic-type rabbits can sometimes establish in the wild (for example, Rolls 1969), but they eventually die out, except on some islands.

Increased popularity of pet rabbits may cause the general public to become more favourably disposed towards rabbits. This may make it more difficult to educate the community about the need for rabbit management. When a child's pet rabbit succumbs to myxomatosis, there is often a strong family reaction against the use of the disease in Australia. Greater community awareness and understanding of the impact of rabbits on natural environments and agriculture in Australia is needed to counteract these attitudes.

5.8 The myth of the superbug

Paradoxically, one of the important barriers to effective management of rabbit damage today is community attitude to myxomatosis in wild rabbit populations. Following its spectacular success as a control agent in the 1950s, many landholders came to rely on the disease to provide their annual population knockdown. There is an undue reliance on a myxomatosis agent which cannot be relied on to maintain its effectiveness. Recent field and animal house trials suggest that local field strains now kill less than 60% of susceptible rabbits in some parts of Victoria. The consequence has been a slow but insidious build-up of rabbits in these areas. As an indication of the scale of the build-up, use of 1080 poison in some districts in Victoria has increased ten-fold from 1979 to 1989 (I. Nolan, Vernox Pest Management, Victoria, pers. comm. 1994).

Given the success of myxomatosis in the 1950s and 1960s, there is now a widely held hope that some second generation disease, paralleling or perhaps exceeding the performance of myxomatosis, will solve the rabbit problem. Thus, the introduction by the South Australian Animal and Plant Control Commission (APCC) of the arid-adapted rabbit flea (*Xenopsylla cunicularis*) and research on RCD and viral-vectored immunocontraception (Sections 7.4.12–14) are widely seen by many landholders and the general community as the ultimate answer to the rabbit problem.

In fact, the current candidates for a 'new myxo' will require many more years of careful research and, even then, there is no guarantee that the selected agents will achieve long-term effective rabbit management, or even a medium-term reduction in numbers. No reliance should be placed on some magic cure for rabbit management. The management of rabbit damage must rely on conventional control techniques. Even if new techniques become available they will not solve the rabbit problem, but will need to be integrated with conventional control techniques.

Obviously, in many areas, conventional control can never be carried out to the extent of causing regional eradication, or even to maintaining low densities in remote or unproductive areas, and some form of biological control should be sought. Even if a future biological control agent is effective, on its own it will never control rabbit populations, and pastoralists will need to be encouraged and ready to capitalise on results by destroying occupied and unoccupied warrens.

PART FOUR

TECHNIQUES AND MANAGEMENT

4

6. Past and Current Management

Summary

Prior to the introduction of myxomatosis efforts to manage rabbit populations were generally misdirected or inefficient. Poisoning, fencing and various forms of biological control were tried with little success in terms of damage control. Bonus systems were common but ineffective. Some land managers successfully managed rabbits by working within rabbit-proof boundary fences.

The reduction of rabbits to low numbers has mostly been due to a combination of myxomatosis, introduction of the European rabbit flea, and changes to the environment, either through intensive clearing and cultivation or through warren and harbour destruction. Another important contributing factor has been the improvement in strategic use of 1080 poison based on the results of research on rabbit behaviour by CSIRO.

Rabbit management has been most successful in states with a centralised authority that has developed technical expertise, and encouraged input from regional and local groups.

A successful strategy for rabbit management requires an integrated approach at the local, regional, state and Commonwealth level. Each level should have a clear and common aim, supported by appropriate legislation which should apply to all land managers, including governments.

Extension programs are needed that develop land managers' awareness and understanding of rabbit damage and what can be done to alleviate it. Land managers need sound technical advice on rabbit control.

The success of extension programs depends on the motivation, professional approach and expertise of staff involved. All state and territory or local government agencies involved in rabbit control need to ensure that their staff have a sound understanding of rabbit biology and population dynamics, damage and control strategies. An interstate curriculum in rabbit management would ensure that training needs are met and that appropriate standards of control practices are maintained. Such a scheme should form part of an extension and training package that can be tailored to meet the needs of people involved in rabbit management.

6.1 Development of rabbit control practices

'The history of the rabbit the world over is a history of the incomprehensible lethargy of landholders and the deficiency of governments' (Rolls 1969). The first response to the spread of the wild rabbit was the introduction by all states and territories of legislation to make rabbit control compulsory. Legislation was also passed to protect rabbit predators, notably goannas (*Varanus* spp.).

The first *Rabbit Destruction Act* was passed in South Australia in 1875 to ensure that farmers and graziers met their obligations to control rabbits. In local government areas rabbit control was supervised by district councils, while elsewhere rabbit district boards were formed, with rates levied to ensure the Act was enforced. As rabbit numbers increased, new legislation enabled the South Australian Government to employ groups to carry out rabbit control on the properties of uncooperative land managers on a cost-recovery basis.

In New South Wales, the earliest attempts to legislate against rabbits (1880) involved levying landholders to pay scalp bonuses. The law *'… was amended the next year to make it compulsory to control rabbits, with appropriate penalties for failing to do so'* (Rolls 1969). Western Australia legislated to make land managers responsible for rabbit control in 1883, even though rabbits did not become established there until much later.

4

In the debate on the *Rabbit Nuisance Bill* in the New South Wales Legislative Council in March 1883 there was discussion on a clause which would permit a magistrate to send a child to jail for six months for turning loose a tame rabbit (Rolls 1969).

There were concerns about the effectiveness of early programs. A correspondent to *The Observer* in 1886 described the government's policies for control of the rabbit in South Australia as 'trying to stop the tide with a pitchfork'. Almost all rabbit control prior to myxomatosis could be described in similar terms. Initially, private and government rabbiters were employed on a weekly wage. It soon became obvious that these rabbiters had a vested interest in maintaining rabbit populations. In 1884 the farmers in New South Wales demanded that a bonus system be introduced. It did not work. By the end of 1887 editors and farmers demanded that the bonus system be terminated as the $30 million (1990 prices) 'spent this year might as well have been thrown into the sea'. Bonuses were withdrawn in July 1888 when the Treasurer estimated that bonus claims that year would be $23 million in excess of the amount allocated. In 1894 one bounty scheme offered two pence per rabbit tail (Sheail 1971).

'Almost all rabbit control prior to myxomatosis could be described as trying to stop the tide with a pitchfork. Methods were indiscriminate and often resulted in substantial deaths of native wildlife and considerable risk to people and livestock.'

Rabbit poisoning began after the rabbiters walked off the runs when the bonus system collapsed. There were concerns about the effectiveness of some of the government sanctioned programs. David Stead, the Special Rabbit Menace Commissioner in New South Wales, was sacked and lost his superannuation for criticising the government and Pastures Protection Boards for persisting with useless methods, having no desire to change their ways, and for needlessly poisoning wildlife (Rolls 1969).

The Australian farmer used numerous methods, chosen by trial and error. There was little systematic examination of the long-term effectiveness of the methods, nor was there any understanding of rabbit biology as the key to effective control. A mythology about control methods built up. Each rabbiter had his own, often secret, method for trapping and poisoning. In the absence of scientific experiments it was impossible for the average landholder to decide which method was best. Most methods were ineffective. They killed many rabbits but left many behind. Some of the methods were more destructive to predator populations than they were to rabbits (Gibb and Flux 1973). Trapping, ferreting and shooting rarely killed more than a third of the population (Phillips 1955; Cowan 1984; Williams and Robson 1985). Commonly used poisons included cyanide, arsenic and phosphorous placed in a variety of bait materials chosen for their ready availability and supposed palatability to rabbits. Baits included apples, a range of root vegetables, cereal grains, thistle roots and even sandalwood twigs laced with strychnine. Water points were often poisoned with cyanide.

Methods were indiscriminate and often resulted in substantial deaths of native wildlife and considerable risk to people and livestock. Chemicals such as yellow phosphorus and carbon disulphide were as dangerous to the user as they were to rabbits. There was no formal evaluation of the effectiveness of these poisons.

Determined landholders were able to control, and in some cases eliminate, rabbits from their properties. A determination to have a property virtually free of rabbits and a persistence in pursuit of this goal were then, and remain today, the most important ingredients in effective rabbit control. Poisoning, dogging, destruction of cover and the digging out of warrens were all used to eliminate rabbits from land that had been enclosed in rabbit-proof netting (Fenner and

Ratcliffe 1965). Some techniques, such as poisoning water, or funnel traps on dams, killed or caught thousands of rabbits in a night during droughts, but these rabbits would have died anyway. People not only netted rabbits out, but in difficult areas they also netted them in to protect the rest of their property.

Various forms of 'biological' control such as the Rodier method were tried. This involved trapping and killing all females while all trapped males were released; the assumption being that excess males would harass the remaining females to death. W.E. Abbott (1913) insisted that releasing cats was the answer. Other forms of biological control suggested were rabbit scab (*Psoroptes cunicula*), Natal ants, pasteurella, Tintinallogy disease, bladder fluke (*Taenia* spp.) and liver rot (*Eimeria stiedae*). In an attempt to claim a New South Wales Government reward of about $2 million for an effective rabbit control method, Louis Pasteur sent his nephew to Australia to demonstrate that chicken cholera would kill rabbits. He was not, however, able to convince the authorities that this method would be successful.

By 1890, rabbit-proof fencing was recognised as a useful weapon in protecting areas from the effects of rabbits and other pests such as dingoes and emus. Legislation required fence construction with government assistance or provided for fencing costs to be shared between neighbouring landholders. By 1913, 50 000 kilometres of rabbit-proof fences were being erected each year (Schedvin 1970).

In 1901 the Western Australian Government authorised construction of the Number 1 Rabbit-Proof Fence, stretching more than 1700 kilometres from the south coast near Hopetoun to the southern end of the Eighty Mile Beach near Port Hedland. By the time it was completed in 1907, rabbits had already moved west of the fence into the area to be protected (Rolls 1969). People persisted in believing in the value of barrier fences long after fences had demonstrably failed. Up until 1962 the Queensland Government maintained a netting fence on the border to protect the state against New South Wales rabbits, even though rabbits were well established in Queensland at the turn of the century.

Smaller-scale fencing projects were successful in protecting areas in which rabbits had been controlled. In South Australia, the *Fences Act 1892* meant that a landholder who rabbit-proofed boundary fences could claim half the cost from the adjacent landholder. Rabbit-proof fencing schemes on individual properties were successful in keeping rabbits out when landholders devoted sufficient resources to maintaining them.

'Bounties and the erection of barrier fences wasted valuable resources.'

From 1880 to 1950 the methods used most consistently were fumigation, poisoning and warren destruction. The same methods are used today with the difference being that modern chemicals and implements are far more effective, and there is a better scientifically-based understanding of rabbit behaviour. Rabbit netting, once very popular, is rarely used. The netting is expensive and considerable labour is required to keep the fence rabbit-proof. Few farmers now aim to exterminate rabbits on their properties and therefore see no point in building and maintaining costly rabbit-proof fences to protect their land from reinvasion from neighbouring properties.

The ready availability of cheap labour during the depression of the 1930s contributed greatly to the success of control operations (Rolls 1969). During and immediately after World War II however, very high rabbit numbers resulted from favourable seasons and the lack of farm labour. In the 1950s landholders and almost the entire Australian community believed that the rabbit problem had been eliminated by myxomatosis (Section 3.7.4). Fortunately, this period saw the first substantial research by CSIRO on the biology and behaviour of rabbits under natural conditions, and the systematic investigation of control methods such as the newly recognised rodenticide sodium fluoroacetate or compound 1080 (Section 5.5.2).

With the resurgence of rabbit populations in the late 1950s and early 1960s, most state and territory governments recognised the need to be more involved in rabbit management. State and territory agencies actively sought scientific and technical staff to extend and adapt the CSIRO findings.

Recommendations, and in some cases directives, from these state and territory agencies eventually came to be based on a sound understanding of rabbit biology and behaviour rather than on traditional practices.

Most states and territories have some form of regional or district rabbit control organisation. In the past, this has been the traditional form of rural local government (in Western Australia and South Australia) or a regional organisation set up at least in part for the purpose of rabbit control, such as Pastures Protection Boards in New South Wales. Local government bodies have now divested responsibility for rabbit management, delegating responsibility to the state organisation in Western Australia, or by forming regional control boards in South Australia. Those states with a centralised authority have been more effective at rabbit control, at least partly because of the ability of the central authority to develop and maintain a team of technical experts (Fenner and Ratcliffe 1965). This does not diminish the importance of local groups and organisations that can more readily become involved in local matters of priority and offer appropriate encouragement and, where necessary, coercion. The organisational structures for vertebrate pest control in each state and territory are further outlined in Braysher (1993).

In the past, rabbit management has almost entirely been directed at protecting agricultural production. In the last 15 years the principles of natural resource management have been widely accepted and promoted, and the need to protect non-agricultural resources recognised.

Rabbit management is now commonly included in management plans for parks and reserves. The degree to which control is implemented often depends on how well the problems caused by rabbits are recognised and the resultant priority assigned to rabbit management. Because there is a lack of understanding and recognition of rabbit damage, the conservation value of many parks and reserves is still threatened by rabbits. For example, the Flinders Ranges National Park Management Plan (South Australia, Department of the Environment and Planning 1983) specifies as one of its

Early rabbit management efforts failed in Australia because:

- there was too much reliance on legislation;
- bounties and the erection of barrier fences wasted valuable resources;
- professional trappers and others with a vested interest in a continuing rabbit population ensured that rabbit populations were not effectively managed;
- there was little understanding of rabbit biology and behaviour and the application of this to control operations;
- there was a lack of specific organisational structures set up to deal with rabbits and their impact;
- control efforts concentrated on agricultural land, and ignored the impact of rabbits on areas of natural vegetation and the likelihood of reinvasion of farmland from rabbits moving from areas of natural vegetation;
- there was no scientific testing of the techniques used nor standardisation of their use; and
- there was no recognition that locally-based schemes such as Landcare groups provide a primary avenue for government to work with landholders.

objectives the management of vertebrate pests. There is, however, no clear indication of the degree of control required, or any indication of what this control will achieve. As a result, rabbits have only been spasmodically controlled in areas of relatively low conservation value and where control is easiest.

In areas off reserves, the level of control needed to protect native vegetation is often different from that needed to protect adjoining crops and pastures from economically significant damage. For example, all acacia seedlings can be removed by rabbits at a density of less than one per hectare, a level which traditionally may have been acceptable to organisations charged with ensuring effective rabbit control (Lange and Graham 1983). Governments need to reassess the need to manage rabbit damage on road reserves and other areas of remnant vegetation, in line with the management objectives for these areas. There is a similar need for improved rabbit management where tree-planting and other revegetation schemes are being implemented.

6.2 Current management

The charters of most state and territory pest agencies now require protection of all resources from the harmful effects of rabbits (Table 13). For example, the Agriculture Protection Board (APB) of Western Australia exists to '… safeguard Western Australia's rural industries and natural and community resources from the harmful effects of certain plants and animals' (Working Group on Ecologically Sustainable Development 1991). Within the general aim of protection, state and territory organisations adopt policies designed to minimise the spread of rabbits and to control them in areas where they are already established (Table 14). In South Australia for example, it is an offence to transport live rabbits around the state or to release them. On offshore islands, where rabbits are not generally established, the South Australian *Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986* requires that wild rabbits be controlled, i.e. the animals and their warrens and harbour destroyed to the greatest extent practicable.

'While private land managers are required to control rabbits, they often complain about a lack of action on government-managed lands such as national parks.'

The legislative basis for rabbit control is not always rationally based. States and territories have regulations that insist on continuous suppression and destruction wherever rabbits are found. In most instances there is little attempt to relate the costs of control to the benefits gained from lowered rabbit densities.

In practice, most states and territories aim for long-term suppression of populations rather than eradication. Enforcement of control under legislation is used sparingly and as a last resort. There are advantages of integrating research, extension and regulation within the one system (Henzell 1989). The credibility of extension advisers and inspectors, as perceived by landholders, is enhanced by working closely with research staff who can help to ensure continuing and technically sound advice. Similarly, land managers and extension officers need to be able to communicate with research staff to ensure that research meets the needs of land managers and that land managers understand the advantages of managing rabbit impact.

A number of factors prevent effective rabbit management in New South Wales (Korn 1991), including:

- unrealistic legislation requiring ultimate eradication of rabbits;
- lack of compulsion for independent Rural Lands Protection Boards (RLPBs) to enforce the legislation, resulting in different levels of control in different parts of the state;

Table 13: Legislative and organisational responsibilities for rabbit control.

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Rabbit control in legislation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overseeing state or territory organisation	Parks and Cons Service	RLPBs	CCNT	Dept of Lands	APCC	DPIF	DCNR	APB
Who provides research services?	Parks and Cons Service	NSW Ag	CCNT	Dept of Lands	APCC	DPIF	DCNR	APB
Who provides extension services?	Parks and Cons service	NSW Ag	CCNT	Dept of Lands	APCC/ APCBs	DPIF	DCNR	APB
Is landholder financially responsible for control?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Who carries out control work?	Parks and Cons Service	Land-holder	CCNT/ land-holder	Land-holder	Land-holder	Land-holder	Land-holder	APB
Who assesses need for rabbit control?	Land-holder	RLPBs	Dept of Lands/ Land-holder	Land-holder	APCBs	Land-holder	DCNR	APB
Who controls supply of 1080 poison?	Parks and Cons Service	RLPBs	CCNT	Dept of Lands	APCBs	DPIF	Dept of Health	APB
Who is responsible for training, extension and field staff?	Parks and Cons Service/ NSW Ag	NSW Ag	APCC	Dept of Lands	APCC	DPIF	Dookie Ag College/ DCNR	APB
Length of formal training (days)	5	5	5	5	10	0	10	20
Training needed to handle poisons (e.g. 1080)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

APB Agriculture Protection Board
APCBs Animal and Plant Control Boards
APCC Animal and Plant Control Commission
CCNT Conservation Commission of the Northern Territory
DCNR Department of Conservation and Natural Resources
DPIF Department of Primary Industry and Fisheries
RLPBs Rural Lands Protection Boards

Table 14: State and territory objectives for rabbit control management.

State/ territory	Relevant legislation	Stated objectives for rabbit control
ACT	Rabbit Destruction Act 1919	Landholders required to destroy rabbits on their land.
NSW	Rural Lands Protection Act 1989	Occupiers of any land are required to fully and continuously suppress and destroy all noxious animals. Government is exempt.
NT	Parks and Wildlife Conservation Act 1980	None — rabbits are not currently proclaimed under this legislation.
QLD	Rural Lands Protection Act 1985 (currently under review)	All landholders are responsible for ensuring that rabbits are destroyed. Import and keeping of rabbits prohibited.
SA	Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986 (currently under review)	All landholders must destroy rabbits and their warrens, burrows, nests or harbours, and reduce the extent to which the land is infested, as far as is reasonably achievable. Import and keeping of live rabbits is prohibited.
TAS	Vermin Destruction Act 1950	Landholders are required to suppress and destroy vermin.
VIC	Catchment and Land Protection Act 1994	All landholders are responsible for taking reasonable and sufficient action to destroy and suppress all vermin and to keep land clear and free of vermin.
WA	Agriculture and Related Resources Protection Act 1976	To prevent the introduction and spread of wild rabbits and to reduce their numbers.

- no data on the relative cost-effectiveness of rabbit management compared with other land management practices; and
- exemption of the Crown from rabbit control on government land, leading to further lack of uniformity in management effort.

The last point is a continual source of friction between private land managers and most state and territory governments. While private land managers are required to control rabbits, they often complain about a lack of action on government-managed lands such as national parks. This inaction undermines the efforts of the pest control authorities to achieve a higher level of control among private land managers, as well as threatening the success of these efforts. Even if state and territory governments were bound to control pest animals, it would be very difficult to force government land managers to carry out appropriate rabbit control, especially if the enforcement authority were the same agency as the land management agency.

Most states and territories aim for a level of rabbit management that achieves long-term protection of resources damaged by rabbits. Research findings are implemented either through field staff employed by the state or territory pest agency or through regional or district organisations (RLPBs and equivalent) that enforce relevant legislation and receive technical and administrative

At the state or territory level, effective rabbit management requires an organisational strategy that includes:

- legislation that aims for achievable goals in terms of long-term suppression of rabbit damage and that also binds government to manage rabbits on Crown Lands;
- regulatory enforcement used as the last resort;
- control practices based on appropriate application of research findings;
- recognition that the aim of management must be to promote ecological sustainability and the maintenance of the resource base in both primary production and conservation of land;
- integration of research, extension and regulatory activities within the one system at state / territory, regional and district levels;
- capacity to coordinate rabbit management across the state or territory;
- adequate training for operational field staff and extension officers; and
- a system to assess rabbit problems and the success of control programs.

support from the state or territory agency. Effective rabbit management requires relevant agencies (both at state/territory and regional levels) to give high priority to managing rabbit damage. Too often rabbit management is buried in a long list of tasks.

Training and extension programs, for both agency advisory and operational staff and land managers, are based on research findings (Sections 6.3 and 6.4). A study in the north-west of Victoria demonstrated that an intensive publicity and extension campaign, aimed at developing awareness and understanding of rabbit damage and control methods, could produce significant changes in landholder attitudes and their willingness to undertake rabbit management (Presser and Russell 1965). There are advantages in involving groups of land managers in small areas in a cooperative approach to rabbit management (Chapter 11). Henzell (1989) estimates that the results of rabbit research implemented in South Australia produced, in 1989, a benefit of $74 million for the sheep, cattle and cereal industries in the agricultural areas of that state at an annual cost of about $1.9 million.

6.3 Extension and technical advice

Effective extension and provision of technical advice have the greatest potential to improve the management of rabbit damage on agricultural and pastoral land in the higher rainfall areas of southern Australia. There are adequate control techniques for most situations — what is lacking is their effective implementation.

Many policy makers are probably unaware of the degree to which landholders lack the knowledge of how to plan and effectively implement rabbit management.

'There are adequate control techniques for most situations — what is lacking is their effective implementation.'

Between 1985 and 1990, I. Nolan (Vernox Pest Management, pers. comm. 1992) investigated complaints from field staff and landholders in Victoria concerning 'unsatisfactory results' from myxomatosis, poisoning (1080) and fumigation operations. The study included field trials to investigate the efficacy of the recommended control techniques. It was clearly demonstrated that the poor results were due to a lack of knowledge, or poor understanding of how to implement rabbit control techniques.

A sociological survey of a rabbit control program conducted in the north-west of Victoria in 1962, documents the value of extension work in changing landholders' attitudes to rabbit control and encouraging them to adopt recommended control techniques (Presser and Russell 1965). It is the only study of its kind and covered a large area (64 750 km^2), had a high intensity of extension effort and stressed adoption of the results of rabbit research studies. All landholders adopted the main rabbit control recommendations within five months. In addition, the campaign induced considerable positive changes in behaviour, opinion, attitudes and aspirations regarding the management of rabbits.

The survey concluded, 'well organised campaigns using all possible means of persuasion (e.g. communication of research results, social, economic and legal obligations) can achieve major changes in attitude, opinions, beliefs and behaviour in a short period of time'.

The central pest control agency or regional body can also assist groups or individual landholders by making available, at reasonable hire costs, specialised rabbit control equipment. Usually smaller landholders cannot justify the capital expense involved in purchasing specialised equipment such as baitlayers, baitcutters and fumigation equipment.

To prevent possible abuse of poisons, provide for accurate and monitored figures on their use, and enable tighter quality control, governments must continue to regulate use of dangerous poisons used in rabbit control operations. For example, state and territory governments have agreed that 1080 poison not be commercially available. It can only be supplied through certified government or semi-government operators.

6.4 Contribution of training

Effective pest management requires appropriately trained extension and practical control staff. Training and extension programs should be seen as a continuum to transfer research findings to those who will use and benefit from them (Table 15). The role of specialist, dedicated rabbit-control officers has long been recognised as crucial to effective management (Ratcliffe 1959). Most states and territories have adopted a two-tiered system.

At one tier are field inspectors who deal directly with land managers concerning both the need for management and their legal obligations. Training of these officers is conducted by the state and territory vertebrate pest control agency or their nominees. The amount of formal training that field staff undertake varies within Australia from 0–20 days. Staff who receive little or no training are largely ineffective. As a matter of urgency, all vertebrate pest control authorities should jointly assess the training needs of field staff and ensure that all staff are suitably trained. The development of a national curriculum in rabbit control, with allowances for local variations, is seen as the most efficient approach.

'The development of a national curriculum in rabbit control, with allowances for local variations, is seen as the most efficient means of meeting training needs.'

At the second tier are extension staff, with expertise in pest animal control, who supervise and train the field inspectors. In the past these officers have been solely devoted to pest control activities and, in the last 10–15 years at least, have generally been tertiary trained in some field of resource management such as agriculture or biology. This background has been supplemented by additional in-service training and experience. The success of extension programs depends on the motivation, professional approach and expertise of all staff, both field and professional, involved in conducting such programs.

Recently, however, many governments have cut back expenditure on resource protection. In South Australia for example, officers of the Animal and Plant Protection Commission now cover pest plant control as well as vertebrate pest control. In Victoria, amalgamation of resource-based departments has resulted in some instances to rabbit control being given a lower priority than it deserves, because decision makers are unaware of its importance.

Table 15: Extension and training needs for successful rabbit control.

Skill	Public	Land managers and land-holders	Resource management advisers	Extension staff	Field staff	Local group organisers
Technical detail, i.e. biology, impact, control	low	mod	mod–high	high	high	mod–high
Ability to interpret and apply research findings to practical situations	low	low	mod	high	mod	low
Motivation to see rabbit control done	high	high	high	high	high	high
Understanding of links between natural resource management and rabbit control	mod	high	high	high	mod–high	mod
Understanding of other issues influencing rabbit control, e.g. animal welfare, Aboriginal land tenure	mod	mod	high	high	mod	mod
Implications of the low use / abuse of 1080	low	low	mod	high	high	mod
Communication and group dynamics skills	low	low	high	high	high	high
Practical control skills	low	high	mod–high	high	high	mod–high

There has been a growing realisation that rabbit control must be integrated with the general principles of land and resource management rather than pursued as an end in itself. Multi-disciplinary extension and field staff must be appropriately trained in rabbit control, which should be given emphasis, but be part of a generic training package on vertebrate pest management that is based on a broad land management approach.

Relevant tertiary education institutions have a role in pest animal training. Until now they have largely ignored rabbits when developing courses on primary production and on natural resource and environmental management issues. Rabbit biology and management should be an integral component of these courses.

Extension officers also need practical experience in rabbit management. Without

Extension/training package for rabbit-control field officers

- Biology of rabbits
  - — taxonomy, history, distribution
  - — reproductive biology including reproductive potential, mortality factors and dispersal
  - — behaviour including the role of dominance, territoriality and warren formation
  - — nutritional requirements
  - — factors affecting rabbit distribution and abundance, and techniques for assessing rabbit distribution and abundance
- Rabbit damage
  - — agriculture, pastoralism, forestry and the natural environments
  - — methods for assessing the economic and environmental impact of rabbits
- Practical aspects of rabbit control
  - — the advantages of integrating control techniques
  - — biological control techniques, including myxomatosis and its vectors, its effectiveness, use in integrated control programs and the potential for improved biological control in the future
  - — mechanical and chemical control methods
  - — practical field experience in rabbit management including assessing damage, planning a management strategy, implementing management techniques, evaluating program success and conducting extension programs and group management schemes
  - — costs and benefits of rabbit management
  - — integration of rabbit management into land management practices
  - — occupational health and safety aspects of control
  - — animal welfare considerations
  - — minimising non-target impact
- Extension and communication aspects
  - — oral and written communication skills
  - — effective use of the media
  - — negotiation skills
  - — understanding of the attitudes of Aboriginals and ethnic minorities to pest animals and their management
  - — elements of effective group dynamics
  - — development and organisation of local or district rabbit management schemes
  - — role of legislation and its enforcement.

it, advice they give has less credibility with both government field staff and land managers. Nolan (1981) concluded from studies of regional pest control staff in Victoria that the most important factor working against effective rabbit management in that state was the lack of desire for effective management among land managers.

This may be due, in part, to a lack of landholder awareness or understanding of the damage rabbits cause, but poor extension work and inadequate technical support skills of extension officers and field inspectors undoubtedly contribute. Wider public understanding of rabbits, of the damage they cause, and of what can and should be done about them is necessary. An interstate education program is recommended (Section 12.7)

Group schemes and demonstration projects help generate and reinforce enthusiasm and show how to run programs. There is a need for an extension and training package for field officers (Parer and Pech 1988; Coman and Arundel 1991). The content and emphasis of different sections of the package would depend on the needs of the potential recipients as outlined in Table 15. The regional differences in rabbit behaviour, and therefore differences in appropriate techniques, would also need to be incorporated within the package.

7. Techniques to Measure and Control Rabbit Impact and Abundance

Summary

Rabbit impact and abundance — *To assess rabbit damage and monitor the management program, both impact and abundance of rabbits must be measured. Quantifying damage is usually difficult and costly. Rabbit abundance can be used as an approximate indicator of rabbit damage, although it is not reliable in all circumstances. There is a pressing need for low-cost techniques for assessing rabbit impact. At present, managers generally rely on estimates of rabbit abundance as an indicator of damage. There are risks in this approach because rabbits, at densities almost undetectable to a casual observer, can prevent regeneration of some native plants. Thus, the perception of low numbers may give a false sense of security.*

The number of rabbit warrens is the best indicator of the capacity for land management units to support rabbits in the long term, that is, the relative proneness of land types to rabbit infestation. The best indicator of the abundance of rabbits is the number of warren and burrow entrances currently being used by rabbits. Recent rabbit-sign such as dung counts, tracks or scratches, is an indicator of rabbit density. Where dense vegetation obscures rabbits, warrens or burrows, assessments of rabbit density can be based on rabbit-sign.

Control techniques — *The most cost-effective methods for long-term rabbit control are methods that combine clearing surface harbour, warren ripping with dogs present, and regular maintenance treatment. Poisoning is negated rapidly by recolonisation. Its application is limited to initial 'knockdown' that must be followed by destruction of rabbit habitat, particularly warren ripping if possible. Repeated maintenance control is essential to prevent resurgence of rabbits. Costs can be expected to decline to a low, slowly-declining plateau after about 4–5 maintenance treatments if these are efficaciously conducted.*

Rabbit control must rely on conventional methods for the foreseeable future. Several lines of current research, such as rabbit calicivirus disease (RCD), immunocontraception borne by genetically-manipulated micro-organisms, and Spanish fleas as vectors of myxomatosis in arid regions will, if successful, create additional control tools in the future. Their implementation would not replace conventional rabbit control but could make it cheaper and more effective.

7.1 Measuring rabbit impact

7.1.1 Introduction

Programs to minimise rabbit damage need to be assessed carefully. Rabbits at very low densities can prevent regeneration of mulga *Acacia aneura* in the arid zone (B. Cooke, Animal and Plant Control Commission, pers. comm. and Section 4.3.2). A general impression of rabbit numbers is too insensitive for judging the effectiveness of a program. Rabbit numbers can vary more than 4 to 5-fold before most landholders notice changes in numbers or in their impact.

In addition, desirable plant species may not regenerate, even where there has been effective rabbit control, until there is an appropriate sequence of favourable weather. This may not occur for a decade or more in the arid zone. Hence lack of regeneration in the short term is not evidence that a control program has failed.

Rabbit density, unlike rabbit impact, can be measured relatively easily, quickly and cheaply, and is the most practical indicator of a potential rabbit problem. Quantification of rabbit impact is usually difficult, costly and laborious, and requires scientific expertise. It is not economically or practically feasible for many land managers. There are a number of ways in which farmers and graziers can recognise serious problems without detailed quantification. For example, (1) crops eaten out 50 metres from warrens; (2) 40 cm grazing lines on shrubs; (3) twigs cut through with chisel-like cuts; (4) weedy pastures; and (5) scratching and soil disturbance. For most practical purposes it is more economical and effective if relative rabbit density or abundance is assessed and assumed to correlate with rabbit impact. Nevertheless, there is also a need for research to better quantify rabbit damage and the relationship between rabbit density and the costs and benefits of control. Research priorities in this area are:

- the costs and benefits of control relative to rabbit density; and
- economic techniques for quantifying rabbit impact.

7.1.2 Measuring crop damage

Rabbits usually damage the edge of crops (Wheeler and Nicholas 1987) but other factors, such as micro-climate, also reduce productivity on crop edges. When assessing damage it may be difficult to separate these edge effects from rabbit impact. Exclosures that exclude rabbits can be used to take these effects into account, but exclosures are impractical for most land managers to set up and use. Micro-climatic effects could be ignored and the periphery of crops harvested by the usual means and the yield compared with that of the crop interior, or measured sections of the periphery and the interior could be harvested by hand, and the yields compared.

Alternatively, yields from sections of the periphery of the crop that are not prone to rabbit damage, could be compared with yields from rabbit-prone sections of the periphery. However, care needs to be taken with yield variations due to site differences as they could be due to other factors which affect yield, such as soil moisture or fertility. Where crop yield records exist for different paddocks for several years, it may be possible to compare yields in paddocks where rabbits have been controlled with yields in untreated areas using the past records as experimental controls. But caution is needed in interpreting results because crop yields vary between years.

These problems make it difficult to obtain reliable measurements of rabbit damage to crops.

7.1.3 Exclosures

Interpreting the impact of different grazers (rabbits, kangaroos and stock), using exclosures is difficult and should remain the province of researchers. Exclosures discriminate on body size and cannot exclude rabbits from areas accessible to stock. Therefore rabbit impact must be determined by difference in damage between exclosures where the different species are allowed to graze alone and in combination. A complication is that rabbits tend to graze selectively where stock are excluded (Grice and Barchia 1992).

Exclosures are useful to determine the effects of total grazing pressure and may be most useful with respect to assessing the extent of regeneration of desired native plant species. They do not, however, measure grazing by insects. Exclosures of all grazing animals excluding insects may become valuable seed sources for species otherwise not regenerating on a property.

7.1.4 Stock returns

Graziers frequently move stock between paddocks, usually making it impossible to compare stock returns between paddocks that have been treated for rabbit infestation with those that have not. Consequently, assessment of rabbit impact based on stock returns usually relies on comparisons before and after rabbit control treatments. These need to be corrected for other variables, such as weather sequences, fertiliser applications and changes in other land management practices. Experimental control areas with no rabbit control would overcome this measurement problem, but these may be too expensive to establish. Furthermore, recolonisation by rabbits from the untreated areas may negate much of the investment in control measures, making this approach impractical. Data over a number of years are required before comparisons can be made on stock returns before and after control is implemented, but these are still subject to variations due to weather and changes in management practices, and interpretation must be judicious.

Measuring rabbit impact

- Programs to minimise rabbit impact need to assess both rabbit density and rabbit impact on the valued resource.
- In most situations, detailed economic assessment of rabbit impact by land managers is impractical, being laborious and costly and requiring specialised expertise.
- Estimation of rabbit density or other indices of damage may substitute for assessment of rabbit impact. Examination of the age (size) structure of tree populations usually provides a ready assessment of impact.
- Research is needed to:
  - — quantify the relationship between rabbit density and rabbit impact, and particularly in the rangeland, the minimum rabbit density at which regeneration can occur;
  - — identify simple and economical indices of rabbit impact for use by land managers; and
  - — quantify the costs and benefits of rabbit control for various cases of rabbit damage.

7.2 Measuring rabbit abundance

7.2.1 Introduction

Rabbit density can either be estimated directly by counting rabbits, or indirectly by counting warrens, active warren entrances or various rabbit-sign.

Measures of density can vary with weather (temperature, wind, rain), time of day (light intensity and activity phase of the rabbits), season (weather, vegetation condition, breeding activity), vegetation type, length of pasture, observer and details of methodology. Therefore the assessment of rabbit density should use the most robust and standardised technique. The selected technique should be used for the full period of the assessments otherwise comparisons of rabbit densities before and after control treatments and during the control program will be invalid.

Rapid visual assessments are useful where more elaborate methods are not justified or feasible. A very practical system used by the Tamworth Rural Lands Protection Board (E. Dekkers, RLPB, NSW, pers. comm. 1994) combines rapid visual assessment of the potential of an area or property to sustain an increase in rabbit numbers quickly (based on the abundance of warrens, active and inactive burrows, surface harbour and the proximity of heavy infestations), and the actual number of rabbits present at the time of inspection. Both factors may be scaled into four categories. Rabbit abundance is graded as: '0' = no signs of rabbits; '1' = very few rabbits; '2' = a medium number of rabbits; and '3' a heavy infestation. Their potential for increase is graded as: 'A' = no potential; 'B' = a slight potential; 'C' = medium potential; and 'D' = high potential. Although the assessments of abundance are highly subjective and therefore variable, this system evolved through practice and is highly effective.

This system originated from experience with landholders and is designed to suit their needs and that of the RLPB. Such a classification is easily understood and can be included in computer management systems to provide an overall assessment very quickly. The aim is to reach an 'A0' grading if this is feasible and cost-effective. A '3D' grading indicates a heavy infestation with a high potential for increase, requiring rapid action. This system could be very useful in developing a regional approach to rabbit management (Chapter 9).

7.2.2 Vehicle spotlight transect counts

In this technique, rabbits are counted at night from a slow, constant-speed vehicle over a fixed route with the aid of a hand-held spotlight. Rabbits are counted if they are seen within a fixed distance, say 100 metres, either side of the transect path. Vehicle transects require one person driving while another operates the spotlight and counts the rabbits. At least two and preferably three counts on near consecutive evenings are needed to obtain a reliable estimate. The transects should be scheduled soon after nightfall to coincide with the daily period of most apparent rabbit activity, which varies seasonally. Preliminary observations on several evenings before the counting nights of each season will enable the most suitable starting time for different seasons to be established. In addition to having a standardised technique for determining rabbit density, spotlight counts should also be standardised, taking into account route, distance, rate of travel, spotlight power, distance included either side of travel path, type of vehicle used, observer and height of the observer in the vehicle (standing or sitting).

7.2.3 Walk transect counts

Walk counts can be made either at night using a hand-held spotlight or earlier in the afternoon or evening during daylight. Counts are made over standardised distances, walking along the same route at the same time each day, for example, one hour before or after sunset. These counts also need to be repeated on two and preferably three near-consecutive days to obtain a reliable average.

7.2.4 Counts of rabbits on or near warrens

Counts of rabbits in open places can be made over standardised areas or on particular warrens when rabbits emerge from warrens or cover in late afternoons. These counts need to be repeated on two and preferably three near consecutive days to obtain reliable indices of rabbit density.

Vehicle spotlight transect counts

Advantages	Disadvantages
• Rapid and simple • Large distances can be sampled • Many habitat types can be sampled quickly and under similar conditions • Suitable for large properties	• Highly variable with weather conditions and lag effects of recent weather • Wet and windy weather conditions are unfavourable • Highly variable with vegetation type and height of pasture • Data not comparable between routes that differ in degree of hilliness, amount of human disturbance, vegetative cover • Data not comparable among seasons • Start time for counts needs to be adjusted for seasonal variation in rabbit patterns of emergence and activity

Walk transect counts	
Advantages	**Disadvantages**
• Rapid and simple • May be performed by one person • Suitable for small properties • Helps identify rabbit feeding grounds for poisoning	• Highly variable with weather conditions and lag effects of recent weather • Wet and windy weather conditions are unfavourable • Highly variable with vegetation type and height of pasture • Data not comparable between routes that differ in amount of human disturbance and vegetative cover • Data not comparable among seasons • Start time for counts needs to be adjusted for seasonal variation in rabbit patterns of emergence and activity

Counts of rabbits on or near warrens	
Advantages	**Disadvantages**
• Useful where terrain or vegetation excludes transect counts • May be useful on small properties or for small areas of infestation	• Time consuming if only small areas can be observed from vantage points

7.2.5 Counts of warrens

Rabbit density can be assessed indirectly using transect counts of warrens coupled with estimates of warren density in plots of known size for each land type, to estimate warren density per unit area. The process is as follows (Low 1983):

- The land is divided into distinguishable land types based on soil, land-use or other appropriate maps.
- Several parallel, straight-line transects are run across the property to cut across the land types but to avoid, where practicable, roads and running along the edges of land types. (The number of transects and distance between them will depend on the property size and variation in land type).
- The number of active and inactive warrens in a strip, for example 10 metres either side of the transect, is recorded for the distance the transect cuts each land type. During drought in sand dune country, warrens may be difficult to detect even though subsurface warren structure remains intact.
- The density of warrens per unit area for each land type is calculated from (1) the length of the transect in each land type; (2) the width of the transect, for example 20 metres; and (3) the number of warrens counted.
- The average density for all transects for each land type is used to calculate the number of rabbit warrens for each land type by multiplying the average by the total area of each land type.

Counts of warrens	
Advantages	**Disadvantages**
• Robust measure • Reflects long-term rabbit-proneness and infestation of different land types (Burley 1991) • Can accurately estimate cost and effort to destroy warrens by ripping • Can estimate total rabbit abundance per land type	• May require specialist advice on implementation of assessment and subsequent calculations • Affected by dense vegetation, but not if all warrens are in the total search of the marked areas • During drought, in sand-dune country, warrens may be difficult to detect even though subsurface warren structure remains intact

The accuracy of this method can be increased by randomly selecting blocks (e.g. 500 m x 100 m) along the transect for each land type. The number of warrens in each block is then counted. The average for all blocks for that land type gives the average warren density which can then be used to correct the value obtained by the strip transect.

Warren density can be converted to an estimate of rabbit density by counting the number of actively-used entrances in a sample of warrens in each plot (Section 7.2.6). For the non-breeding period, 1.6 active warren entrances equals one adult rabbit.

Estimates and standard errors of (a) the density of warrens, and (b) the numbers of warrens, within land systems on a property can be calculated by the following method (G. Caughley, CSIRO Wildlife and Ecology, pers. comm.) where, for a land system:

n = number of transects in the land system

y = number of warrens in a transect

a = area of the transect (transect length x width)

A = total area of the land system

D = density of warrens in the land system

Y = total number of warrens in the total area of the land system (A)

Density of warrens

Estimate $(D) = \Sigma y \div \Sigma a$ (1)

standard error of estimate $(S.E._{(D)}) =$

$$n \div \Sigma a \sqrt{[(y^2 + D^2\Sigma a^2 - 2D\Sigma ay) \div n(n-1)]} \times \sqrt{[1 - (\Sigma a) \div A]} \quad (2)$$

Number of warrens

Estimate $(Y) = A \times D$ (3)

$(S.E._{(Y)}) = A(S.E._{(D)})$ (4)

Accuracy is reasonable if the standard error is 10–15% of the mean.

To combine estimates for several land systems:

The total number of warrens across land systems = ΣY (5)

$$S.E._{(\Sigma Y)} = \sqrt{[\Sigma(S.E._{(Y)})^2]} \quad (6)$$

7.2.6 Counts of active entrances

Active entrances are identified by close observation for sign of recent passage by rabbits, indicated by the presence, absence or disposition of sign. Negative sign may include rainwashed soil, wind-blown soil, layers of old faeces, vegetation debris and spider webs. Positive sign may include soil disturbance, impressions of feet and claws in

Counts of active entrances	
Advantages	**Disadvantages**
• Rapid • Reliable for individual observers • Can be used to estimate total abundance of rabbits	• Cannot be used for about four days after significant rain • Requires experience before results are comparable between observers

Dung counts	
Advantages	**Disadvantages**
• Not affected by wind and temperature • Can be used in difficult terrain such as scrub • Sampling schedule can be flexible and done during the day	• Rain washes dispersed dung into dung banks; method cannot be used for some time after significant rain • Rate of production of dung affected by quality of diet and season • Not an accurate measure

the soil, fresh urine or faeces and rabbit hairs. The method is rapid and reliable and requires little experience. A regression analysis of the number of active entrances in relation to afternoon counts of rabbits observed emerging from warrens and from digging out warrens revealed that the regressions differed for non-breeding and breeding seasons (Parer 1982a; Parer and Wood 1986). The appropriate regression equation can be used to convert the number of active entrances to the number of rabbits. Alternatively, comparisons can be made only within breeding and non-breeding seasons or within the same season among years. A useful conversion factor for the non-breeding period is 1.6 active warren entrances equals one adult rabbit.

7.2.7 Dung counts

Dung heaps can be counted over standardised distances by walking, on motorbike or horseback, or they can be counted by searching a standardised area. Dispersed dung can be counted in many small quadrats by either method. Both require random sampling design stratified for vegetation type, including recently burnt or unburnt areas if applicable (Wood 1988).

Dung found in each random quadrat can be used as an index of recent rabbit density. Alternatively fixed quadrats can be cleared of all dung and its accumulation over a fixed time used as an index of current rabbit density. Wood (1988) used the latter method to obtain a regression equation of dung counts on numbers of rabbits counted within enclosures.

7.2.8 Other sign of rabbits

Other rabbit-sign can also be quantified to assess rabbit distribution and abundance. Counts may be made of:

- rabbit tracks crossing standardised distances of sandy or dusty vehicle tracks that have been driven over the previous afternoon. This method can be used to assess rabbit activity in areas of scrub that are dissected by suitable tracks; and
- the numbers of rabbit scratches counted over standardised walk transects in pasture.

'The best indices of rabbit distribution and abundance rely on counts of semi-permanent features such as warrens and entrances.'

Other sign of rabbits	
Advantages	**Disadvantages**
• Sampling schedule can be flexible and done during the day • Can be used in difficult terrain such as scrub	• Sign may be obliterated by humans, wind or rain • Sign may vary seasonally • May be unsuitable in some terrain • Not accurate

Measuring rabbit abundance

The best indices of rabbit distribution and abundance rely on counts of semi-permanent features such as warrens and active and inactive entrances. These measures can be used to assess current and potential abundance of rabbits for different land types, and likely costs and effort needed for rabbit control programs. Indices based on short-lived features such as counts of rabbits and various forms of sign require standardisation. They vary by time and season and reflect rabbit activity only at the time of assessment. They do not indicate how prone the land type is to rabbit infestation. While measures of more permanent rabbit features are recommended in most of Australia, features such as rabbit counts and short-lived rabbit-sign may be the best ones available for areas such as south-western Australia and much of Tasmania where rabbits do not construct extensive warrens.

7.3 Use of rabbit impact, distribution and density measurements

7.3.1 Introduction

Management of rabbit impact will be effective and economical if plans for the management program are based on analyses of measures of rabbit impact, distribution and density. Collating information in tables or on maps, either for whole properties or composite properties for cooperative or group rabbit management programs, has two benefits: (1) it highlights patterns of distribution of damage which can reveal underlying causes, best remedies and the most economical approach to applying management programs; and (2) trends in rabbit damage over time are revealed, and help to assess the effectiveness of remedial action. Detection of time trends requires a monitoring system that is continuous through the management program (Section 12.5).

A major deficiency in current rabbit management is the unavailability of a simple, readily applied system for measuring rabbit density and abundance and for recording it in a suitable pest management information system (PMIS). The elements of a suitable PMIS were identified recently by state and territory pest management authorities (Fordham 1991). It is important that the system caters for the needs of on-site land managers, and the needs of local, state, territory and Commonwealth governments. The system adopted by the Tamworth RLPB is an example of a simple system which seems to work well at the local level (E. Dekkers, RLPB, NSW, pers. comm. and Section 7.2.1).

'A major deficiency in current rabbit management is the unavailability of a simple, readily applied system for measuring rabbit density and abundance and for recording it in a suitable pest management information system.'

Eventually such a PMIS could be linked to geographical information systems (GISs) which would greatly assist land managers and authorities to assess progress on

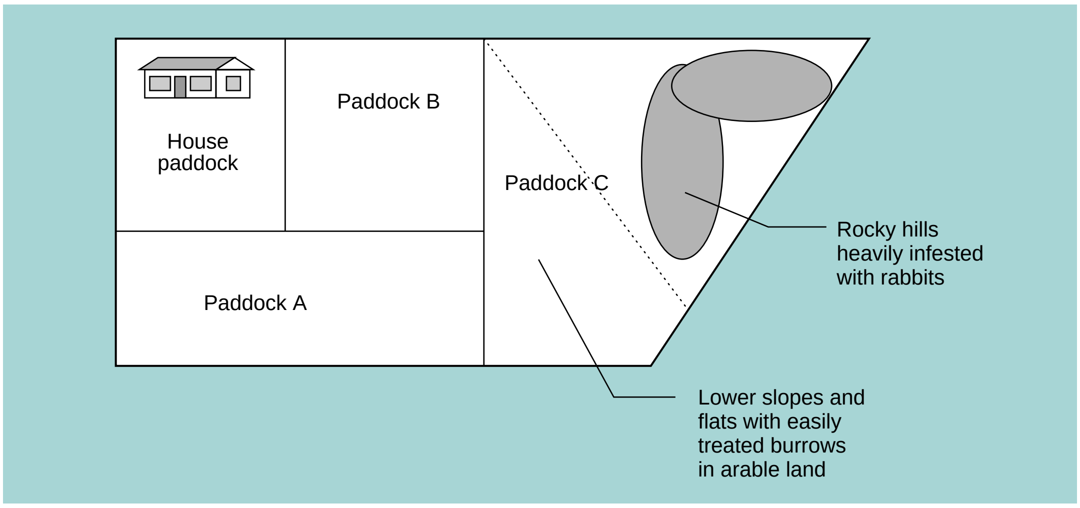

Figure 24: A hypothetical example of a simple map a farmer could use to assist planning rabbit management.

The map exemplifies the situation on many farms. Paddock C is the 'back paddock' with an area of rough hill country inaccessible to vehicles and harbouring high numbers of rabbits. The rest of paddock C, however, is flat or gently sloping and rabbit control is a much simpler operation here. The position of the existing fence line is clearly not conducive to good rabbit management because, for instance, treating the hill country via baiting means that all stock must be removed from the whole paddock. A new fence line as indicated by the dotted line will allow the hill country to be treated separately. It will also improve general stock management. These sorts of improvements are often not really appreciated until some attempt is made to sit down and map the farm, paying particular attention to existing rabbit harbour, paddock sizes and locations of existing rabbit-proof fences.

controlling rabbit impact and appropriately allocating resources.

Detection of patterns and trends in measured rabbit damage or rabbit distribution and density requires that the steps outlined below be taken.

7.3.2 Recording assessments

Photographic records should be catalogued. After damage or density is measured it should be tabulated. This form of data presentation is most convenient for checking that all required observations are included and for transferring data to various other forms such as graphs, maps or computerised databases. State and territory land management agencies could prepare and distribute ready-made tables, charts and graphs that guide landholders in keeping records in a format that can help clarify trends in impact and rabbit abundance over the course of a control program. Advice on how to interpret the data would also help landholders.

7.3.3 Mapping

Maps are valuable for showing correlations between environmental variables and the distribution of damage and rabbit abundance. They can be integrated readily with whole-farm planning, which requires the collection, recording and examination of a range of other factors in addition to pest animals. Maps can be of various types: (1) simple hand-drawn charts; (2) topographic maps; (3) land system or land unit maps; (4) aerial photographs; or (5) interactive computerised GISs; the choice depending on: (1) availability; (2) cost; (3) scale of the property; and (4) the extent of the problem.

'Maps are valuable for showing correlations between environmental variables and the distribution of damage and rabbit abundance.'

A series of maps showing rabbit distribution and abundance over time may indicate changes associated with land and rabbit management practices and provide the basis for evaluating a control program and modifying it where needed. Maps show the extent of problems and may help indicate the best solutions.

'A series of maps showing rabbit distribution and abundance over time may indicate changes associated with land and rabbit management practices and provide the basis for evaluating a control program and modifying it where needed.'

Maps should include the boundaries, fences and roads of a property and main topographic features such as creeks, swamps, gullies, hill contours and rock outcrops, windbreaks, shelter belts and roadside vegetation (Figure 24). Mapping soil types may reveal influences of soil on rabbit impact and rabbit control operations. Soil type affects: (1) the extent to which rabbits dig warrens; (2) size and depth of warrens; (3) nature of natural vegetation and prevalence of weeds; (4) vehicle access; and (5) whether ripping and digging are possible. Rabbit-proof fences should be mapped with indications of breaches.

Rabbit impact, distribution and abundance should be mapped at scales relevant to the size of the control operation, extending to adjacent land where there are no effective rabbit-proof fences. Individual warrens and burrows could be mapped in small operations, or in larger ones it may be practicable to map warrens according to scales of rabbit density, such as none, sparse, medium and dense. Maps should also include: (1) crops and plantations; (2) fertiliser applications; (3) tillage; (4) areas of damage; and (5) assessed degree of damage to the crop, pasture and soils.

An effective means of assessing and comparing overall information, whether it is hand-drawn or printed GIS data, is to plot each type of information on separate transparent overlay sheets, and place them over a topographic map, aerial photograph or satellite photomap. Patterns will become evident, perhaps correlating rabbit density and distribution with (1) soil type; (2) slope; (3) vegetation patches; or (4) with property boundaries in group operations. Again, correlations should be sought to determine relationships between rabbit abundance and rabbit damage.

Computerised GISs are ideal for determining correlations in the complex systems that often occur in group rabbit management schemes. Such correlations may show, for example, that rabbits cause more damage in certain situations, and indicate priority areas for control. Conversely, where perceived rabbit damage does not coincide with rabbit distribution, there is a need to look for other causes such as grasshoppers, hares or wallabies. Where rabbit impact correlates well with indices of rabbit abundance, rabbit impact or rabbit-sign may be used to monitor the progress of the control operations.

7.3.4 Allocating management units

The information in maps can be used to identify practical management units. Boundaries of the management units will usually be natural or artificial barriers that cause breaks in rabbit distributions that may be correlated with soil type or some topographical variable, or the location of a sensitive area such as a crop. The boundaries of the management units should be placed where rabbits are least likely to recolonise neighbouring units after control treatment. Division of the system into management units allows managers to set individual objectives for different problem areas and assign priorities for treatment so that recolonisation is minimised. The maps may indicate where stock or rabbit-proof fences need to be erected to divide the property into more effective management units or units of more manageable size.

7.3.5 Allocating priority to management units

Priority for treatment of management units will depend on the following factors which need to be judged by the land manager:

- type and value of resources affected by rabbits;
- severity of the impact of rabbits, usually correlated with rabbit density;
- feasibility of reducing or curtailing rabbit impact in time to save the resource;
- sizes of the management units, techniques to be used and time available to complete the treatment;
- the necessity to move stock and the availability of alternative suitable paddocks; and
- availability of funds, time, labour and equipment.

Further considerations are:

- The density of rabbit populations. Generally low density areas should receive higher priority, although this must be judged against saving a high-value resource.
- Contraction of rabbit distribution to survival areas. The treatment of these areas should be given very high priority.
- The presence of barriers to recolonisation, such as a rabbit-proof fence adjacent to areas of low rabbit density, or areas recently treated for rabbits. These areas should receive high priority for control.
- The proximity of the management unit to a neighbouring property. The density of rabbits and the attitude of managers of neighbouring land will affect priority.

7.4 Rabbit control techniques

7.4.1 Introduction

The aim of rabbit control should be to minimise rabbit damage, not simply to reduce rabbit density. Managers should first consider varying land management procedures to reduce rabbit impact. Examples are locating sensitive crops away from rabbit areas or changing burning practices to make land less suitable for rabbits. Then application of suitable techniques should be considered. Chapter 10 and Appendices B and C describes four examples of rabbit management programs. In this section we describe and assess direct methods for reducing rabbit numbers. Details of the techniques are presented in Appendix A.

Rabbit management programs aim to affect three main aspects of rabbit biology:

- reducing survival by a range of methods including poisoning and gassing, warren ripping, habitat manipulation to reduce shelter from weather and predators, and introducing parasites, disease and disease vectors;
- reducing breeding by destroying warrens, making habitat less favourable,

Stock fencing	
Advantages	**Disadvantages**
• Better management of pastures • Better management of stock • Facilitates poisoning operations • Near permanent, functional and a capital asset	• Initial cost • May require additional water points for stock

and by introducing parasites, diseases and disease vectors; and

- deterring dispersal of rabbits into treated areas by destroying warrens, controlling rabbits in refuge areas, and erecting and maintaining rabbit-proof fences.

7.4.2 Integrated rabbit control

Integration of several rabbit control techniques improves effectiveness (Cooke 1981a; Williams and Moore, in press). Control techniques should also be integrated where practicable with the following: (1) other aspects of land management; (2) seasonal cycles of weather, vegetation, pasture and soil; (3) seasonal cycles of rabbit biology; (4) dry periods or droughts; and (5) myxomatosis outbreaks.

7.4.3 Timing and priority of control

Treating rabbit populations when density is low greatly improves effectiveness, economy and humaneness of control. Fewer rabbits suffer and there are fewer rabbits to breed on-site when conditions permit, less recolonisation, and hence reduced costs for current and subsequent treatments. Rabbit numbers decline seasonally, being low in autumn after outbreaks of myxomatosis, and after dry periods or droughts. These events can cause different aggregations of the remaining rabbits and these may require different control action. Hot, dry summers and myxomatosis lower rabbit density, while during drought in arid and semi-arid regions rabbits survive mainly in moister refuge areas (Myers and Parker 1975b; Wood 1980).

'Treating rabbit populations when density is low greatly improves the effectiveness, economy and humaneness of control.'

Controlling rabbits in drought refuge areas should be given high priority. Between droughts, high priority may be given to protecting vulnerable plant associations such as regenerating trees, crops, or endangered plant species or native wildlife habitat. The relative contributions to population resurgence of rabbits in survival–refuge areas and of individuals dispersed widely at very low density are not known. If survival areas contribute most to rabbit population resurgence, where practicable warrens in these areas should be treated first, although all warrens need to be treated eventually to prevent future recolonisation.

The optimum season for control varies with climatic region. For example, poisoning is generally most effective when rabbits are not breeding and are least territorial, and when the quality and quantity of available forage is low. Under these conditions more rabbits are likely to find and eat poisoned baits. These events usually coincide with late summer in the mediterranean, semi-arid and arid regions, but in the subalpine and alpine regions they tend to occur in winter.

7.4.4 Stock fencing

Effective control of rabbits is sometimes difficult in extensive rabbit-infested areas because of the nature of the terrain or vegetation. Repeated poisoning across such areas is inadvisable because of the risks of selection for poison aversion and bait shyness (Section 7.4.8).

Stock fencing can be used to assist rabbit control. A farm plan could include internal subdivision by stock fencing to separate country where rabbits are difficult to control, say stony hills, from country where rabbits are easier to control, such as gentle slopes and creek flats.

7.4.5 Rabbit-proof fencing

'Rabbit-exclusion fencing is not an option in many circumstances due to the high cost.'

Rabbit-proof fencing, including rabbit-proof gates, deters immigration, and is particularly useful where control methods are to be

Rabbit-proof fencing	
Advantages	**Disadvantages**
• Enables effective rabbit control irrespective of lack of control on adjacent land • Enables sequential control operations on large management units • Eradication may be possible within enclosures • High-value, functional and capital asset • Better management of pastures • Functions also as a stock fence • Facilitates poisoning operations	• High cost • Requires high maintenance • May require additional water points for stock

applied only on one side of the fence, or for sequential control operations over large areas. The entire length, including gates, must always be maintained in good repair. Falling trees or limbs occasionally breach rabbit-proof fences, as do stock, feral animals and wombats. Rabbits may dig under fences that are not constructed properly or are constructed over light soils. Fence patrols may be required every 1–2 weeks. In addition, some rabbits may climb over a rabbit-proof fence. If rabbit-proof fencing is installed, return on the investment requires regular patrol and maintenance and both intensive and maintenance rabbit control in the fenced-off area. Fencing can be used on perimeters of properties, or it may be used internally to protect high-value assets such as tree plantations, or to contain rabbits in areas where control is difficult. Internal fences may enable a sequential control program through a property with minimum recolonisation of paddocks already treated. Rabbit-exclusion fencing is not an option in many circumstances due to the high cost, currently $1.70 per metre.

7.4.6 Pasture management

Pasture may be modified to reduce its rabbit carrying capacity. When poisoning reduced rabbit density and grazing in high rainfall areas in New Zealand, the grass formed a dense sward which prevented rabbits from returning to high densities (Howard 1958). Thereafter rabbits could be controlled by regulating sheep grazing to ensure the sward was not grazed too short. Rabbits graze wheat fertilised with superphosphate less than unfertilised wheat (Spence and Smith 1965). Similar effects might occur in sown grazing pastures, although this has not been investigated.

In national parks, grazing by kangaroos may promote high rabbit densities by creating ideal grazing for rabbits. Fires function in a similar way by producing a short pasture of a high nutritional content (Leigh et al. 1987, 1991). In Kosciusko National Park, the reproductive rate of rabbits progressively declined after the cessation of grazing by domestic stock (Dunsmore 1974). Grazing intensity, and hence the suitability of pasture for rabbits, may be reduced by reducing stocking rates,

Pasture management	
Advantages	**Disadvantages**
• Better management of pastures and soils • Low cost	• Unsuitable for rangelands

Clearing surface harbour	
Advantages	**Disadvantages**
• Increases efficiency of control programs • Retards recolonisation	• May reduce habitat for native animal species

or by culling or excluding feral herbivores. Pasture management for rabbit control will not work in lower rainfall areas because dense swards do not form. Instead, grass may form tall dispersed clumps which could provide excellent cover for burrows and warrens.

Clearing surface harbour

Surface harbour, such as scrub, briars, hollow logs and rock piles, allows many rabbits to remain above ground most of the time. Under these conditions rabbit densities can increase and rabbits can survive warren ripping or fumigation. Rabbits survive in the surface refuge and recolonise treated areas by re-opening warrens or digging new ones. Preliminary clearing of surface harbour by burning fallen timber, removing bracken (*Pteridium esculentum*) and blackberries (*Rubus fruticosus*) and blocking crevices in rocks, greatly enhances the efficiency and effectiveness of control programs and slows recolonisation.

However, clearing surface harbour such as native vegetation, logs and rock piles also removes shelter for native animals, thereby possibly reducing biodiversity locally. In conservation areas, an alternative to clearing surface harbour prior to ripping warrens may be to use trained dog packs to flush surface rabbits and drive them underground. The dogs may also find rabbits sheltering in hollow logs and crevices, although care must be taken where there are populations of native mammals and reptiles. A decision on whether to use dogs may be made locally according to the native animals present and other circumstances.

7.4.7 Poisoning

Poisoning is a commonly used rabbit management technique, but it is also commonly misused, with serious but hidden consequences. Its primary use should be to knockdown dense rabbit populations prior to warren ripping or fumigation. It is also an important management tool where rabbits are mainly surface dwelling, a common situation in several parts of Australia (Section 3.3.2). Appendix A describes poisoning techniques.

The effects of tactical poisoning on rabbit populations are short-lived (Rowley 1968; Martin and Atkinson 1978; Foran et al. 1985; Williams and Moore, in press). Resources per rabbit are increased leading to increased survival and breeding, and the warren, the rabbit's main form of shelter, remains intact and available for recolonisation. Other deficiencies of poisoning include: (1) potential kills of non-target animals; (2) animal welfare concerns; and (3) selection for bait shyness and poison aversion. Once a rabbit population becomes selected substantially for bait shyness and poison aversion, poisoning is useless.

Poisons (1080 and pindone)

Both sodium monofluoroacetate (compound 1080) and pindone are used for rabbit control, although 1080 is used most. 1080 is an acute metabolic poison without antidote. Dogs and foxes are extremely susceptible to it, rabbits, sheep and cattle and people are moderately susceptible, while birds are relatively tolerant. Where fluoroacetate occurs naturally in native vegetation, such as in south-western Western Australia, some native animal species have a high tolerance to 1080, reducing the danger of non-target poisoning (King et al. 1981).

Pindone is a chronic anticoagulant poison which requires several consecutive doses. Phytomenadione (Vitamin K) is an effective antidote. Dogs, sheep, cattle and people are fairly tolerant to pindone, birds are moderately susceptible, and rabbits are highly susceptible. 1080 is cheap and is used where there is little risk of poisoning dogs, sheep or cattle. Pindone is relatively expensive and is used in areas close to human settlement where there is significant risk of poisoning dogs or people. Pindone is less soluble in water than 1080 and is often supplied preprepared in oats or cereal pellets.

New Zealand studies have shown that 1080 is readily degraded by bacteria and fungi to non-toxic compounds (Eason 1992). Unlike second generation anti-coagulants, such as brodifacoum, 1080 is rapidly eliminated from animals that consume a non-lethal dose, presenting a negligible risk to people who consume meat from stock from areas treated with 1080 poisoned baits (Eason 1992).

The selectivity of poisoning is enhanced by: (1) prebaiting with unpoisoned bait and ensuring that only rabbits are taking the bait; (2) using baits that are most attractive to rabbits; (3) using the minimal concentration of poison sufficient to kill rabbits; (4) placing the bait in the prime feeding areas of rabbits; and (5) collecting carcasses of poisoned rabbits to minimise secondary poisoning.

Second generation anticoagulants and cholecalciferol

Second generation anticoagulants, such as bromodialone and brodifacoum, are both acute and cumulative poisons which can kill after one dose. If their price declines they may have a future role in the tarbaby technique (discussed later in this Section) (Myers 1976).

Table 16: Ideal properties of rabbit poison and properties of commonly-used rabbit poisons and cholecalciferol.

Desirable properties	1080	Pindone	Cholecalciferol
Causes painless death	?	No Eason 1993)	Probably (Marshall 1984;
High toxicity to rabbits	Yes	Yes	Yes (Eason 1993)
Low toxicity to: mammals	No[a]	Yes	Probably (Marshall 1984)
: birds	Yes	Yes	Probably (Marshall 1984)
Odourless and tasteless	Yes?	Yes	Probably
Slow-acting No	Yes	Yes (Eason 1993; Marshall 1984)	
Re-accepted readily	Yes	Yes	Yes (Marshall 1984)
Has an effective antidote	No	Yes	?
In baits has a long shelf-life	Yes	Yes	?
Does not require prebaiting	No	Yes[b]	Yes
In baits resists rain and dew	No	Yes	Probably
Does not persist in livestock	Yes	No	?
Cumulative No	Yes	?	
Degrades rapidly in dead rabbits	No	No	Yes (Marshall 1984)
Degrades rapidly in field	Yes	No	?
Low cost Yes	No	No (Eason 1993)	

a Depends on the species.
b See Appendix A4 for recommendations of the various states.

Advantages and disadvantages of tarbaby using second generation anticoagulants	
Advantages	**Disadvantages**
• Does not rely on voluntary taking of baits • Avoids bait shyness and aversion to poison in problem areas such as rocky hills where sometimes poisoning is used repeatedly • Well suited to rocky hills	• More labour intensive than conventional trail poisoning • All active entrances must be found and treated • Not suitable for large areas

Advantages and disadvantages of anticoagulant poisons compared with 1080	
Advantages	**Disadvantages**
• No neophobia or bait avoidance after a sub-lethal dose • Most rabbits die in burrows, reducing the chances of rabbit predators being poisoned • Lower risk to dogs • An antidote is available • Not soluble and can be used during wet weather	• High cost • Residues of second generation anticoagulants such as bromadialone are detectable in the livers of livestock for a long period of time (Laas et al. 1985), whereas pindone is lost quickly. • Known toxicity to some potential non-target fauna • Prebaiting is desirable, often essential for 1080

The low use of anticoagulants for rabbit control is due to the effectiveness and cheapness of 1080. Second generation anticoagulants kill slowly, taking up to five days after a single feed. Prebaiting, however, is desirable to estimate the amount of poisoned bait required to attract and poison all rabbits. Second generation anticoagulants have some advantages and disadvantages compared to 1080 (Bell et al. 1983; Williams et al. 1986).

Cholecalciferol is not used for rabbit control. Recent research demonstrates that the wild rabbit is more sensitive to it than any other species tested (Eason 1993). Therefore it has potential as a safe and effective poison for rabbit control. Because cholecalciferol uses different biochemical pathways to the anticoagulants (Marshall 1984) and 1080 (Mead et al. 1979), it would be useful as an alternative poison in situations where methods of rabbit control other than poisoning are difficult or impractical, such as in rocky hills. The alternate use of three types of poison would assist in preventing development of poison aversion and poison tolerance, although not bait shyness. Cholecalciferol apparently possesses other qualities suitable for rabbit control. The suite of known qualities compares favourably with those of 1080 and pindone (Table 16), except for cost. Further research is needed on the suitability of cholecalciferol for rabbit control and, in view of its higher cost, its potential for use as an alternate poison with 1080 and anticoagulants.

At present, the disadvantages of anticoagulants outweigh the advantages but there may be a role for second generation anticoagulants in the tarbaby technique. In this technique, poison is mixed into grease and placed down burrow entrances. Rabbits eat the poison when grooming the grease from their paws and fur. Combining second generation anticoagulant with tarbaby overcomes the main objection to tarbaby, the high concentration of 1080 in the grease carrier. The technique could have a useful but very specific role as a follow-up technique to destroy rabbits in rocky areas. The effectiveness of this technique requires further assessment.

7.4.8 Baits

Tradition and convenience usually determine choice of bait. There is little evidence that carrots are better than the more convenient and cheaper cereal pellets or oat grain. Carrots must be chopped prior to use, preferably to a standard size. Rabbits may receive a sub-lethal dose of poison if they eat small bait particles, and the efficiency of poisoning is therefore reduced. Carrot baits need to be used immediately, otherwise they deteriorate, for example, when rain interrupts prebaiting and poisoning.

'When used in conjunction with ripping or fumigation and follow-on control, poisoning can be a cheap and effective component of integrated rabbit management.'

Oats and cereal pellet baits do not have these difficulties, although poison may leach more rapidly from oats than from other baits. This can either be an advantage or a disadvantage depending on the circumstances. Carrot bait may be more attractive to rabbits in very dry weather, but may be less attractive than oats or pellets when rabbits have adequate moisture but low available energy in the diet. Baits of all types will be more acceptable if they are in good condition. Little is known of the many factors that impinge on bait acceptability under the complex conditions in the field. The choice of bait should be based on factors such as local conditions, past experience, convenience and availability.

Method of application

Research on rabbit behaviour (Rowley 1963) demonstrated clearly that the rabbit is not attracted to a bait if the rabbit does not encounter it in its normal daily pattern of movement. Therefore the bait should be laid in the main areas of rabbit activity (Appendix A, A1.3).

Poison baits can be delivered from aircraft or from baitlayers towed by vehicles including four-wheeled motorcycles. Aerial bait laying is useful for broad-scale application but is less accurate. It should not be used where non-target animals occupy habitat close to the proposed treatment area.

Vehicle-drawn baitlayers can broadcast the bait in a swathe or lay it in a shallow ploughed furrow. The ploughed furrow may not improve poisoning efficiency (Wheeler 1991) but it provides a clear path for accurately positioning subsequent prefeeds and poisoned bait, and may facilitate burying residual baits. On the other hand, the furrow may channel rain runoff and accelerate erosion on slopes. Bait can be laid manually in small areas. The choice of method depends primarily on the scale of the operation, the terrain, and the cost and availability of equipment.

Free-feeding, conventional poisoning and one-shot oats

Conventional poisoning methods rely on applying unpoisoned bait in two or more applications over about 7–10 days prior to laying poisoned bait. About eight days are needed for most of the rabbits to feed on a bait trail. The one-shot oats technique requires no prebaiting, relying on rabbits becoming accustomed to eating the oat bait while consuming the unpoisoned grains, before encountering the 'one in a hundred' oat grain containing more than sufficient 1080 poison to kill it. Claims that the one-shot oat technique kills lower proportions of rabbits than conventional 1080 poisoning are confounded by different test locations and conditions, and by bait shyness in Western Australia (Oliver et al. 1982), the only state in which the one-shot oat technique is used.

The two techniques were equally effective when tested under similar conditions in South Australia during summer/autumn, but not during the winter/spring breeding season (Cooke 1968).

One-shot oats also proved less effective than conventional poisoning during the rabbit breeding season in other trials (Gooding 1968b). Where rabbits are not bait shy, the one-shot oat technique may achieve kills as high as those achieved in eastern Australia by conventional 1080 poisoning. If further research proves this to be the case, poisoning could become cheaper and more conveniently applied. One-shot oats poisoning was used for three years in South Australia. Its use was discontinued because of severe non-target losses (B. Cooke, Animal and Plant Control Commission, pers. comm). The two systems rely on different principles of habituation and poisoning. Free-feeding before poisoning is an essential and integral part of the conventional method. One-shot oats requires less time, effort and cost in application. They are usually applied only by qualified personnel because of the high levels of 1080 in the poisoned grains, although mixed one-shot oats are now available to farmers in Western Australia.

'A decline in percentage kill from 95% to 85% will preclude effective management because of the rabbit's high reproductive potential.'

Cost of poisoning

Poisoning, if used alone, is an expensive method of controlling rabbits because the treated areas are rapidly recolonised. When used in conjunction with ripping or fumigation and follow-on control however, poisoning can be a cheap and effective component of integrated rabbit management. The total cost, about $5 per hectare for large-scale contracts, and about $20 per hectare for small-scale experimental trials (Williams and Moore, in press), comprises:

- The cost of the poison. It is negligible for 1080 ($0.01/mL stock solution), approximately $0.15/kg bait. Pindone is relatively expensive, being $2.50/kg bait.
- The cost of the bait. Oats are cheap, $250/t. The price of carrots varies widely but is considerably more than for oats, and commercial rabbit pellets cost about $403/t.
- The cost of application. This includes labour costs in applying two or more free-feeds as well as the poisoned bait (usually one person), and the costs of running a ground vehicle and baitlayer or of hiring an aircraft.

Bait shyness and aversion to poison

The effectiveness of poisoning as a long-term control strategy is limited. There is an emerging problem of bait avoidance (neophobia) by rabbits. Rabbits are suspicious of new objects, such as bait or a poison trail, in their environment (Rowley 1963). Repeated use of poisons over a number of years risks evolutionary selection for genetically determined bait shyness resulting in increasing proportions of the rabbit population refusing to approach trails or eat even unpoisoned bait (Bell 1975, 1991; Fraser 1985). Changing poisons does not overcome the problem.

'Many poisoning campaigns conducted by farmers and even trained operators kill insufficient rabbits and merely reduce populations to levels at which the rate of increase is greatest.'

Enhanced neophobia has been detected in Western Australia (Oliver et al. 1982) and New Zealand (Bell 1975, 1991; Fraser 1985). Currently the New Zealand Government is spending $25 million over five years to determine how best to manage an area of 400 000 hectares infested with neophobic rabbits (Martin 1994). Even a slight increase in the proportion of neophobic rabbits will result in ineffective poisoning campaigns. A decline in percentage kill from 95% to 85% will prevent effective management because of the rabbit's high reproductive potential.

Although 1080 is described as colourless, tasteless and odourless, after repeated 1080 poisoning campaigns in New Zealand rabbits were able to detect it in bait and avoid being poisoned (Bell 1991). Apparently repeated poisoning has selected rabbits for poison aversion, possibly through an ability to detect 1080 by taste or smell and avoid ingesting it. Some brush-tailed possums could detect and avoid 1080 carrot baits (Morgan 1982). Rabbits also can be expected to evolve a tolerance to a poison that is used repeatedly. Tolerance to 1080 can be rapidly selected for in rats and mice by breeding from survivors in poisoning trials (Howard et al. 1973). Many native animals in Western Australia and other parts of Australia have a relatively high tolerance to 1080 compound, which occurs in local native plants (King et al. 1981).

Many poisoning campaigns conducted by farmers and even trained operators kill insufficient rabbits (Tomlinson 1959; Oliver 1983) and merely reduce populations to levels at which the rate of increase is greatest. For example, repeated poisoning at one to two year intervals is necessary in rabbit-prone country (Rowley 1968; Foran et al. 1985). Ineffective poisoning leads to bait-shy rabbits. Many rabbits may receive a sublethal dose if insufficient bait is laid or if rain or dew leaches the poison. This then makes them less likely to eat poisoned baits.

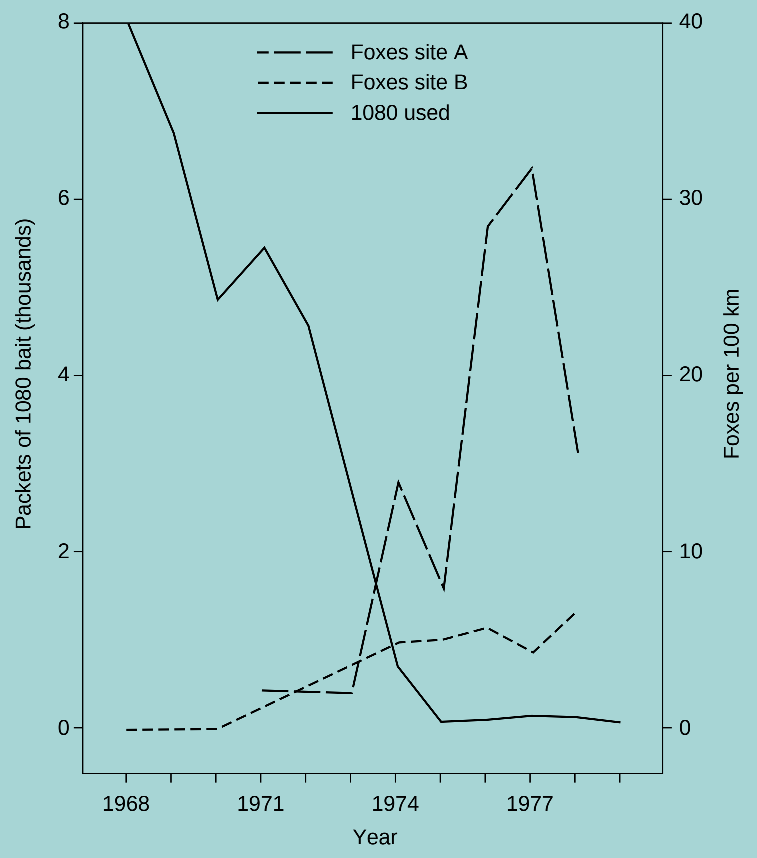

Figure 25: Abundance of foxes as determined by spotlight counts at two sites and the amount of 1080 used in the south-west of Western Australia (after King et al. 1981).

It is essential that poisoning is infrequent and that each poisoning operation kills as many rabbits as possible.

Non-target kills

In conservation areas poisoning is a risk to non-target fauna (Section 4.3.5). Primary poisoning of non-target herbivorous animals can be minimised by following the correct procedures for presenting poisoned bait.

Secondary poisoning of predators is a bigger problem. Anecdotal evidence suggests that secondary poisoning of predators may be counterproductive to the long-term aim of sustained, strategic management. Subsequently the predators may be too few to keep rabbit numbers low (Newsome et al. 1989).

Predators play a valuable role in regulating rabbit populations or limiting their rate of increase when they are reduced to low densities by factors such as drought or myxomatosis. Poisoning campaigns can severely reduce predator populations. After rabbit poisoning at Kinchega National Park, foxes were often found dead, and feral cats occasionally (Eveleigh 1986). Using 1080 to poison rabbits is risky because it has a higher toxicity (lower LD_{50}) to the main predators of the rabbit (fox, dog, feral cat) than it has to the rabbit itself, although in conservation areas secondary poisoning of these species may be considered desirable. Predators also kill other wildlife considered desirable. The higher density of predator populations due to the abundance of rabbits may lead to increased predation on native wildlife. Predator populations can be reduced, leading to reduced pressure on native wildlife, by reducing rabbit density and maintaining it at a low level by sustained rabbit management.

In Western Australia, after the introduction of the European rabbit flea, the use of one-shot 1080 decreased by 95% and the number of foxes increased (King et al. 1981; Christensen 1980) (Figure 25). When a rabbit population was poisoned in south-western New South Wales, seven resident foxes and three non-resident foxes were also killed (Birchfield 1979). One week after another rabbit poisoning operation on the Southern Tablelands of New South Wales, foxes had declined by 75% on a treated area and by 60% on an adjacent untreated area (McIlroy and Gifford 1991), suggesting that foxes are killed beyond the poisoned area. In a tarbaby trial (1080 in grease), 30 foxes were found dead on the 325 hectares treated area (Parer and Libke 1991). This number of foxes is 3–6 times that expected in such an area (Coman et al. 1991). Foxes move rapidly into depopulated areas (Catling 1988; Newsome et al. 1989) so more deaths could be expected as immigrating foxes feed on rabbit carrion which remains toxic for a considerable time (Lugton 1991). Even old rabbit carcasses can be a significant food for foxes in winter (Birchfield 1979).

A key issue for future research is to determine which poisoning techniques: (1) one-shot oats; (2) oats used conventionally; or (3) carrots entail the most risk for predators where this is a problem. Feral cats eat less carrion than foxes and probably would be affected less (Catling 1988), although there are no data on the extent of feral cat mortality.

'It is essential that poisoning is infrequent as possible and that each poisoning operation kills as many rabbits as possible.'

Poisoning may adversely affect the ability of neighbours to deal with their rabbit problem because predators may die over a much larger area than the treated property. Repeated poisoning may increase the rabbit problem both on the treated property and on neighbouring properties and may result in more frequent poisoning on both. Fumigation and warren ripping may also kill feral cats and foxes because they sometimes live in rabbit warrens.

Timing of poisoning

The development of strategic timing of poisoning, based on CSIRO research, and its adoption by local rabbit control authorities, dramatically improved the

Baiting substantially reduces rabbit numbers prior to ripping and other control methods. Small baitlayers linked to a four-wheel motorbike allow good manoeuvrability and access to difficult areas. *Source: Bathurst RLPB*

effectiveness of poisoning in the 1960s and 1970s, even to the extent that use of 1080 by landholders during the rabbit breeding season was not permitted.

Poisoning of rabbits is suitable only when rabbits are not breeding and when the quality and accessibility of food are lowest, which is summer/autumn in most areas except subalpine areas, where winter is the best time for poisoning. Poisoning at other times results in ineffective kills for the following reasons (Burley 1986):

- rabbits are more likely to encounter a poison trail in summer/autumn when they range most widely for food and defend territorial boundaries less strongly;
- baits are more attractive when high-quality food is scarce;
- baits are found more easily when pasture is less dense;
- young rabbits remain close to their warrens and will feed only on trails close by the warren. These young rabbits may comprise one-third to one-half of the population;
- 1080 poison is less likely to be leached from the bait by rain and dew in summer/autumn; and
- rabbit populations are at their lowest level in summer/autumn and poisoning is more likely to add to total mortality rather than replace some other mortality factor.

Labour costs can be reduced if poisoning coincides with sheep drenching during the summer. Sheep can be moved to clean paddocks immediately after drenching, and the vacated, unclean source paddocks can be poisoned.

Except in special situations, poisoning should be used only in conjunction with other methods that destroy or disrupt the warren (Williams and Moore, in press). Poisoning alone may be justified only where other methods are impossible because of terrain or economic impracticality, although even in these cases repeated poisoning should be avoided because of the risk of evolution of bait shyness and of aversion to poison. One-off poisoning in high rainfall areas, perhaps

It is important to erect signs to warn people that 1080 poison bait has been laid.

Source: Unknown

Baits	
Advantages	**Disadvantages**
• Relatively cheap if 1080 can be used, otherwise not cheap • Can be used in difficult terrain, including by aerial application • Useful to reduce dense rabbit populations prior to ripping and fumigation campaigns, thereby reducing recolonisation • Can be integrated with stock quarantine measures • One of the few effective techniques for surface-dwelling rabbits (parts of Western Australia and Tasmania)	• Commonly applied ineffectively, selecting for bait shyness, aversion of poison and poison tolerance • Non-target kills but suitable if precautions are taken • Short-term effect • Requires continuous dry conditions with little available feed • Need to remove stock and provide suitable water supplies, pasture and fencing • Only part of grazing properties can be treated in any one year, increasing the risk of recolonisation • Difficult to know when it is safe to return stock to poisoned paddocks • Removes rabbit predators • Usually unsuitable in built-up areas • 1080 very toxic to dogs; the alternative pindone is expensive

in conjunction with destocking or reduced stocking rate, might promote vegetation growth that deters recolonisation by rabbits.

On grazing properties rabbit poisoning needs to be integrated with the availability of suitably fenced alternative pastures for stock. Adequate pasture is needed for stock until uneaten bait can be removed or buried, or rainfall or dew has leached out the poison. There is no precise guide on when to return stock to a poisoned paddock. Stock may be at risk unless substantial rain has fallen. If suitable alternative paddocks are available, poisoning can be integrated with spelling of paddocks or quarantine measures.

7.4.9 Ripping warrens

The primary purpose of ripping is to destroy warrens. Ripping removes the principal shelter used by rabbits to avoid weather extremes and predators. Rabbits may also live among surface shelter, such as logs, fallen branches, rock piles and dense vegetation, but these are inferior to warrens where, in most circumstances, the main breeding populations live. Rabbits do not dig new warrens readily. Destruction of warrens greatly inhibits resurgence and recolonisation of treated areas, especially if surface harbour is removed beforehand and follow-on control by reripping or fumigation is undertaken. In parts of south-western Australia and Tasmania, rabbits are mainly surface dwelling and ripping is not effective in these areas. Poisoning and, where appropriate, destruction of surface harbour are the only suitable techniques.

'Where rabbits use warrens, ripping is the most cost-effective and enduring of the available single control techniques. The effectiveness of ripping is greatest when followed with other control treatments or with repeated ripping.'

Warrens should be ripped as deeply as possible, at least to 0.5 metres, but preferably

Ripping with rubber-tyred tractors can be effective for treating small numbers of warrens on relatively flat and non-clay soils.

Source: Unknown

deeper, especially in sandy soils, and at least four metres (preferably more) beyond the surface extent of the warren. In sandy country warrens may extend deeper than the depth of the rippers, leading to significant re-opening of warrens, so either follow-up control is essential, or warrens that are too deep for the ripping tines can be dug out using the crawler tractor blade. This technique is time consuming but effective.

Both tracked and cheaper rubber-tyred tractors may be used. Tracked vehicles are usually more powerful and can cope with steeper slopes. The maximum slope that can be ripped varies with the nature of the surface. Only lesser slopes can be ripped where the surface is rough or rocky. Slopes must be judged on site for safe operation.

Erosion is a potential problem but can be reduced by (1) ripping along the contour rather than down the slope; (2) seeding ripped areas with grass; and (3) refraining from ripping slopes when heavy rain is likely. Although it has not been demonstrated experimentally, experience suggests that light soils should be ripped when dry, to collapse the ripped tunnels. Conversely, heavy soils should be ripped when damp so that they compress into the ripping swathe.

Ripping of warrens is most effective when the soil is friable and flows into the deeper parts of the ripped warrens. These conditions occur in dry summers in much of inland Australia where soils are sandy. Conversely, where clay predominates, ripping breaks up soil more effectively when it is slightly damp. When dry, clay soils become hard and tend to remain in large lumps when ripped. The tunnels of the warrens fail to collapse sufficiently and rabbits may survive and continue to live in the modified warrens. Ripping is not advisable when soils are wet.

Difficult areas such as gullies, sloping banks, amongst trees and along roadside verges can be ripped with little disturbance to the surrounding soil and vegetation using a recent innovation, a ripper mounted on a mobile hydraulic arm (drag-arm ripper) such as an excavator or backhoe.

Recent innovations for large-scale ripping operations, mainly on inland rangelands, have increased efficiency and reduced costs markedly (W. Tatnell, CaLM NSW, pers. comm. 1992). Large high-powered crawler tractors follow a motorcyclist who locates and flags the warrens in advance (Hams 1991; Lord

Warren ripping

Advantages	Disadvantages
• The most long-lasting of the standard techniques • The most cost-effective of the standard techniques in the long term • Relatively cheap • Compatible with prior poisoning and follow-on fumigation • Suitable for large-scale operations	• Unsuitable for steep slopes and very rocky land • Unsuitable where rabbits inhabit scrub with few warrens, as occurs in parts of southern Western Australia and Tasmania • Availability of necessary equipment

Steel or rubber-tracked equipment may be more efficient for ripping large areas with a high number of warrens and warrens on steeper slopes. Rubber machinery such as the "Cat Challenger" shown above are especially useful in sand country where they cause less damage to vegetation.

Source: Mike Braysher, BRS

1991). A possible high technology innovation for the rangelands is satellite positioning of warrens by the motorcyclist using a global positioning system. The data are downloaded into a computer in the tractor cab which calculates and displays the most efficient path between warrens for the operator to follow. A further development is attachment of seed boxes to tractor ripping tines so that warrens are automatically seeded with grass as they are ripped. Winged rippers may increase efficiency in dry, lighter soils.

Where rabbits use warrens, ripping is the most cost-effective and enduring of the available single techniques (Cooke 1981a; Williams and Moore, in press). In most country it is more comfortable and less tiring than fumigation, particularly pressure fumigation. Comfort and convenience are likely to be significant factors in determining whether a landholder manages rabbits or suffers rabbit damage. Ripping is also the most suitable method for treating large areas (Myers et al. 1976; Martin and Eveleigh 1979; Wood 1985; Lord 1991; Tatnell 1991).

The effectiveness of ripping is greatly enhanced when followed with other control techniques, or with repeated ripping (Cooke 1981a; Williams and Moore, in press). Ripped areas in semi-arid regions were gradually recolonised, but after European rabbit fleas were introduced and the effectiveness of myxomatosis increased thereby, the effectiveness of ripping lasted much longer, although other factors may also have been influential (Cooke 1992).

The efficiency of ripping is also enhanced by ripping warrens when the rabbit population is low. When rabbit populations are high more rabbits may survive on the surface or in parts of the warrens missed by the ripping tines. Dogs or trained dog packs, which send surface rabbits underground, improve the efficiency of ripping. They reduce the likelihood of surface-living rabbits surviving to re-open ripped warrens or dig new ones.

7.4.10 Explosives

Operators must be trained and licensed in handling explosives. If excessive explosive is used, the blast may create a crater and pulverise surface soil or stone, which rabbits may dig easily, leaving the deeper warren structure amenable to recolonisation. On the other hand, skilled operators may destroy deep warrens effectively. Explosives are especially useful for the destruction of warrens which are among rocks and boulders because few other techniques are effective in these areas. Costs are high.

7.4.11 Fumigation

There are two fumigation methods: (1) pressure fumigation, in which the fumigant gases or vapours are generated outside the warren and forced into the warren under pressure, usually from a pump; and (2) diffusion fumigation, in which the gases or vapours are generated inside the warren through which they diffuse (see Appendix A for technical details).

Both methods are labour-intensive. Only small areas can be treated because of cost, the time required, and the intensity of the operation. The methods are useful where

Explosives for warren destruction	
Advantages	**Disadvantages**
• Effective in rocky and inaccessible places • Compatible with follow-on fumigation • Humane	• Effectiveness depends on the skill of the operator • High cost • Danger • Unsuitable around settled areas

warrens cannot be ripped and for follow-up ripping programs where re-opened entrances are few or widely spaced, or the ripping machinery is no longer available. Warren re-opening rates of 23% have been found eight days after treatment (Bromell 1968), although more modern fumigators may have increased the effectiveness of fumigation. Nevertheless, re-opening is a problem, especially if fumigation is used as the primary technique. Williams and Moore (in press) observed warrens for two years after they had been fumigated with chloropicrin by a modern motorised pressure fumigator, and found that 49% of fumigated entrances had re-opened one month after treatment, and all had effectively re-opened one year after treatment (see also Table 19). In a subsequent operation in the same area, 47% of fumigated warrens had re-opened one year after treatment, in contrast to only 11% of ripped warrens (C.K. Williams, unpub.).

Limited trials have shown that re-opening rates of fumigated warrens may be reduced substantially by plugging warren entrances with tight wads of low-grade wool of long staple-length prior to filling with soil (Thompson 1993a, b). Inexpensive suitable greasy wool includes stained wool, flyblown wool and wool plucked from dead sheep. Carded wool is claimed to be superior to greasy wool for this purpose, and 30 cm squares of woollen insulation batts are reported to be ideal.

As for ripping, using dogs to drive rabbits into the warren greatly increases the efficiency of fumigation. When fumigated, warrens should be rendered unusable by securely blocking entrances. In rocky situations entrances can be blocked with stones, old superphosphate bags or balls of crumpled wire netting. This is labour-intensive but suitable for warrens that cannot be destroyed by other means. It is likely to be more cost-effective than repeated fumigation.

Both diffusion and pressure fumigation are best conducted when the soil is damp and can be dug easily to seal the entrances. Under these conditions the toxic gases are least likely to diffuse out of the warren tunnels. Damp soils are less prone to collapse into the entrances where tunnels descend steeply. Effective seals can be made quickly, minimising escape of rabbits and pressurised fumigants.

Pressure fumigation

Warren entrances are dug back for about 0.3 metres using a hand shovel. A hose is inserted into an entrance and sealed there

Fumigation reduces rabbit numbers in warrens prior to ripping and as follow-up treatment for re-opened warrens.

Source: Unknown

Pressure fumigation	
Advantages	**Disadvantages**
• Useful in inaccessible places including steep slopes • Suitable near settled areas • Effective follow-up to ripping • Indicator smoke often locates unseen entrances, especially in long vegetation	• Chloropicrin is inhumane and has a low margin of safety; phosphine or carbon monoxide are preferable. • Effectiveness depends on the skill of the operator • Treated warrens are readily recolonised • Labour-intensive and slow • Expensive • Not suitable for large areas • Uncomfortable and tiring for operators • Gas masks are uncomfortable so operators often expose themselves to danger • Equipment can be heavy and cumbersome, although lighter fumigators are available • Is a cumulative poison

with soil. Toxic vapour and indicator diesoline smoke are generated in a fumigator machine and forced through a hose into the warren using a powered fan or engine exhaust. Unsealed entrances are sealed by soil only when smoke issues freely from them. It is important that the indicator smoke and toxic vapour issue freely from the entrances before they are sealed, otherwise pockets of clean air may enable trapped rabbits to survive long enough to dig out. The smoke is extremely useful in revealing concealed entrances. Entrances not found, and left untreated, decrease the effectiveness of the control operation, especially where vegetation is dense or long. The main fumigant used is chloropicrin. The authors consider the use of chloropicrin inhumane and it has disadvantages compared with phosphine and carbon monoxide (Oliver and Blackshaw 1979; Section 5.5.1). The highly irritating action of chloropicrin can favour safety of the operators.

During operations, irrespective of the care taken, it is impossible for operators to avoid entirely the vapours of either chloropicrin or phosphine. Suitable gas masks are recommended, but they are uncomfortable to wear for long periods, especially in warm weather. On the fumigators, metal containers are necessary to hold the chloropicrin because glass containers are a hazard to operators. However, these are not readily available. Further research is required to identify better fumigant gases or vapours (Section 12.5).

Diffusion fumigation

Warren entrances are dug back about 0.3 metres using hand shovels. A sample of chloropicrin is squirted into each entrance or placed there on porous material. Alternatively an aluminium phosphide tablet is placed down each entrance. If the soil is dry, the speed of release of phosphine may be increased by wrapping the tablet in wet newspaper. Then wadding such as crumpled newspaper is placed down the entrance which is then sealed with soil. The chloropicrin vaporises and diffuses through the sealed warren. The aluminium phosphide pellets react with moisture in the warren, releasing phosphine gas which diffuses through the sealed warren.

Diffusion fumigation is useful for impromptu treatment of isolated warrens or re-openings detected by chance during normal property practices. Little equipment is required and it can be carried readily in a vehicle, on a motorbike, or by an operator walking in difficult terrain.

Pressure or diffusion fumigation?

The authors consider pressure fumigation using chloropicrin to be inhumane, although more humane toxicants such as carbon monoxide may be developed as substitutes. The smoke of pressure fumigators often reveals entrances concealed in vegetation which would otherwise be missed by operators. On the other hand, pressure fumigation requires several items of equipment that are either heavy or inconvenient to carry, usually requiring a vehicle, trailer or wheelbarrow. Diffusion fumigation requires little equipment and is relatively convenient, but more entrances may be missed by the operators. Conversely, found entrances may be sealed better because operators are not working to a pace determined by the fumigation equipment. Experimental comparisons showed that diffusion fumigation with phosphine gave more effective control and more sustained control than pressure fumigation with chloropicrin (Williams and Moore, in press). There was less frequent re-opening of entrances because of better sealing. This may, however, have been because of the operator preference for one of the methods and might not be intrinsic to the techniques.

7.4.12 Myxomatosis

Myxomatosis, a disease specific to leporids (Section 3.7.4), is caused by myxoma pox virus which was released into Australian wild rabbit populations in 1950. Initially it caused extremely high mortality, but the virus quickly attenuated (weakened) and rabbits with a genetic resistance to the disease became more common. Rabbits that survive myxomatosis acquire lifelong immunity (Section 3.7.4). Strains of myxoma virus were graded as I, II, III, IV or V according to the survival times of test samples of five susceptible unselected rabbits (Fenner and Ratcliffe 1965). The original introduced strain was of high virulence and caused mean survival times of less than 13 days, which is equivalent to killing more than 99% of infected susceptible unselected rabbits. It was classed as grade I. More than 50% of unselected rabbits infected with the least virulent strains (grade V), survive the infection. Most field strains appear to be grade IIIA (mean survival time 17–22 days, equivalent case mortality rate of 90–95% in unselected rabbits) or IIIB (mean survival time 23–28 days, equivalent case mortality rate 70–90% in unselected rabbits). Current field strains kill about 40–60% of the susceptible rabbits in field populations. However, myxomatosis has selected field populations for some degree of genetic resistance. If the field strains were tested on unselected susceptible rabbits, it is likely that the field strains would be classed as grades I or II.

Diffusion fumigation	
Advantages	**Disadvantages**
• Can be used in inaccessible spaces including steep slopes • Little equipment needed • Effective follow-up to ripping • Suitable for impromptu treatment of isolated or re-opened warrens • Can be used near settled areas	• Chloropicrin is inhumane and has a low margin of safety • Phosphine seems to be more humane • Warrens readily recolonised • Labour-intensive, slow and expensive • Unsuitable for large areas • Tiring for operators

Myxoma strains

Since myxomatosis established in Australian rabbit populations, highly virulent grade I strains, first Glenfield and then Lausanne, have been introduced many times on the premise that they would kill a high proportion of rabbits and thus control their populations. There is no evidence that any of these releases achieved their objective.

The reason introductions of Glenfield and Lausanne did not succeed is that highly virulent strains kill quickly and never achieve high infection levels, and thereby they fail to spread widely in the field (Parer 1991). It would be desirable to introduce suitable strains of myxoma virus in areas just before rabbit populations are expected to explode, for example in the rangelands following high rainfall. At present we do not have the knowledge, techniques or appropriate strains of virus to achieve rabbit population control using this approach. For this reason we do not currently recommend using myxomatosis as a deliberate control method. Further research is necessary to provide:

- a myxoma strain of suitable grade, say I, II or III that causes high mortality but with long survival time to death so that there is maximal chance to spread the virus (Parer 1991);
- a method for producing large amounts of pure strain virus cheaply;
- a method for disseminating the virus effectively and cheaply. Possible methods include aerosols (Conolly and Sobey 1985) and baits that might also include a mild haemorrhagic agent to facilitate infection; and
- a resident insect vector. Current research on a Spanish arid-adapted flea (*Xenopsylla cunicularis*) may provide an answer for arid regions. The European rabbit flea fills this role in areas where rainfall exceeds 200 mm.

Characteristic symptoms of myxomatosis include swelling of the eyelids, anal and genital areas, lumps on skin and general listlessness. *Source: NSWAF (Nyngan)*

European rabbit flea

The European rabbit flea (*Spilopsyllus cuniculi*) was introduced into some Australian wild rabbit populations in 1968 (Sobey and Conolly 1971). This ectoparasite lives specifically on rabbits and its reproduction depends on breeding of its rabbit host (Mead Briggs 1977). The flea is considered to be an efficient vector of myxomatosis, for which purpose it was introduced. The flea is unable to cope with arid conditions and does not occur permanently with the rabbit in areas with less than 200–250 mm rainfall (Cooke 1984).

The European rabbit flea is unlikely to extend its distribution much further into arid areas than its present limit, even if translocated. Minor extensions and retractions may accompany weather fluctuations (Cooke 1984). Foran et al. (1985) introduced fleas to rabbit populations in central Australia without significant effect on rabbit abundance and pasture biomass because the fleas died. The failure of the European rabbit flea as a vector of myxomatosis in arid regions has prompted researchers to seek other species of fleas which may fulfil an equivalent role in arid regions.

Arid-adapted fleas

The Spanish flea occurs in the arid areas of Spain. It is being introduced into Australia and is expected to become established over most of the rabbits' distribution in arid regions (Bartholomaeus 1991). That distribution will complement that of the European rabbit flea, *S. cuniculi*.

Unlike the European rabbit flea, reproduction of Spanish flea does not depend on rabbits breeding. Highest infestation levels are in summer/autumn (Abreu 1980), the time when myxomatosis is most prevalent in inland Australia (Parer and Korn 1989). Whether *X. cunicularis* will improve the transmission of myxoma in the rangelands cannot be predicted with certainty. It has transmitted myxoma in laboratory trials and it assists the spread of myxoma in Europe (Launay 1989). Its breeding potential has been tested on 20 species of native mammals. The flea can reproduce, albeit poorly, on several species and relatively well on one species of native rodent, the sticknest rat *Leporillus conditor*. This rat now occurs only on offshore islands (B. Cooke, Animal and Plant Control Commission, pers. comm.). If *X.cunicularis* is found to be unsuitable, another arid-adapted Spanish flea, *Caenopsylla laptevi ibera*, could be considered.

Monitoring at release sites in inland Australia has shown that the Spanish flea has established at most sites, failing to establish, as predicted, only at wetter sites. The rate of spread was found to be approximately two kilometres a year, similar to that of the European rabbit flea when it was introduced; the rate of spread may depend on the behaviour of the rabbit more than on traits of the flea.

Only when Spanish flea has spread more widely will it be possible to determine whether its presence increases the frequency and effectiveness of myxomatosis in arid regions of Australia. Until then, the management of rabbits in the arid zone is best planned assuming that the new fleas will not help spread myxomatosis. Should arid-adapted fleas help spread myxomatosis, conventional rabbit management may become more effective and economical in arid Australia.

7.4.13 Rabbit calicivirus disease (RCD)

RCD, known also as viral haemorrhagic disease (VHD) and rabbit haemorrhagic disease (RHD), is caused by a calicivirus which has potential as a biological control agent (ANZECC/ARMCANZ Working Party on Rabbit Haemorrhagic Disease 1992). It appears to be a new disease of rabbits possibly crossing from another mammal host species. It was first observed in its virulent form in China in 1984 and in Europe in 1988. In Italy it is estimated to have killed 30 million domestic rabbits. In Czechoslovakia, retrospective examination of earlier blood samples of rabbits showed that antibodies to the virus were present in blood collected 12 years before the virulent strain was detected. The disease is now endemic in populations of wild rabbits in Europe. Studies to date indicate that the disease is species-specific, infecting the European wild rabbit and the domestic strains derived from the wild rabbit. The European brown hare is susceptible to a closely related virus causing European brown hare syndrome, but is not susceptible to RCD virus infection.

There are no external signs of the disease until 24 hours after infection, when the rabbits become listless with a high temperature. Rabbits at the CSIRO high security laboratory at Geelong die quietly at 30–40 hours after infection with no

Myxomatosis

Further research is required before myxomatosis can be used for tactical control of rabbits. For the near future rabbit control must rely on other methods. The European rabbit flea has probably occupied all areas where it is able to survive. Research into the use of arid-adapted species of fleas as vectors of myxomatosis in arid regions of Australia is being conducted, and Spanish flea has been released. Myxomatosis should be considered a natural event which cannot be influenced directly by rabbit managers. Other control techniques should be used to take advantage of reduced rabbit densities due to periodic outbreaks of myxomatosis.

indication of distress. At autopsy the spleen and liver are swollen. Due to extensive death of cells, the liver is pale and crumbly. The effects on the lungs are variable but they may fill up with fluid and the blood vessels may be blocked by fibrin. The cause of death is probably acute lack of oxygen and heart failure.

Nestling rabbits, less than 18 days old, do not die, but they excrete virus and develop antibodies. The mortality rate at Geelong to the virulent strain was 50% for 4–5 week-old rabbits and more than 95% for rabbits nine weeks or older. It is not known whether rabbits would be susceptible to a second infection. The disease is highly infectious by contact and there are indications that it may also be spread by insects. Despite the short period of infectivity, RCD spreads rapidly through wild populations in Spain, 15 km per month, with infection rates and mortality rates of about 90% (Leon-Vizcaino and Cooke 1991). It is not known how the disease persists in the field. Carrier rabbits are a possibility, although there is no evidence for this (Lenghaus 1993). The virus can be detected in frozen rabbit meat and may persist in protected environments, such as warrens, for up to six months.

Table 17: Assessment of biological control options (after Taylor Baines and Associates 1991).

	RCD	Immuno-sterilising virus type
Technically possible	Yes	Unknown
Practically feasible	Yes	Unknown
Economically beneficial	Yes	Yes
Politically acceptable	Unknown	Unknown
Environmentally acceptable	Unknown	Unknown
Socially acceptable	Unknown	Probably

Promising results from preliminary testing at the Australian Animal Health Laboratory mean that it is now appropriate to assess the possibility of releasing the virus into the field. Should release occur, it would require the approval of the Commonwealth Minister for Primary Industries and Energy, whose Department administers the Quarantine Act. Other ministers, notably the Minister for the Environment, may well be involved in the ultimate decision. Their decision on the release of RCD will rest on an assessment of the scientific evidence relating to (1) host specificity; (2) economic and conservation impacts; (3) animal welfare considerations; (4) effectiveness; and (5) community views on the potential release of a relatively new and unknown virus. It will be a significant decision.

Until recently, the debate about the economic and social desirability of introducing the disease into Australia was confined to the scientific community (Cooke 1991a; O'Brien 1991; Munro and Williams 1994). With plans to transfer the virus to confined pens on an island for trial under quarantine, the debate will increasingly include the community in general, and special interest groups in particular. A decision about field release will involve consideration of: (1) RCD's effectiveness in controlling rabbit damage; (2) animal welfare; (3) public and animal safety; (4) commercial, Aboriginal and recreational use of wild rabbits and their products; (5) impacts on laboratory, pet and commercial rabbits; and (6) international trade (Munro and Williams 1994). A recent assessment of the biological control options for New Zealand provides a useful summary of the feasibility and acceptability of a RCD introduction (Taylor Baines and Association 1991) (Table 17).

7.4.14 Immunocontraception

Current research in molecular biotechnology aims to insert into the myxoma virus genetic information coding for specific antigens derived from surface proteins of rabbit sperm, egg and reproductive tract. It is hoped that infection of rabbits by this modified virus will cause an immune response, blocking fertilisation or embryo implantation in females that survive the disease (Tyndale-Biscoe 1991; Tyndale-Biscoe and Jackson 1991). The intended strategy is for such a genetically-modified myxoma virus to infect wild rabbit populations and induce sterility in sufficient proportions to cause rabbit populations to decline. If both sperm and egg antigens are inserted into the virus the proportion of infected and sterilised rabbits required for population decline is much lower than if only one antigen were used. No species other than the rabbit would be at risk, because the system would possess double species-specificity, the species-specific virus and the species-specific reproductive antigens.

Rabbit calicivirus disease (RCD)

RCD is not currently available as a means of controlling rabbits in Australia, but initial results are encouraging. Several matters need to be investigated before the virus could be released. These include:

- further studies of the disease and its impact on wild rabbits in Europe. For example, it is not known (1) how long rabbits which recover from the virus remain immune, (2) whether rabbits pass the immunity onto their offspring, or (3) whether RCD will be effective in reducing rabbit damage;
- clarification of the legal requirements that need to be met before a release of RCD would be possible, and of the international trade implication;
- detailed assessment of community views on the benefits and risks of introducing the disease for various interest groups, including conservationists, agricultural producers, commercial and pet rabbit industries, Aboriginal and recreational harvesters and animal welfare groups.

These studies and processes will take several years. Because a decision may be made to release RCD, planning has commenced to ensure that the benefits it may provide for controlling rabbit damage are fully captured.

The concept is a humane method of rabbit control in that it reduces rabbit numbers without increasing the incidence of myxoma infection. It is a long-term project that will require at least 10 years of research and development. An effective virus would need to be approved for release by the successor to the Genetic Manipulation Advisory Committee (GMAC) after exhaustive investigations into its stability, species-specificity and safety. For such an immunocontraceptive virus to be effective it must produce a long-lasting immune response. Initially it would be advantageous if the virus could provoke an adequate immune response in a second infection in rabbits that have had myxomatosis previously.

Effective dissemination of the virus into the field in Australia will be a formidable challenge, because it will need to be able to spread and infect a high proportion (more than 80%) of rabbits in competition with existing field strains of myxoma virus (Parer et al. 1985). Breeding by the European rabbit flea, a major vector of myxoma virus, is linked intimately with the breeding of rabbits (Mead-Briggs 1977). Therefore, flea populations may decline after the introduction of an immunocontraceptive virus. Intensive annual introductions of the immunocontraceptive virus may be needed, and this would add significantly to the cost. A substantial reduction in fertility may eliminate rabbits from marginal habitats, such as subalpine areas, where females produce only 15 young per year (Gilbert et al. 1987). In environments more favourable to rabbits, an effective immunocontraceptive virus would make the rabbit problem more amenable to solution by conventional techniques.

The rate at which wild rabbits would be selected for genetic resistance to the modified virus is not known.

7.4.15 Integrated biological control

Myxomatosis is the only successful example of biological control of mammals though other biological control agents have been investigated for a range of mammal pests. Three potential biological control agents are under investigation in Australia for rabbit control: RCD; a genetically-modified immunosterilising myxoma virus; and the Spanish flea, which is a potential inland vector of the myxoma virus. There is thus available a rare and valuable opportunity to develop an integrated strategy using all three agents. A resident vector such as the Spanish flea will be essential if an immunosterilising virus is to spread in the rangelands. We must consider how best to use this potential vector and ensure its dissemination throughout arid and semi-arid regions before beginning the next stage. If an effective immunosterilising virus can be produced and approved for release, and if permission is given to release RCD, simultaneous and intensive release of both viruses over very large areas would seem to be an effective strategy for the following reasons: often high proportions of adult rabbits have antibodies to myxoma virus; RCD could kill them within a few days; the immunosterilising myxoma virus then could kill or sterilise young rabbits.

An intensive maintenance warren ripping program could take maximum advantage of epizootics of myxomatosis, RCD or both. A follow-up warren ripping program, or a tactical poisoning program for areas of dense rabbit-infested scrub, is an essential component of such a strategy of integrated biological control. Elements of these hypothesised interactions could be tested by examination in high security quarantine. The data from these trials could be used then in mathematical models of rates of transmission of both viruses and the effects on rabbit abundance.

Immunocontraception

Because an immunocontraceptive virus will not be available for release for many years, rabbit management strategies must be planned for the near future, and it should be assumed that the research will not succeed. However, a successful outcome would make the essential and ongoing conventional rabbit control more effective and economical.

The long-term future prospect of an immunocontraceptive virus must not divert land managers from their urgent and immediate task of planning and implementing sustained effective rabbit control by conventional methods.

Integrated biological control depends on the outcome of current and future research. It is unlikely to be a useful option for many years. In the meantime rabbit management will depend on integrated conventional methods.

An alternative strategy may be to release a modified immunocontraceptive RCD virus instead of the natural form. The modified virus would kill adults, probably with very high death rates among the totally native populations. Any infected kittens less than five weeks would probably survive the disease but become sterile. The high transmissibility of RCD virus would facilitate such a strategy. However, genetic modifications of the RCD calicivirus may be difficult to achieve and are not possible with current technology.

7.4.16 Commercial use

There is no evidence that commercial harvesting, including hunting, (Section 4.4 and 5.6) is effective in controlling wild rabbits. Shooting may remove about 35% of rabbits locally, based on New Zealand data (Williams and Robson 1985), a relatively small loss (Gilbert et al. 1987) that is replaced readily by reproduction.

'There is no evidence that commercial harvesting is effective in controlling wild rabbits.'

7.5 Monitoring techniques

Monitoring is an essential, integral and continuing part of a rabbit management program. The minimum monitoring

4

necessary includes (1) monitoring rabbit density before a control operation; (2) monitoring again one month after the control operation and then (3) annual monitoring.

Monitoring begins before the management program. It is part of assessing the problem and an integral part of the planning of a management program. The outcomes of monitoring provide the basis for many decisions on expenditure of effort and resources. Monitoring is used also to evaluate and if necessary adjust, reorientate, or perhaps abandon a program if desired objectives are not being achieved. Therefore it is crucial that monitoring programs be well planned and executed. Monitoring programs should, where possible, be designed to:

- monitor impact on both valued resources and rabbit abundance;
- monitor before and one month after control operations and then annually or more frequently;
- use indices of impact and abundance that are standardised to enable comparison over time and among different land types and among different types and heights of vegetation (Sections 7.2 and 7.3);
- use methods that are easy and rapid. A better assessment is given by many crude assessments over many sites than by few precise assessments over relatively few sites;
- record information in a standardised format that allows the sequences of indices to be compared over time. State and territory extension services could prepare suitable forms and graphs on which landholders may record and assess their data;
- assess rabbit abundance, if possible, by indices that are long-lasting, such as warrens and burrows, in preference to ephemeral indices such as rabbit counts, footprints and scratches in soil (Section 7.2);
- ensure that roadways, tracks, steep slopes and other features that facilitate or impede human movement do not bias sampling; and
- seek advice from experienced extension professionals.

Assessment of impact may be laborious and time consuming unless simple measures can be used; see Sections 7.2 and 7.3 for complete details of assessment.

In almost every instance, the assessments provide indices rather than exact measures of impact or abundance. Hence the importance of standardisation must be emphasised. Standardisation of assessments of rabbit abundance depends on the use of robust indices that reflect long-term trends in rabbit abundance. Rabbit numbers and rabbit-sign, such as soil scratches, vary with seasons and other factors so that counts of rabbits and sign may not necessarily indicate the long-term trends in rabbit abundance, unless several years of data are available. Counts of rabbit warrens and burrows provide the best indicators of long-term abundance of rabbits for land types, and indicate the relative propensities of land types to rabbit infestation and reinfestation (Burley 1991). Dekkers' system gives similar benefits rapidly (Section 7.2.1).

7.6 Evaluation techniques

The rabbit management program must be evaluated against established objectives. Generally, objectives should be set in terms of desired rabbit density. In some cases it may be practical to set objectives in terms of degree of damage to a valued resource, although often this is complex, expensive and difficult for private landholders (see Section 7.1). In some cases rabbit damage information may be obtained as part of ongoing management in the form of crop yields and stock returns.

Objectives are discussed in more detail in Sections 9.2 and 9.3. Land managers may need advice from government agencies on how to set performance objectives. It may take more than one year to reduce damage to insignificant levels. In these cases it is necessary to set a series of interim objectives over several years. Low rabbit abundance can be expected on average after about four maintenance treatments. Different rates of decline in rabbit populations can be expected with treatments in different situations and climatic regions.

Similarly, the objectives may need to relate to progressively increasing proportions of the property that are treated. Interim objectives may need to vary among years due to rainfall variations that influence rabbit breeding and rates of increase. Objectives that account for varying availability of funds as rabbit management progresses may prevent hard times from jeopardising gains already achieved.

The rabbit management program is evaluated by comparing the information acquired in the monitoring program against chosen objectives. In few cases will there be opportunity to assess the program with reference to control areas with no rabbits. Landholders should be advised and encouraged to treat all areas of their properties in their schedule priority for treating management units because rabbits are too adept at recolonising for large areas to remain untreated. Therefore the evaluation is based on before and after comparisons and other means of evaluation where possible, as outlined in the four examples in Chapter 10 and Appendices B and C. Usually the decision on the suitability of the existing program will be based on uncertain or equivocal evidence. The evaluation will be more soundly based if data from more years of monitoring are available.

Experience and caution are needed in interpreting short-term monitoring. Rabbit damage monitoring may not indicate the effectiveness of the program until appropriate weather sequences eventuate, such as the case where abundant rainfall is necessary to trigger regeneration of vegetation. In the absence of experimental controls, outcomes may be misleading in years of exceptionally high or low rainfall and enhanced or poor rabbit breeding. Land managers should be encouraged to seek advice from experienced professionals when evaluating their monitoring data.

PART FIVE

STRATEGIC RABBIT MANAGEMENT

8. Economics of Rabbit Management

Summary

Economic frameworks are needed to assist in the assessment of the relative value of alternative control strategies. Such frameworks require: definition of the economic problem; data on the relative costs and benefits of various rabbit management strategies; and an understanding of why the actions of individual landholders may not lead to optimal rabbit management. Land managers can use such economic frameworks to select the most appropriate rabbit management strategy for their land and circumstances. If collective private decisions on rabbit management strategies do not meet the public interest for conservation of biological diversity and long-term sustainable land use, an assessment of socially equitable means by which governments can intervene to meet these broader conservation benefits may be warranted.

There are many factors a land manager has to take into account when attempting to assess the economic costs and benefits of rabbit control. Commodity prices for meat and wool greatly influence the gross margin value used to calculate increased profit due to the potential capacity to run and turn off more sheep resulting from rabbit control.

Approximate costs of conventional rabbit control in large-scale contracts are: (1) poisoning = \$6–8 per hectare; (2) warren ripping = \$3–20 per hectare; (3) fumigation = \$10–20 per hectare; and (4) explosives = \$30–60 per hectare. The cost of rabbit control depends on the type of country, the methods used and how long their effect lasts, and whether farmers use their own labour and equipment. Even with warren ripping, the costs of follow-up work can vary greatly. Re-opening rates of ripped warrens can be as low as 12% after ten years on heavy soils or as high as 62% after six months on sand dunes. Required intervals between poisoning campaigns may vary from one to more than six years.

Experiments have shown that poisoning by itself is relatively cheap initially but ineffective in the medium term, and expensive relative to the benefit obtained. Some combinations of treatments achieve a high level of control for little more cost than some single treatments, and at much lower cost per benefit obtained. Combinations which include warren ripping, compared to treatment combinations which lack ripping, are cheap, highly efficacious and cost less per benefit obtained. The high cost of diffusion fumigation indicates that re-ripping may be a cheaper maintenance treatment.

Rabbit management becomes progressively cheaper as repeated maintenance treatments achieve higher levels of control. In an experimental trial, the cost of maintenance treatment declined with repetition, approximately halving on each successive maintenance treatment. Costs can be expected to decline to a low plateau after about 4–5 maintenance treatments. Therefore, a land manager would receive greatest return on investment in rabbit management if maintenance treatments were repeated indefinitely, that is, if maintenance rabbit control became a regular part of land management.

Properties on which rabbits and other pest animals have been effectively managed may increase in value where property values reflect stock carrying capacity. Effective rabbit management promotes regeneration of perennial pasture plants and perennial shrubs and trees which make a property more drought resistant. It is, however, difficult to place dollar values on this.

Apart from the direct economic costs, the presence of rabbits limits management options. Land managers are reluctant to exclude stock from a paddock in order to provide reserve fodder if they think that the reserve fodder will be eaten by rabbits.

Several studies demonstrated that rabbit control was profitable in the 1980s when wool prices were high. The economics of rabbit control have not been estimated for the lower wool prices of the 1990s.

There is, however, little reliable quantitative information about the relationship between rabbit density and level of impact, or on the cost of control and its effectiveness for reducing damage, which makes economic cost–benefit modelling for rabbit management difficult and unreliable.

8.1 Economic framework

Economic frameworks are needed to assist in the assessment of the relative value of alternative control strategies. Such frameworks require: (1) definition of the economic problem; (2) data on the relative costs and benefits of various rabbit management strategies; and (3) an understanding of why the actions of individual landholders may not lead to optimal rabbit management.

Land managers can use such economic frameworks to select the most appropriate rabbit management strategy for their land and circumstances. If the strategies selected by individual land managers do not meet broader social goals, such as the need for conserving biological diversity or protecting the long-term productivity of the land by preventing land and vegetation degradation caused by rabbits, then an assessment of the socially equitable means by which governments can overcome these identified market failures is warranted.

8.2 Defining the economic problem and assessing the costs and benefits of control

Economic and environmental impacts of rabbits are described in Chapter 4. Land managers have a legal obligation to control rabbits. To determine the most appropriate rabbit management strategy, land managers will first need to consider which of these impacts are most significant for them, and attempt to estimate the cost of this damage in economic terms. They will then need to assess the costs and benefits of rabbit control.

8.2.1 Assessing costs and benefits

'There are sound ecological and practical reasons for conducting rabbit management when rabbit densities are lowest.'

An economically efficient rabbit control program would be one in which the last dollar of expenditure (incremental cost) is equal to the savings in production and conservation (incremental benefits) which are attributed to control. At present, suitable data are not available to estimate accurately the incremental costs and benefits of rabbit control, particularly the benefits. Ideally, land managers would use an economic model to evaluate these cost and benefit data for their properties and determine the most appropriate strategy to control their rabbits (Section 9.3.2).

There are many factors a land manager has to take into account when attempting to assess the economic costs and benefits of rabbit control. Some of these are discussed below.

Value used for gross margin

Commodity prices for meat and wool greatly influence the gross margin value used to calculate increased profit due to the potential capacity to run and turn off more sheep resulting from rabbit control. This can make it extremely difficult for land managers to estimate costs and benefits in many circumstances. For example, the Western Division economist for the Soil Conservation Service of New South Wales (SCS) had to issue three economic notes within a year to keep up with the rapidly changing economics of rabbit control due to changes in gross margins (Wynne 1990).

The economic break-even time for rabbit control on a property carrying 0.25 DSE per hectare was 0.87, 1.38 and 2.77 years for February, July and October 1990 respectively. Perhaps a more realistic figure for gross margin DSE per hectare would be the average over the last five years or half the average for the previous three years plus half the projected average for the next three years.

Rabbit density

Estimating absolute density of rabbits is difficult, and results have wide standard errors (Section 7.2). The only calibrated method for estimating the number of rabbits is counts of active warren entrances (Parer 1982a). For a count of 100 active entrances, the predicted number of rabbits is 60, but the 95% confidence interval is 32 to 111. Management may be economic for the upper figure and not for the lower figure.

'Ripping will have a longer lasting effect than poisoning, requiring less extensive maintenance control.'

In the rangelands, where rabbit densities may fluctuate widely over seasons, an estimate of the average density covering many years may be the appropriate figure to use. An economic model with current rabbit densities as data input would advise management to control rabbits only at moderate to high densities. However, there are sound ecological and practical reasons for conducting rabbit management when rabbit densities are lowest (Myers and Parker 1975a, b). Broadacre warren ripping requires time, and if management is undertaken only when a certain density is reached, considerable economic loss and environmental damage could occur before the initial treatment is completed. Furthermore, demand on available warren ripping machinery will be excessive because most farmers in a district will require the machinery at the same time.

Increase in production due to reduced number of rabbits

An accurately assessed figure for the relative food intake of sheep and rabbits is 16 rabbits = one DSE per hectare (Short 1985). Short used the large-framed western merinos in his experiments. A lower figure would be appropriate for the smaller sheep in higher rainfall country. Michelmore (1991) used 12 rabbits = one DSE per hectare. This or a lower figure may be appropriate if sheep cannot consume all the pasture available, as appears to be the case especially in good seasons. For example, with the rangelands of New South Wales, competition between rabbits and sheep may only occur when pasture biomass is less than 250 kilograms per hectare (Short 1985). However, rabbits are more selective grazers than sheep, eat the most nutritious components of a pasture and cause long-term pasture degradation. Consequently, a figure lower than 12 or 16 may be appropriate. The figure used to convert rabbit numbers to DSE per hectare will greatly affect the calculated economics of rabbit management.

Tax

There are taxation concessions for rabbit control — 100% deduction in the year of expenditure. The benefit of this will vary depending on each farmer's financial position. The benefits will be negligible for landholders who make little or no profit, a common situation for many rangeland properties.

Cost of control

The cost of rabbit control depends on the type of country, the method used and whether farmers use their own labour and equipment. For example, the destruction of warrens by ripping with contract crawler tractors operated by experienced operators can sometimes be cheaper than farmers doing the ripping themselves. An experienced operator with a crawler tractor can rip 200–300 warrens a day (Wynne, CaLM, NSW, pers. comm. 1992). An inexperienced operator with a wheel tractor may rip as few as one warren every 30 minutes (Martin and Atkinson 1978; Mutze 1991), or only 24 warrens a day (Wood 1985).

Discount rate

The discount rate used affects the calculated economics of rabbit control (Michelmore 1991). Over a 15-year period the net present value of ripping a warren is 2.7 times higher with a 3% discount rate compared to an 8% discount rate. Whilst the recommended rate is 8% in higher rainfall grazing areas, there is no general agreement as to the most appropriate rate for different costs and benefits (Braysher 1993).

Control strategy

'Incorporating maintenance rabbit control into normal farm management will result in annual control costs declining to low levels, at least in higher rainfall areas.'

Incorporating maintenance control into normal farm management will result in annual control costs declining to low levels, at least in higher rainfall grazing areas (Williams and Moore, in press; Section 8.3.3). Rabbit damage to production will be minimal as rabbits are always kept at low densities (Chapter 9). If control is undertaken only when there is a perceived problem, there will be less decline in annual costs and greater production losses. Economic data comparing these two strategies are not available, and results will vary locally and regionally depending on type of country, seasonal conditions and the rabbit density in adjacent paddocks.

Control techniques

Costs are affected by the control methods chosen and how long their effect lasts. For example, ripping will have a longer lasting effect than poisoning, requiring less extensive maintenance control. Even with warren ripping, the costs of follow-up work can vary greatly. Re-opening rates of ripped warrens can be as low as 12% after ten years on heavy soils (Mutze 1991) or as high as 62% after six months on sand dunes (Wood 1985). Required intervals between poisoning campaigns may vary from one to more than six years. Predicted costs also depend on future rainfall patterns and myxomatosis outbreaks.

Potential for rabbit numbers to increase

'Effective rabbit management promotes regeneration of perennial pasture plants and perennial shrubs and trees which makes a property much more drought resistant.'

In the higher rainfall areas of Australia, rabbit management on low density rabbit populations is sometimes undertaken as a form of insurance. It is assumed that without management, rabbit populations will explode. This assumption may be correct in some areas, but not in others. It is difficult to determine the likely effect on rabbit populations in a given area if management is relaxed. In New Zealand it was demonstrated that most rabbit control by shooting in the higher rainfall districts was a waste of money as the low density populations remained at low densities whether controlled or not (Williams and Robson 1985). This is, however, unlikely to be true for drier areas in Australia or areas with fluctuating rainfall.

Effectiveness of control (% kill)

Economic models use figures on the effectiveness of various rabbit control techniques that are based on experimental studies. However, the percentage kill in experimental studies is usually much higher than that obtained by farmers or even fully trained operators (Tomlinson 1959; Oliver 1983).

Increase in farm value

Properties on which rabbits and other pest animals have been effectively managed may increase in value where property values reflect stock carrying capacity. This factor should be included in calculations of the economics of management. For example, a grazier in the Flinders Ranges in South Australia spent $125 000 on rabbit control and increased the carrying capacity of the property by 3000 DSE (Hunt and Rasheed 1991). As a rough rule of thumb a property's value increases by five times the gross margin for each unit increase in DSE carrying capacity. For a gross margin of $10, the value of the South Australian property would have increased by $150 000 (3000x5x10) less the annual cost of maintaining low rabbit numbers, approximately $10 000.

Long-term improvement in pasture

Effective rabbit management promotes regeneration of perennial pasture plants and perennial shrubs and trees which make a property much more drought resistant (Wilson and Harrington 1984; Wilson et al. 1984; Hodgkinson 1992). It is, however, difficult to place dollar values on this.

Limits to increasing stocking rates

In much of the rangelands, maximum stocking rates are set by legislation, reducing the incentive of land managers to manage rabbits and other wild herbivores. If stocking rates cannot be increased after rabbit control then this may make the economic returns from rabbit management more doubtful (Michelmore 1991). Good managers should be rewarded for their efforts. The South Australian *Pastoral Land Management Act 1989* is an attempt to meet this need.

Even without increasing the stocking rate following rabbit control, it is likely to be profitable to manage rabbits. Conservative stocking can be more economic (Figure 26) for a number of reasons, including the survival of dry periods without destocking (Stafford-Smith and Foran 1988 and 1992; Meppem and Johnson 1990; Friedel et al. 1990; Hodgkinson 1993). Managing rabbits is not an end in itself, it is one step in the process

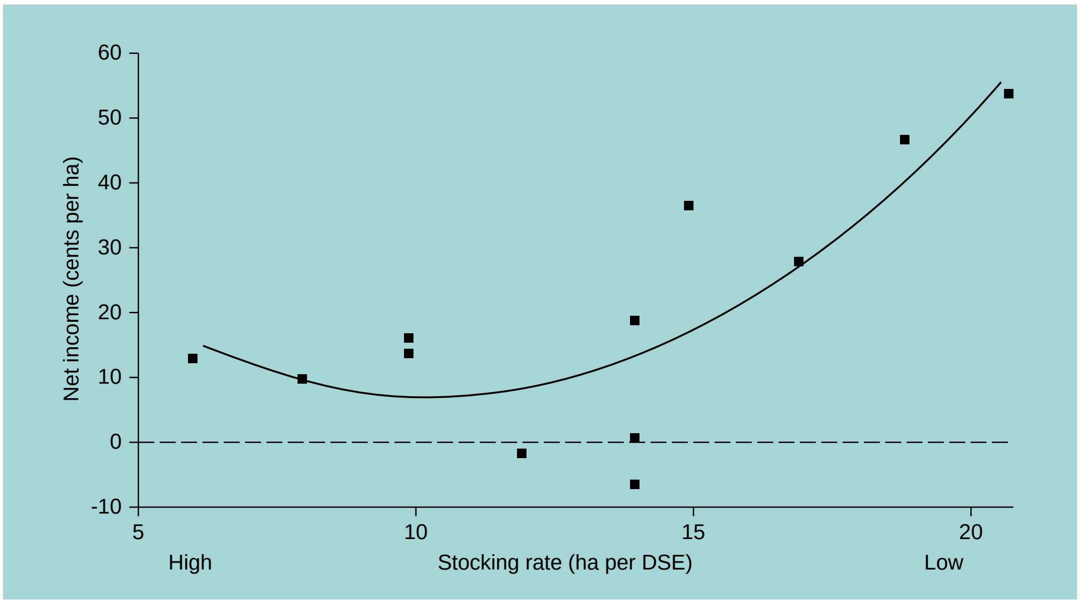

Figure 26: Results of an economic survey of 12 station properties in the winter rainfall zone of Western Australia showing the higher profitability on properties with lower stocking rates (after Friedel et al. 1990).

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Table 18: Hypothetical examples of benefits of rabbit control for properties with different stocking rates carrying 4000 DSE.

(a) Model 1: assumptions

- Gross margin/DSE = $10
- Initial rabbit density = 4/ha
- Post control rabbit density = 0/ha
- 1 sheep replaces 8 rabbits
- No increase in wool cut DSE/hectare
- No increase in lambing percentage
- Control costs are higher on country with high sheep carrying capacity as warrens are smaller, more difficult to find and are now usually only in the more difficult country. Maintenance costs are also higher as every year is favourable for rabbits, and recolonisation from neighbours is more probable because of smaller property sizes.
- Improvement in land value = 5 x gross margin increase
- Discount rates have not been considered

Type of property	High production	Moderate production	Low production
Stocking rate before control (DSE/ha)	4	1	0.25
Number of sheep	4 000	4 000	4 000
Size (ha)	1 000	4 000	16 000
Gross margin ($/ha) before control	40	10	2.5
Gross margin ($/ha) after control	42.5	12.5	5
% increase	6.3	25	100
Increase in property value ($)	10 000	40 000	160 000
Five-year control costs ($/ha)	7	5	3
Maintenance control costs ($/ha/yr)	0.25	0.2	0.15
Break-even time (years)	4	3	2

(b) Model 2: assumptions

- As for Model 1 except 32 rabbits = 1 DSE, that is only half the biomass which would have been consumed by rabbits can be productively used by sheep
- Initial rabbit density is 2/ha instead of 4/ha

Type of property	High production	Moderate production	Low production
Stocking rate before control (DSE/ha)	4	1	0.25
Gross margin/ha increase (%)	1.6	6.3	25
Increase in property value ($)	2 500	10 000	40 000
Break-even time (years)	18	12	6

If the stocking rate is not increased after control, the benefits of control will come from increased fleece weights, increased lambing percentages and better survival of lambs. In this situation rabbit control has higher returns on properties with higher carrying capacity as farm variable costs are lower and control costs for each DSE are lower. Wynne (1990) calculated that a property carrying 0.5 DSE/ha could recover control costs in 0.7 years; for a property carrying 0.125 DSE/ha it would take 2.8 years. (Assumptions: no increase in stock after control; wool value = $7/kg; lambing % = 75% before control, 90% after control; fleece weight = 6 kg before control, 6.5 kg after control).

of improving the ecologically sustainable use of the land.

It is commonly believed that rabbit management provides the greatest benefits in highly productive country. Control costs per stocking unit are lower in the better country but the proportion of the pasture being eaten by a given density of rabbits is much higher in low rainfall areas. Consequently, proportionally more sheep can be added to a low rainfall property than to the more productive property as a result of rabbit management. The economics of rabbit management are less clear where stocking rate cannot be increased after rabbit management, such as where water availability limits stock numbers, where legislation or industry restrictions limit stock numbers, or where the manager limits stock numbers to allow the land to recover (Michelmore 1991).

In the hypothetical example illustrated in Table 18, rabbit management gave the greatest return from the property with the lowest stocking rate prior to management. Gross margin per hectare increased by 6% on the property carrying four DSE per hectare but by 100% on a property carrying 0.25 DSE per hectare. It also shows that by varying only two of the assumptions, rabbit management can change from being economic (Table 18a) to uneconomic (Table 18b).

Apart from the direct economic costs, the presence of rabbits limits management options. Land managers are reluctant to exclude stock from a paddock in order to provide reserve fodder if they think that the reserve fodder will be eaten by rabbits.

8.2.2 Limits to knowledge about the costs and benefits of rabbit management

Currently it is difficult to estimate the economic returns from rabbit management because:

(1) There is little reliable quantitative information about the relationship between rabbit density and level of impact, or on the cost of control and its effectiveness for reducing damage.

(2) The relationship between rabbit density and the cost of damage differs according to the type of damage being considered. For example, in the rangelands, a density of less than one rabbit per hectare may be needed to allow tree and shrub regeneration (Lange and Graham 1983), but higher densities may be acceptable to protect other pasture plants or stock productivity.

(3) The cost of damage caused by rabbits is affected by other factors in addition to their density. For example, in the rangelands of western New South Wales, competition between rabbits and sheep may only occur when pasture biomass is less than 250 kilograms per hectare (Short 1985). Pasture biomass is largely dependent on rainfall and to a much lesser extent on total grazing pressure (Robertson 1987). So the effect of a given density of rabbits on stock productivity will be affected by pasture biomass, and when there is plenty of pasture, rabbits may not reduce stock productivity.

(4) Reducing rabbits to very low densities prevents them from rebounding quickly to high numbers when conditions are favourable. This will reduce future control costs. Therefore, although the initial costs of reducing rabbits to very low numbers may be high, relative to the immediate benefits, the cost of maintaining them there may be low, relative to the longer-term benefits.

The following are some generalisations:

- Rabbit management with high recurrent inputs, such as poisoning at two-yearly intervals, will be less profitable than long-term sustained management with warren and surface harbour destruction (Chapter 9).
- Effective rabbit management will almost always be profitable if rabbits are

generally at moderate (3–4 per hectare) and high densities. Management of these populations should be undertaken when rabbit densities are low to minimise costs and to increase effectiveness of the techniques.

- The greatest economic (wool clip, land values) benefits from management on an individual property are in the rangelands as it is there that the highest percentage of the pasture is being consumed by rabbits. However, because the large areas involved may make control costs high, sufficient ready cash to undertake rabbit control may not be available. Maintenance control is a fundamental component of rabbit management in the rangelands, especially to protect the large initial investment in ripping land and to facilitate long-term rehabilitation of the land.
- Management in areas where rabbits are usually at low densities (less than one per hectare) may or may not be profitable but even these low densities can prevent tree and shrub regeneration and affect the value of the property.

With the high wool prices of the 1980s rabbit control was calculated to give good economic returns for stock productivity. For example, Martin and Atkinson (1978) calculated that by the time a three-year warren ripping program has been completed, the capital outlay plus interest would have been repaid by increased productivity. Similarly, Mutze (1991) calculated a potential return in investment of 24% and Michelmore (1991) up to 67% for rabbit control in South Australian rangeland. The economics of rabbit management have not been estimated for the lower wool prices of the 1990s (Michelmore 1991).

8.2.3 Comparative costs and benefits

There are no published figures for rabbit control costs. The following figures indicate approximate costs of conventional rabbit control in large-scale contracts.

The cost of poisoning is relatively insensitive to variations in density of rabbits and warrens. Conversely, the cost of ripping can vary greatly depending on the type of country and warren density. The figure of $20 per hectare applies to rocky hills with a high density of warrens. Costs would be higher if a tractor had to be transported to a site for a small job. Cost per hectare of fumigation also varies depending on the density of warrens and the nature of the terrain and vegetation.

Cost of rabbit control

Method	Cost ($/ha)
Poisoning	6-8
Ripping	3-20
Fumigation	10-20
Explosives	30-60

Costs, efficacy and cost-effectiveness of combinations of the main conventional methods of rabbit management used in most Australian states have been compared experimentally (Table 19 and Williams and Moore, in press). The experimental plots were small compared to most commercial operations. The small scale of the study and the long edge zone relative to the total area favoured recolonisation by rabbits, which undoubtedly influenced the results. Also the researchers probably implemented the rabbit control more thoroughly than do many land managers (Oliver 1983). Nevertheless, the same relativities of costs and efficacy can be expected for the experimental and commercial operations.

Land managers usually know at least some of the costs of rabbit management operations, but efficacy is unlikely to be monitored, except by simple inspection immediately after implementation. The relative cost-effectiveness of the different techniques, or combinations of them, depends on the initial cost, the cost of maintenance control, and how the different treatments retard population resurgence. Techniques or combinations which are expensive initially may be more cost-effective in the long run, and vice-versa.

Table 19: Cumulative cost, effectiveness, and index of cost per benefit of combined treatments in an experimental rabbit control program in the Yass–Canberra district.

(i) Initial treatments without maintenance treatments

Treat-ment*	Cost	Effect-iveness	Cost per benefit
P	0.31	12	4.51
R	0.06	80	3.23
F	1.92	2	5.10
P+R	1.73	91	2.82
P+F	2.71	21	5.56
R+F	1.66	96	1.81
P+R+F	2.2	99	1.28

(ii) Initial treatments with three maintenance treatments

Treat-ment*	Cost	Effect-iveness	Cost per benefit
0+A	6.62	92	3.39
P+A	5.41	96	2.50
R+A	2.50	98	1.38
F+A	6.50	91	3.54
P+R+A	2.89	98	1.48
P+F+A	7.08	92	3.34
R+F+A	3.49	99	1.16
P+R+F+A	2.76	99	1.14

* Treatments: P = poisoning (1080 on oat bait), R = ripping (rubber-tyred tractor), F = pressure fumigation (chloropicrin), 0 = no initial treatment, A = three maintenance treatments of diffusion fumigation (phosphine) at 1, 6 and 18 months after completion of the initial treatment combinations.

Note: Costs are stated as dollars per initial number of active entrances; costs are cumulative over two years that included initial treatments and three maintenance treatments. Effectiveness is the percentage reduction in active entrances. Index of cost per benefit is the natural logarithm of the adjusted cost in dollars per proportional reduction in active entrances.

Outcomes were assessed at one and six months after the first and third maintenance treatments, and at one, six and nine months after the second maintenance treatment. Cumulative costs are shown for the final assessment. Effectiveness and cost-effectiveness were averaged over seven assessments made during the first two years.

The experimental data (Table 19) indicate that:

- Costs alone are poor indicators of cost-effectiveness. Poisoning by itself was cheap initially but ineffective in the medium term, and it was very expensive relative to the benefit obtained.
- Some combinations of treatments achieved a very high level of control for little more cost than some single treatments, and at much lower cost per benefit obtained.
- Combinations which included warren ripping, compared to treatment combinations which lacked ripping, were cheap, highly efficacious and cost little per benefit obtained.
- The initial cost of pressure fumigation was high, and that of diffusion fumigation was very high. Both techniques are laborious and therefore expensive. Treatment efficacy and cost-effectiveness of pressure fumigation were extremely low. Diffusion fumigation was efficacious after three applications, but initially, after the first treatment, there was substantial recolonisation.
- The high cost of diffusion fumigation indicates that re-ripping may be a cheaper maintenance treatment, depending on the location and number of warrens needing re-treatment, and on the economics of transporting the tractor to the re-opened warren.

No control techniques are foolproof. A ripping job done badly, because, for example, many warrens were not found or many surface rabbits were not driven underground by dogs, can waste as much money as a badly implemented poisoning operation. The percentage of rabbits killed can vary from 50% for poorly conducted poisoning operations to 98% for well executed operations. Well executed operations may also waste money if there is no ongoing maintenance to protect the investment.

8.3 Economic framework for strategic, sustained management

The costs and benefits of strategic, sustained management (SSM) are discussed in this section. While the costs and benefits of rabbit control are poorly known in many instances, land managers need to consider the value they place on the components of these unquantified costs and benefits when deciding which control strategy to adopt.

SSM is the strategy which the authors and experienced rabbit control personnel agree is the most practical way to control rabbits in most circumstances. SSM aims to reduce rabbits to very low levels by an *initial control* campaign and to suppress increase by frequent *maintenance control*. Under SSM regular repetition of maintenance control progressively reduces rabbit numbers while the required effort and cost decline concurrently (Section 8.3.2).

'Strategic, sustained management is the strategy which the authors and experienced rabbit control personnel agree is the most practical way to control rabbits in most circumstances.'

Land managers will need to estimate the costs of SSM, considering initial, maintenance and total costs and how these may change during drought. They will then need to make similar estimates for the benefits. Finally they will need to compare these estimates with those for costs and benefits of alternative control strategies (Section 9.3).

8.3.1 Estimated cost of initial control in strategic, sustained management

SSM requires the initial control campaign to reduce rabbit numbers to low levels — lower than the minimum level that a land manager might think likely to damage a current crop or likely to affect the availability of pasture for stock over the following year. SSM takes account of the rabbit's high reproductive capacity and ability to rapidly recolonise. If conducted effectively, initial control is all or nothing, so little additional effort is necessary to reduce rabbits to the required low densities. The choice land managers must make when considering costs and benefits is the degree and frequency of maintenance control. Implementing SSM will greatly reduce the need for and hence the cost of maintenance control. The additional cost for achieving and maintaining low densities may be higher for labour-intensive methods such as warren fumigation, although these techniques should be used only when or where warren ripping is impossible, so the cost increment for these methods also may be small. Experimental measurement of costs of initial control by poisoning (Figure 27a) and warren ripping (Figure 27b) show that cost per active entrance does not increase sharply for lower densities of active entrances (and therefore lower densities of rabbits — Section 7.2.6). Costs of fumigation behave similarly (Figure 27c) (Williams and Moore, in press).

The approximate commercial costs of various methods of rabbit control are shown in Section 8.2. The costs of experimental combinations of control methods are compared in Section 8.2 and Table 19. No data are available to compare the costs of SSM with other strategies such as no control, or strategic, targeted management (Section 9.3.2) which aims to control rabbits to a specified density at which the level of immediate or near-future impact on the existing crop or pasture or other resource is considered to be acceptable.

8.3.2 Estimated cost of maintenance control in strategic, sustained management

Any additional cost of the initial control component of SSM may be offset by the higher long-term costs of the alternative

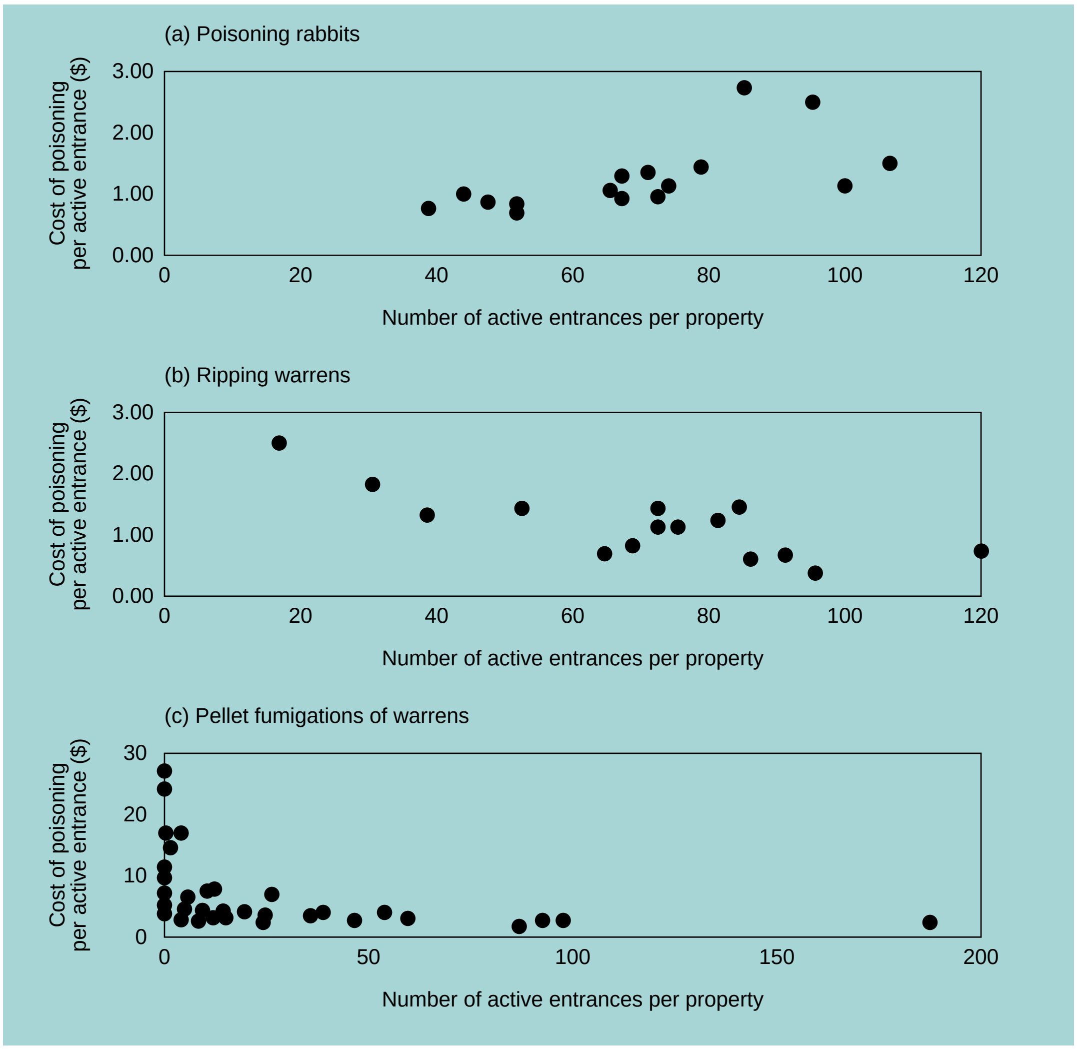

Figure 27a-c: Experimental costs of control for rabbits at different densities on a property near Yass, New South Wales.

(a) Costs of 1080 poisoning. Costs per active entrance remain relatively constant for various medium densities of rabbits on the property; no data are available for very low densities of rabbits.

(b) Costs of warren ripping. Costs remain low for medium densities of rabbits and increase gradually as density decreases to low values.

(c) Costs of pellet diffusion fumigation. Costs per active entrance remain low over a wide range of densities, increasing sharply only at extremely low densities.

NB For the non-breeding period, 1.6 active warren entrances equals one adult rabbit.

strategies which are likely to require the initial control campaign to be repeated perhaps two or more years later when rabbit numbers have increased again in the absence of the maintenance control that is an integral part of SSM. To select the appropriate management strategy, the probable costs of regular maintenance control need to be compared with the probable costs of less frequent repetition of substantial control campaigns.

The costs of maintenance control have been determined experimentally (Williams and Moore, in press). These estimates of costs may be higher than actual costs on a production property where much of the

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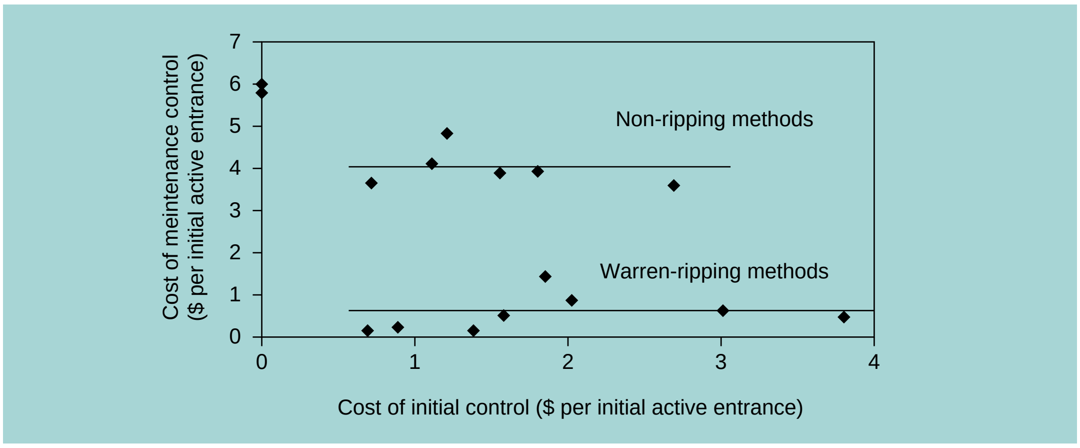

Figure 28: Cost of maintenance control relative to initial control by methods including or excluding warren ripping (Williams and Moore, unpublished data 1994).

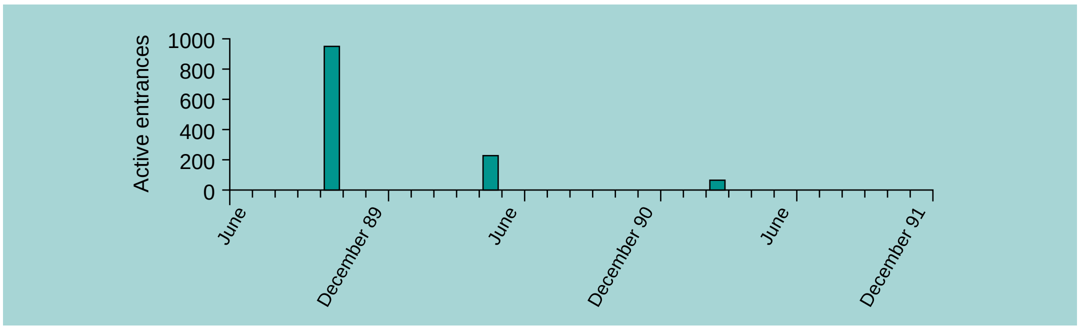

Figure 29: Reduction of rabbit populations by repeated maintenance control in an experimental program of strategic, sustained management.

Numbers of active entrances on experimental sites treated by pellet diffusion fumigation on three occasions in two years (Williams and Moore, in press). The numbers of active entrances were approximately halved on each implementation. Costs reduced similarly.

maintenance control may be undertaken opportunistically in the course of performing other tasks on the property. These data demonstrate the following important points:

(i) The costs of maintenance control are highly dependent on the method of initial control. Methods or combinations that include warren ripping confer much greater economy on maintenance control. Non-ripping methods in the initial control reduce costs of maintenance control by about 33% compared to a reduction of about 92% for warren ripping methods in the initial control (Figure 28).

(ii) When the initial control is done thoroughly, the cost of maintenance control is largely independent of the difficulty and cost of the initial control (Figure 28). This means the cost of maintenance control can be reduced to relatively low levels even in country where rabbit control is difficult.

(iii) The effort and cost of maintenance control reduces markedly, by about half, with each subsequent implementation (Figures 29 and 30), provided maintenance control is undertaken frequently, say annually, or three times in two years as in the experimental data.

(iv) The cost of maintenance control per rabbit or active entrance remains constant even to extremely low densities of rabbits, increasing only near zero (Figure 27c). The important cost is not the cost per rabbit but the total cost of maintenance control on the property, which declines steadily as the numbers of rabbits on the property are reduced (Figures 29 and 30). Costs can be expected to decline further as the land manager repeats monitoring and maintenance treatment and acquires knowledge of such factors as the areas, terrain, and soil types where recolonisation or warren re-opening recur.

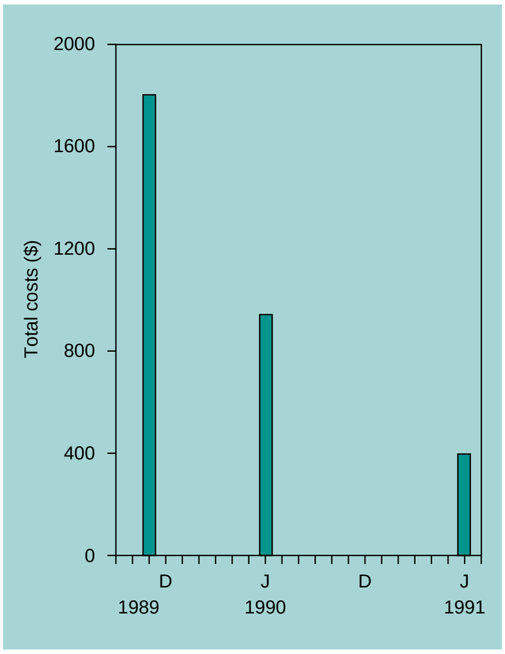

Figure 30: Declining cost of successive maintenance treatments by phosphine diffusion fumigation in experimental trials. Initial treatments of warrens on 16 sites included all combinations of poisoning, ripping and pressure fumigation (Williams and Moore, in press).

8.3.3 Estimated benefits of maintenance control in strategic, sustained management

The experimental data comparing treatment combinations including or excluding three maintenance treatments (Table 19) show that:

- all treatment combinations that included maintenance treatments were highly effective, and many were highly cost-effective;
- some initial treatments greatly reduced the cost of maintenance treatments by diffusion fumigation, as in (1) ripping + three treatments of diffusion fumigation; (2) poisoning + ripping + three treatments of diffusion fumigation; and (3) poisoning + ripping + pressure fumigation + three treatments of diffusion fumigation;
- some initial treatments failed to reduce the cost of maintenance treatments by diffusion fumigation as in (1) poisoning + three treatments of diffusion fumigation; (2) poisoning + pressure fumigation + three treatments of diffusion fumigation; and (3) three treatments of diffusion fumigation alone;
- the cost per benefit was very low for some treatment combinations, especially (1) ripping + three treatments of diffusion fumigation; (2) poisoning + ripping + three treatments of diffusion fumigation; (3) poisoning + pressure fumigation + three treatments of diffusion fumigation; and (4) poisoning + ripping + pressure fumigation + three treatments of diffusion fumigation;
- inclusion of ripping + three treatments of diffusion fumigation in the combined treatments, with or without other techniques, lowered costs, increased effectiveness and reduced the cost per benefit;
- therefore the best treatment combinations include ripping with follow-on maintenance treatment.

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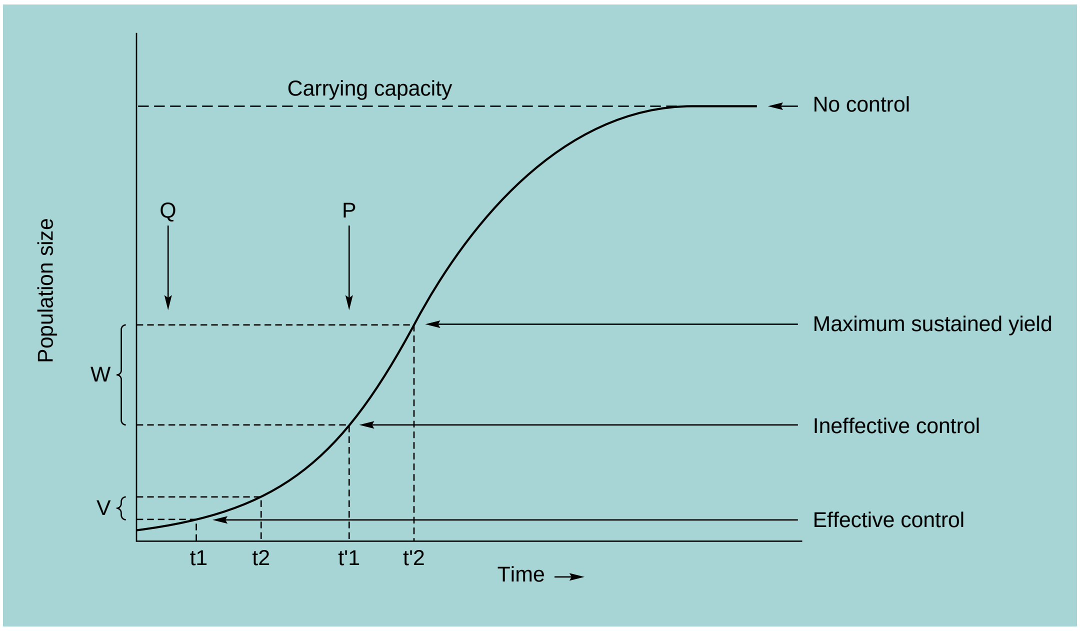

Figure 31: Growth rate (logistic) of a rabbit population at different sizes (modified from Krebs 1972). Over time t1 to t2, a very small population grows by a small amount (V), whereas a larger population grows over the same time interval t'1 to t'2 by a much larger amount (W).

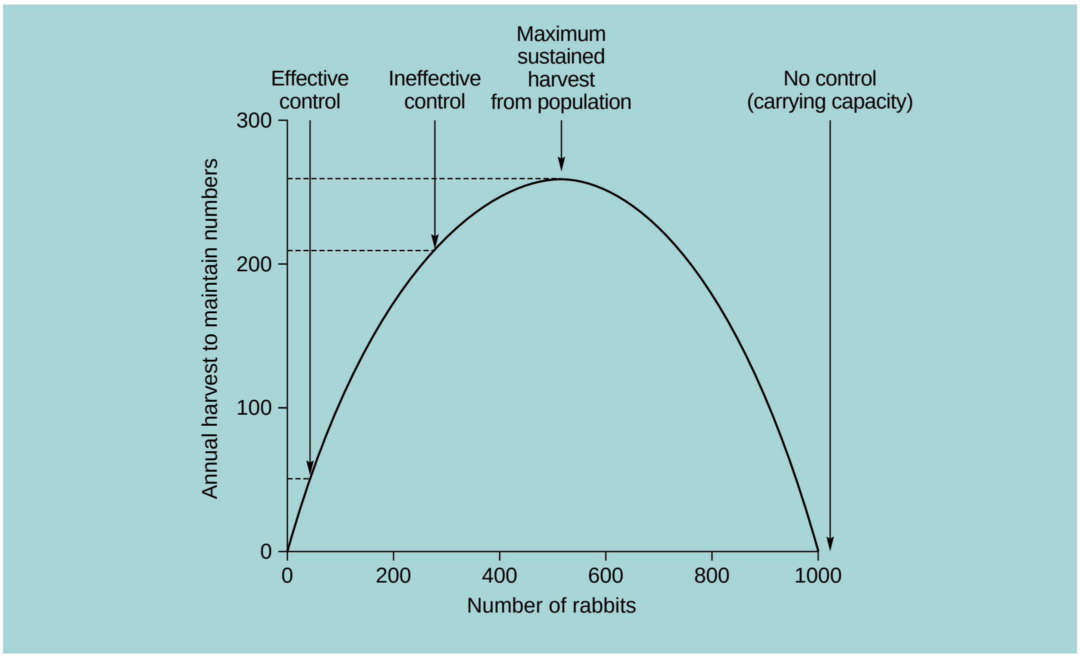

Figure 32: Hypothetical harvest curve for a rabbit population in an area with a maximum carrying capacity of 1000 rabbits. Effective management requires removal of 50 rabbits per year to maintain the population at 50 rabbits. With less effective management, say to 220 rabbits, 210 rabbits have to be removed per year to maintain the population at 220.

Rabbit management becomes progressively cheaper as repeated maintenance treatments achieve higher levels of control. Figure 30 shows that the experimental cost of maintenance treatment declined with repetition, approximately halving for each successive maintenance treatment. Costs can be expected to decline to a low, slowly-declining plateau after about 4–5 maintenance treatments. Therefore, a land manager would receive greatest return on investment in rabbit management if maintenance treatments were repeated indefinitely, that is, if maintenance rabbit control became a regular part of land management. Figure 11 demonstrates the converse, that is, the wastage of the investment in the initial control campaign because of the failure to maintain control.

8.3.4 Cost of suppressing increase in rabbit numbers

The cost of controlling rabbits depends on the numbers of warrens on the property. The number of warrens and burrows increases with rabbit numbers. The rate of increase of rabbits differs for different starting densities of rabbits (Figures 31 and 32). The increase in rabbit numbers would be small (V in Figure 31) when populations have been reduced to very low levels from which they increase over say one year (t1 to t2 in Figure 31). The effort and time required to reduce them back to the starting density Q or lower would be small also. Where the numbers of rabbits are higher, say at P, after the control campaign, an increase in the population over the same time interval (t'1 to t'2 in Figure 31) may mean a big increase in the numbers of rabbits on the property (W in Figure 31) and in the resulting effort, time and cost required for control of the rabbit population back to the starting density P. Reduction of rabbit numbers to low levels by the initial campaign of SSM enables repeated maintenance control to succeed in suppressing increase with low effort and cost. Control only to higher densities in the initial control campaign may require subsequent expenditure and effort resembling those of the initial campaign, with loss of flexibility in timing and choice in price of equipment and services.

8.3.5 Internal benefits of strategic, sustained management

'The implementation of strategic, sustained management can improve good neighbour relations.'

SSM may confer many varied benefits on a property, some tangible, some social, and others that facilitate property management. All of the benefits identified are difficult to measure and none have been quantified adequately. Nevertheless, they are important factors that land managers need to consider as part of rabbit management. Identified benefits are described below.

Benefits to production

Reduction of rabbit numbers by control has an immediate effect in reducing rabbit consumption of crops and pastures. Implementing SSM will reduce rabbit densities to levels lower than those expected to benefit current production, but benefits will accrue to production in following years through maintenance of perennial species and nutritious species in pastures and areas of native vegetation.

Benefits to retention of perennial pastures, trees and shrubs and biological diversity

Reduction of rabbits to very low densities may enable recovery or regeneration of some perennial pasture, shrub and tree species (Section 4.3). Retention of these perennial species may prevent loss of soil and seed banks during dry times when annual species have died, dried and disintegrated, consequently opening up the land to soil erosion and reducing the level of biological diversity. Failure to control rabbits to very low numbers may not protect the seedlings of perennial pasture, shrubs

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and trees from total removal through rabbit grazing (Section 4.3).

Benefits to revegetation programs

Planting tree and shrub seedlings to combat soil erosion or salination is common. Even at relatively low rabbit densities it is usually necessary to protect plantings with rabbit-proof fencing or tree guards. SSM can reduce rabbits to densities where plantings can be protected by plain wire stock fencing, rather than expensive netting (B. Coman, Vernox Pest Management, unpublished 1994).

Benefits in preparedness for drought

Reducing rabbits to very low densities and suppressing increase would assist conservation of pasture reserves for droughts. Contingency planning for drought requires landholders to stock conservatively, minimise losses to rabbits and other wild grazers, and promote the retention of nutritious perennial species in pasture and other vegetation. During droughts rabbits may have greatest impact on the surviving perennial species, removing juvenile plants that may have survived since previous regeneration events, and killing adult plants by severe grazing or browsing and ring-barking. The demands of drought on funds, labour and time may prevent rabbit control from being undertaken at that time, although this is often the most opportune time for control, namely when rabbit populations are very low. SSM will reduce rabbits to low densities and so provide feed reserves, and the detrimental impact of drought will be less (see Section 9.2.1). Higher densities of rabbits would severely jeopardise these benefits during droughts.

Benefits in relations with neighbouring land managers

The implementation of SSM can improve good neighbour relations. Failure to reduce rabbits to low densities can compromise the level of control a neighbour can achieve due to invasion. Cooperation among neighbours, perhaps in group schemes or simply informally, tends to convert former antagonism over rabbit invasion to mutual encouragement and support, and accrues many benefits in cost-efficiency of the control program, such as the ability to work jointly from boundaries, sharing labour and equipment, and greater ability to undertake control at opportune times. Higher densities of rabbits on the property will not allow neighbours the same degree of confidence and trust.

Benefits in flexibility of land management

Regular suppression of rabbits after numbers have been reduced to low levels enables a more relaxed schedule for rabbit control and for other land management tasks. SSM allows for the time required to implement control relative to the time required to suppress increasing populations. Section 8.3.3 explains how higher density populations increase in numbers much more quickly than low density populations and how much more effort, time and expenditure are required to reduce the population back to former levels. Depending on the starting density, containment of the burgeoning population may not be possible because of its rapid growth and the time required to implement control. Rabbit density increases much more slowly from low density populations and land managers have more time to initiate control. Control also requires much less time to complete. Rabbits that are controlled only to higher densities impose much more on schedules for other land management tasks, many of which also have little flexibility. SSM contributes to flexibility of management schedules in other ways, such as requiring little information on the current status of the rabbit population and its impact. Higher densities of rabbits and their impact would require frequent monitoring to determine when action is necessary. In addition, rabbit control techniques such as poisoning require reserve areas where farmers can place stock during and following poisoning until it is safe to restock. SSM eliminates the need for these areas.

8.3.6 Estimated external benefits of strategic, sustained management

Benefits to neighbouring private and government land

Implementation of SSM on a property would prevent invasion of neighbouring land and facilitate the achievement of similar levels of control with reduction in costs of control. Then the neighbouring land could receive the flow-on benefits in other aspects of land management for production and conservation described in Section 8.3.4.

Benefits to the economy

(i) Improvements in efficiency of production may improve the competitive status of Australian produce for overseas markets, perhaps securing sales that otherwise may be lost to competitors.

(ii) Increased profitability of production properties should lead to increased tax revenue.

(iii) Reducing costs of rabbit control should reduce claims for tax concessions for rabbit control. This benefit may be dampened slightly by presently unprofitable properties beginning to show a profit and claiming the concession.

Benefits to the Australian public, present and future

Probably the most important and the least quantifiable external benefit of implementation of SSM is the improvement of conservation of native biota and the flow-on to conservation of soils on both private and public lands. The benefits to society are many and varied and can be listed here only in broad categories.

(i) Reduction in the rate of desertification of the rangelands and possibly its regeneration will obviate many costs and detriments to inland and higher rainfall areas that would otherwise be subject to dust and siltation of waterways and dams (see Section 4.2 and Figure 21).

(ii) Retention of biological diversity in regions varying from arid to high rainfall accrues economic benefits to production and tourism.

(iii) Aesthetic values of retention and restoration of biological diversity are extremely important for present generations, as shown by the extent and depth of present public interest in issues of conservation. These values are likely to increase in importance to future generations as the human population grows and competition for use of space and resources increases.

In some circumstances, individual land managers may choose a strategy other than SSM because they consider that it is the optimal economic strategy to meet their rabbit control objectives, or because they do not have the resources to implement SSM. These alternative strategies may not provide the above conservation benefits. If such cases are sufficiently frequent that collective private actions are not meeting the public good, this may warrant an assessment of means by which governments can intervene to meet these broader conservation benefits that are important to the Australian public.

8.3.7 Comparison of costs and benefits of strategic, sustained management

The choice of levels at which to control rabbits range from very low densities achieved by SSM, assuming that eradication is impractical on a wide scale, through higher levels of rabbit density using strategic, targeted management, to no control at which rabbit density fluctuates around the current carrying capacity of the land. A rational choice would identify the density at which the total sum of all benefits exceeds the total sum of all costs by the widest margin. The costs and benefits are unknown for most components identified, and many, such as conservation values and neighbourly relations, are difficult to quantify in economic terms.

While many of the components of benefit will be difficult to quantify, it is useful to quantify others in controlled studies. Knowledge of benefits such as increased value of production relative to control costs, where rabbits are reduced to low densities, may assist some graziers in rangelands to re-assess the level of rabbit control required, including whether to undertake SSM. Some components of benefit are being examined by the Vertebrate Pest Program of the Bureau of Resource Sciences (see Introduction, page 13).

8.3.8 Adoption of strategic, sustained management, land managers knowledge base and attitude to risk

Whether land managers adopt SSM or not will depend in part on their attitude to risk. Those averse to risk will be more likely to adopt SSM. This is because they are willing to accept the possibility of small annual losses as they control rabbits to below the level which is economically optimal for short-term damage management, so that they can avoid occasional large annual production losses. Those more willing to take the chance that circumstances will be favourable will be less inclined to implement SSM. However, of far greater importance is the land manager's understanding of the factors involved in determining rabbit impact and their judgement of the probabilities that significant events will occur.

Weather sequences are paramount. Many of these factors have been discussed in Sections 8.2.1 and 8.3.5 and include the likelihood of drought, commodity prices, farm and family contingency planning, the ability of rabbits to rapidly rebound from moderate densities, and the cost and ready availability of equipment such as bait layers and tractors for warren ripping. The chance of drought or high rainfall in the near future are barely predictable and never certain. Neither scientists nor land managers can predict the advent of biological control events such as myxomatosis epizootics. The effects of predators in suppressing increase in rabbit populations in Australia have been demonstrated only recently, and cannot be predicted. In addition, the rate of increase of rabbit populations after rainfall is uncertain for most regions, and of little use for making economic decisions on implementing rabbit control. These and other factors must be judged in the context of varying commodity prices, management of stock or crops, infrastructure, and the land, as well as management of staff, finances, and family contingencies. Given such complexity, and without good quantification of all the tangible and intangible costs and benefits of rabbit impact and control, there would seem to be benefits in adopting the SSM approach that: (1) protects the valued resources irrespective of unpredictable weather sequences; (2) conserves the productive base in the long term; (3) functions effectively and efficiently with only limited information on rabbit abundance and impact; (4) allows maximum flexibility in management of rabbit impact and other land management; and (5) declines rapidly in cost and required effort after an initial substantial commitment of labour and cost that can be planned and prepared for in advance.

This is the basis of the precautionary principle for the conservation of non-renewable resources (Intergovernmental Agreement on the Environment 1992). The ability of land managers to meet the initial outlay of money and labour is critical for the adoption of SSM. Research is needed to assess whether landholders have access to these resources. If these resources are found to be inadequate, incentives or other actions need to be identified and implemented where this is appropriate.

9. Strategic Management at the Local and Regional Levels: Principles

Summary

Strategic management of rabbits at the local and regional levels has four stages: defining the problem; developing a management plan; implementing the plan; and monitoring progress.

Defining the problem *— Managers must identifiy the resource being damaged by rabbits, such as vegetation, soil, production, or some combination of these. Other factors can influence the problem, including other pests, weeds, climate, soil fertility, or management practice. The damage needs to be allocated between that due to rabbits and that due to other factors. This requires defining the economic or environmental impact of rabbits. The relationship between rabbit density and the damage they cause can be established only by properly designed studies. Until these studies are concluded, most managers will rely on measuring the abundance and distribution of rabbits or their warrens, and assume damage is directly related to density.*

Developing a management plan *— Managers must set clear objectives in terms of the production or conservation outcome being sought. The ultimate goal, at least on private land in southern Australia, is to reduce rabbits to where, for all practical purposes, the land is rabbit free. The management plan should recognise that the system being managed, whether an agricultural or pastoral property, or a conservation area, is complex. Knowledge, including scientific knowledge, about these systems is always incomplete. Management is further complicated by the dynamics of ecological systems which are mainly caused by fluctuations in weather and the impacts of management. A fixed and predetermined plan is inappropriate. The approach recommended is management which is flexible and responsive to changed conditions, and refined in the light of experience.*

Options for rabbit management include local eradication, strategic management or no management. These guidelines strongly recommend strategic, sustained management. Ideally, rabbit management aims to reduce rabbit damage to the level where the benefits of management exceed its costs, but this aim cannot be achieved in practice. This approach requires knowledge of the relationship between rabbit density and the costs and benefits of management. This is difficult and costly to determine, and it is unlikely that the rabbit, with its high reproductive potential, could be managed with this degree of precision. Therefore, for most circumstances, it is assumed that rabbit damage is related to rabbit density, although it is recognised that there is not always a direct correlation between rabbit numbers and levels of damage. For example, there is evidence that in the rangelands of New South Wales, competition between sheep and rabbits only occurs when pasture biomass is less than 250 kilograms per hectare. The relationship between rabbit density and level of damage will vary with both the type of damage being considered and other factors, such as the total grazing impact from all species, and variation in the vegetation cover. This, of course, has major implications for the selection of appropriate management strategies for rabbits in relation to different land uses and changes in market prices for wool, other commodities and for conservation values which are affected by rabbits.

In the authors' opinion, based mainly on data from field trials, the experience of Rural Lands Protection Boards and rabbit population ecology, reducing and maintaining rabbit populations at minimum densities is more likely to be profitable than some lesser level of control to densities from which rabbit populations can rapidly rebound. Even where resource

damage only occurs when rabbit numbers are high, it is probably most cost-effective to maintain rabbits at very low densities at all times. The relative cost-effectiveness of aiming for sustained minimum levels as a long-term strategy will depend on the cost of this level of rabbit control relative to the benefits resulting from control, in comparison to the cost–benefit ratios of some lesser level of control or no control. The extra cost of achieving very low rabbit numbers can be offset by reduced costs of maintaining control at low numbers and reduced impacts.

The management plan should relate to a sizeable local or regional area, encompassing many properties and land uses. Based on the mapping carried out in the problem definition stage, and having established the objectives, the area should be divided into management units, delineated by natural barriers to rabbit movements. Milestones, stating what is to be achieved and by when, and criteria which indicate whether the management objective is being met, are useful indicators of progress.

The management plan would describe a control strategy, setting out which control procedures will be carried out at which stage in the management process. Strategic, sustained management relies on an initial broad-scale treatment to achieve a major reduction in the rabbit population, with maintenance control dealing with the survivors and immigrants. The choice of the initial and maintenance control techniques depends mostly on the extent to which rabbits shelter by day in surface cover or in underground warrens or burrows. This in turn depends on the type and extent of available shelter. Different strategies may be necessary for each management unit.

***Implementing the plan —** Group action is an essential element in implementing a plan. Those who will be major beneficiaries of the rabbit management program or who have a significant stake in the outcome should be involved in the development and implementation of the management plan. This will foster a sense of ownership of and commitment to the plan, and increase the likelihood of the outcome satisfying everybody involved including government agencies in their roles as policy formulators, regulators and land managers.*

***Monitoring and evaluation —** Monitoring ensures that the management plan is executed in the most economical manner and enables the control strategy to be refined if necessary. In addition, the effectiveness of the program in achieving its objectives (e.g. increased production or reduction in rabbit damage) needs to be monitored so that the goals can be modified if necessary.*

9.1 Introduction

The four steps involved in the strategic approach to rabbit management are problem definition, developing a management plan, implementing the plan, and monitoring progress. The challenge is to develop strategic management of rabbit damage at the local and regional level, using all available knowledge (described in the preceding chapters) and taking into account how the land is being used.

'The challenge is to develop strategic management of rabbit damage at the local and regional level, using available knowledge and taking into account how the land is being used.'

This Chapter explains how strategic, sustained management of rabbits at the property level might be achieved in cropping and grazing lands and low production rangelands. The strategic management of rabbits in forestry plantations and conservation areas is described in Appendices B and C. Chapter 10 then reviews four schemes where many elements of the strategic management approach are being adopted.

9.2 Defining the problem

9.2.1 Economic impact

On farms

The economic impact of the rabbit on farms is likely to include: (1) reduced production of cereal crops adjacent to uncropped areas such as mallee, windbreaks, roadside verges and rocky outcrops, for distances up to about 75–100 metres into the crop; (2) degradation of improved and unimproved pastures with reduction or loss of perennial species; and (3) reduced production of wool and sheep liveweight.

Few farmers can assess the cost to production and conservation caused by rabbits on their properties. An indication of the level of damage may be possible through comparison of production figures over several years with those of equivalent properties in the district on which rabbits do not occur or have been reduced to minimal levels. Alternatively, the farmer might undertake sustained rabbit management and compare production data with those of equivalent properties in the district where rabbits are not managed. For both comparisons, the effects of rabbits may be obscured by variations between or within properties due to rainfall, soil fertility and farming practices such as fertiliser application, crop seed varieties, stock types and grazing intensities.

Low production rangelands

The possible economic impacts of rabbits on low production rangelands are: (1) reduced production of wool and liveweight of sheep and cattle, especially in dry periods when pasture biomass is reduced below the level at which rabbits, sheep, kangaroos and other herbivores compete for pasture — 250 kilograms per hectare for some parts of the rangelands (Short 1985); (2) depletion of drought food reserves, which has implications for profitability and management of stock; and (3) degradation of pastures from the more stable perennial grasses and forbs to annuals.

The economic cost of rabbits to grazing enterprises in rangelands during droughts are recognised but not well quantified (Section 4.2) (Wood and Stanger, CSIRO, unpub. 1990). This includes: (1) depletion of drought feed reserves; (2) the need to reduce stock numbers; (3) selling at depressed market prices; (4) cost of stock transport and agistment and reduced stock numbers; (5) reduced lambing percentages; and (6) reduced fleeceweights and liveweights for both sale and survival.

9.2.2 Environmental impact

On farms

The environmental impact of rabbits on farms includes: (1) negligible regeneration of native shrubs and trees; (2) reduced recruitment in small native animal species; and (3) soil erosion on slopes, in creeks and gullies and around warrens. The environmental impacts such as soil erosion will contribute to the economic impacts.

Low production rangelands

The likely environmental impact of rabbits on low production rangelands are: (1) increased soil erosion due to loss of perennial herbage as well as disturbance of soil by rabbits; (2) increased woody weed species which suppress herbage and thereby contribute to soil erosion; (3) prevention of regeneration of native tree and shrub species and other perennials such as saltbush; and (4) reduced or negligible recruitment of small native animal species.

9.2.3 Measuring impact

General factors likely to affect rabbit impact include: (1) land and soil type and their distribution; (2) the size of the areas infested; (3) the distribution and abundance of rabbits including their abundance above ground; (4) the amount of surface harbour, native vegetation, weeds, logs, rock piles and their conservation value; (5) the presence and incidence of myxomatosis and its vectors; (6) the presence, abundance and impact of other pest species; and (7) the abundance of birds of prey, goannas, foxes and feral cats.

In most cases, managers do not measure rabbit damage directly, but use indicators of rabbit density to estimate damage. The relationship between rabbit density and damage can be established only by replicated, statistically designed studies (Section 7.1). In the interim, managers will rely mainly on estimates of rabbit density to indicate damage and assume damage is related directly to density. Methods for estimating rabbit abundance are described in Section 7.2.

On farms

Special factors likely to affect rabbit impact on farms include: (1) the type of crop and whether it is palatable, nutritious and accessible to rabbits; (2) the growth stages of crops and their vulnerability; (3) the presence and status of rabbits on neighbouring properties; (4) whether neighbours control rabbits and whether there is an effective netted rabbit-proof boundary; (5) the position and condition of internal natural barriers and rabbit-proof fences; and (6) the extent to which pastures are grazed. Rabbits prefer short-cropped pasture both for food and the early detection of predators.

The assumption that rabbit impact is directly related to rabbit density may be true for crop damage but not necessarily for grazing enterprises. In a series of years of above-average rainfall, no difference in wool production was detectable on New South Wales grazing properties for a range of rabbit densities (Williams 1991). In addition, rabbits may prevent regeneration of some native plants even at very low rabbit densities due to the plants being highly palatable (Section 4.3.2).

To measure rabbit impacts, farmers could monitor the composition of vegetation by taking annual standardised photographs of fixed plots in controlled and uncontrolled areas. Similar standardised photographic records could be made of soil surfaces with depth markerpegs at set locations that are vulnerable to erosion. The photographic sequence, if properly labelled and catalogued, can alert the farmer to trends of further deterioration or improvement after effective rabbit management. These procedures would help indicate whether residual rabbits at existing densities threaten the soils, pastures and vegetation, and whether priority for initial or maintenance treatment should be increased.

Low production rangelands

Special factors affecting rabbit impact on rangelands are: (1) stocking rates; (2) densities of native and feral herbivores; (3) distribution of water points; (4) stock grazing patterns; (5) the extent of degradation of the rangeland; (6) whether or not adjoining properties control rabbits; (7) internal and external rabbit-proof fences; and (8) seasonal conditions such as drought.

In the absence of direct quantification, graziers on the rangelands often grossly under-estimate the number of rabbits and warrens on their properties and hence rabbit impact on pasture and vegetation (Tatnell 1991; W. Tatnell, CaLM, pers. comm. 1993). Counting the number of warrens per unit area of land type, based on strip transect counts, is the best method of assessing rabbit abundance (Section 7.2).

The impact of rabbits in rangelands is often confounded by grazing effects of sheep and cattle, kangaroos and a variety of feral herbivores. Total grazing impact, not just that of livestock and rabbits, needs to be managed to combat land degradation in arid and semi-arid regions (Tatnell 1991). Most graziers do not have the knowledge, time or equipment to measure and apportion the impact of each grazing group. It is a complicated task for qualified scientists and requires further study (Section 7.1). However, most graziers would benefit from approximate knowledge of numbers of the various feral herbivores on their properties, obtained in the most systematic manner feasible for them (Section 12.4).

9.2.4 Mapping

On farms

An overview of the rabbit distribution and relative densities on a farm or group of properties is best obtained by mapping this information on whole-farm plans. Maps may range from hand-drawn charts for smaller operations to computerised databases for large operations that may include group schemes (Section 7.3).

Low production rangelands

Subtle patterns are likely to be revealed by mapping. For rangeland properties, assessing rabbit damage and determining how to manage it requires a formal map classifying land type as either land systems or land units. Geographic information systems (GISs) are ideal, especially for group schemes.

'An overview of rabbit distribution and relative densities on a farm or group of properties is best obtained by mapping this information on whole-farm plans.'

The land systems or unit maps should incorporate topography, soil type and vegetation type. Developments such as boundaries, fences, water points, roads and tracks should be added, as well as estimated warren densities. Warrens which appear to be unused should be included, because often a few rabbits use them and more rabbits will occupy them as populations increase.

9.2.5 Assessing impact

On farms

'The distribution and number of warrens and burrows on farms are usually the best indicators of the long-term presence of rabbits.'

The distribution and number of warrens and burrows on farms are usually the best indicators of the long-term presence of rabbits. Warren densities reflect how prone particular areas or land types are to rabbit infestation (Burley 1991). In some cases, such as in dense scrub, the number of warrens may be difficult to estimate.

Low production rangelands

The first step in assessing the impact of rabbits on a rangelands property is to estimate the total grazing impact from sheep, cattle, horses, kangaroos, feral herbivores and rabbits on the various land types. This is done by converting the number of other herbivores into dry sheep equivalents (DSEs) (Tatnell 1991). These data can be divided into managed and unmanaged grazing, and the need for action to reduce grazing impact through control of livestock and, where practicable, wild grazers can be assessed. This method relies on having established limits for grazing pressure for each land type.

'The use of maximum stocking rates is far from ideal in the highly variable rangeland environment.'

Most states and territories have legislation to regulate total grazing pressure on pastoral land. For example, the South Australian *Pastoral Land Management and Conservation Act 1989* enables government authorities, in consultation with lessees and relevant landholders, to set appropriate maximum grazing densities for livestock and native and exotic wild herbivores. While there is some flexibility in the Act to reward good managers with higher stocking rates, the use of maximum stocking rates is far from ideal in the highly variable rangeland environment. There is an urgent need for simple and reliable indicators of rangeland health to assist managers in attaining maximum, ecologically sustainable use of their land. In the meantime, however, it is desirable that grazing management should be based on estimates of total grazing impact.

9.3 Management plan

9.3.1 Objectives

'The over-riding objective of all strategic rabbit management plans is to reduce rabbit damage to the level where the benefits of management exceed its costs.'

The over-riding objective of all strategic rabbit management plans is to reduce rabbit damage to the level where the benefits of management exceed its costs. This approach requires knowledge of the relationship between rabbit density and the costs and benefits of management. This is difficult and costly to determine, and it is unlikely that the rabbit, with its high reproductive potential, could be managed with this degree of precision. Therefore, for most circumstances, it is assumed that rabbit damage is related to rabbit density, although it is recognised that there is not always a direct correlation between rabbit numbers and levels of damage.

'In the authors' opinion, reducing and maintaining rabbit populations at minimum densities is more likely to be profitable than some lesser level of control to densities from which rabbit populations can rapidly rebound.'

In the authors' opinion, based mainly on data from small-scale field trials, the experience of Rural Lands Protection Boards and rabbit population ecology, reducing and maintaining rabbit populations at minimum densities is more likely to be profitable than some lesser level of control to densities from which rabbit populations can rapidly rebound. Even where resource damage only occurs when rabbit numbers are high, it is probably the most cost-effective to maintain rabbits at very low densities at all times. The relative cost-effectiveness of aiming for sustained minimum levels as a long-term strategy will depend on the cost of this level of rabbit control relative to the benefits resulting from control, in comparison to the cost–benefit ratios of some lesser level of control or no control. The extra cost of achieving very low rabbit numbers can be offset by reduced costs of maintaining control at low numbers and reduced impacts.

'The extra cost of achieving very low numbers can be offset by reduced costs of maintaining control at low numbers and reduced impacts.'

This objective will apply at the local or district level but, since success has a strong influence on the efforts of others, and as measurable progress is made, surrounding districts will adopt a similar goal. The merit of this objective is not reduced by it being unachievable in some situations. For example, the 'killer' program in New Zealand did not reach its stated aim of 'rabbit-free', but nonetheless brought rabbits under control over most of the country.

9.3.2 Management options

Adaptive and flexible management

Adaptive management is a relatively new concept for managing complex natural systems (Walters and Holling 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 actions must be ones that achieve an increasing understanding of the system as well as the environmental, social and economic goals desired. The management of rabbits, 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.

'Management actions must be ones that achieve an increasing understanding of the system as well as the environmental, social and economic goals desired.'

Given the paucity of information, including scientific information, about many of the factors that drive natural systems, managers need to adopt a flexible management approach (Danckwerts et al. 1992). That is, managers learn from their 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 this flexible management approach is the monitoring of three variables in the system — livestock productivity (biological and economic); vegetation changes; and environmental conditions and management responses.

'The complete and permanent eradication of all rabbits is rarely possible, except in special circumstances such as on islands.'

The option for rabbit management that land managers choose depends much on whether they are risk-averse or gamblers. Decisions influenced by a land manager's attitude to risk include whether or not they manage rabbits, their preparedness to commit effort and resources to rabbit control, their degree of commitment to follow-up action and their willingness to persist at the task as an integral part of land management.

Options for managing vertebrate pests are: no management, crisis management, commercial management and hunting, local eradication, and strategic management (Braysher 1993). Each is considered below in relation to the wild rabbit.

Local eradication

Local eradication, that is the complete and permanent elimination of all rabbits, is rarely possible except in special circumstances, such as on islands where there is no potential for recolonisation. Rabbits have been eradicated from several small islands: Philip Island near Norfolk Island (Hermes 1987), Bowen Island off Jervis Bay, New South Wales (Martin and Sobey 1983) and a number of islands in Western Australia (Abbott 1980). Eradication from larger islands may be technically possible, but is uneconomic in many cases. Local eradication is difficult to achieve, even within areas enclosed by rabbit-proof netting, although many landholders and groups have eradicated their rabbits. The criteria which must be met for eradication to be possible (Bomford and O'Brien, in press) are described in Appendix D.

Rabbits are adept at digging and climbing, and fencing may be damaged and breached by stock, other animals or treefall. Nevertheless, before myxomatosis was introduced into Australia, many productive properties achieved effective rabbit management by netting property boundaries, diligently maintaining the fences in good repair and relentlessly pursuing any rabbit that breached the fence (Coman 1991). Local eradication may also be achieved by concerted management in environments marginal for rabbits or where management programs have progressively reduced the suitability of the environment for them. Such persistence may achieve results similar to local eradication for as long as appropriate management is maintained.

Strategic management

Strategic management of rabbits is an option where local eradication is not feasible. It involves integrating rabbit control operations into overall land management planning in order to achieve a specific rabbit density or reduced level of rabbit damage. There are three major types of strategic management: sustained, targeted or one-off.

'Strategic, sustained management aims to reduce and keep rabbits at very low levels at minimal cost.'

Strategic, sustained management involves an initial widespread and intensive control campaign to reduce rabbit populations to very low levels, succeeded by maintenance control to prevent population recovery. This is based on three major aspects of wild rabbit biology: (1) their high rate of increase; (2) dispersal by recruits from the social group of the warren or warren group, which may lead to rapid recolonisation and establishment of new warrens in surrounding areas treated previously in control campaigns; and (3) the importance of the warren to the survival and success of the rabbit. Destruction of warrens and burrows, where present, and other forms of shelter, is the key to successful rabbit management.

Strategic, targeted management involves undertaking control when it is most economic to do so, and requires knowledge of the relationship between the cost of control, rabbit density and damage to the resource. This relationship is usually not known for rabbits. It is also likely to be difficult to tune rabbit management so finely. This strategy may be more effective for larger herbivores where the rate of population increase is lower (J. Parkes, Landcare Research New Zealand Ltd., pers. comm. 1992). The rapid rate of increase of rabbit numbers and the effect of the highly variable Australian climate, especially in

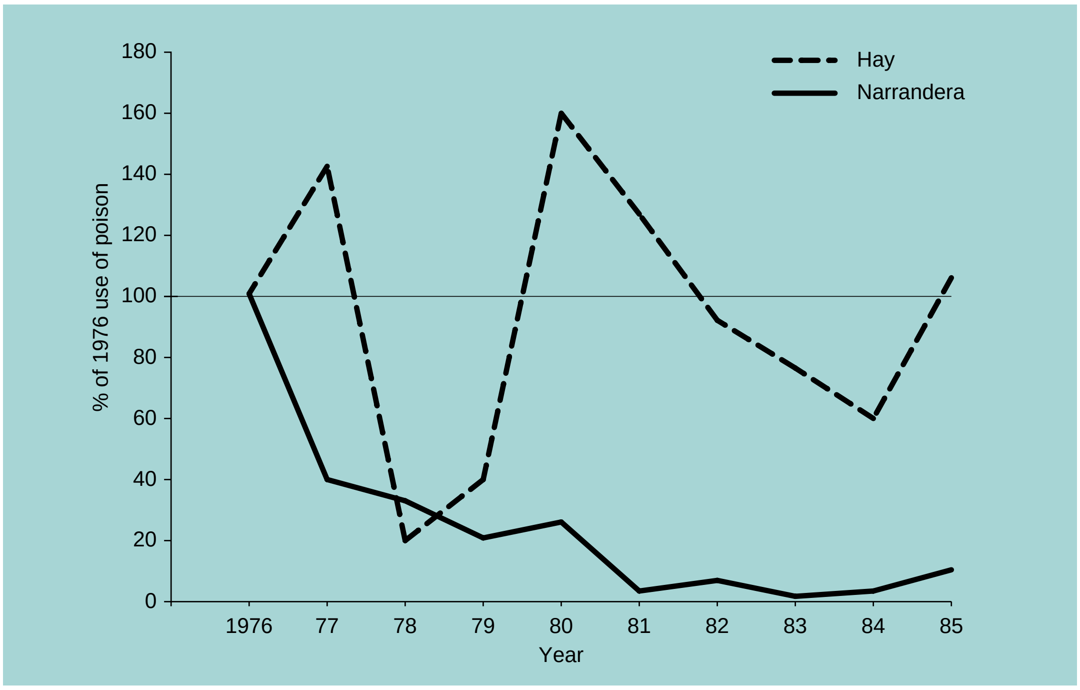

Figure 33: Use of 1080 poison in two group rabbit control schemes expressed as a percentage of the initial amount of 1080 used (in 1976). Maintenance control was undertaken at Narrandera, but not at Hay.

Table 20: Hypothetical example in which the annual cumulative costs of two different rabbit control regimes are compared (after Coman and Nolan 1992).

Year	1	2	3	4	5	6	7	8	9	10
Annual control ($)	5	10	15	20	25	30	35	40	45	50
Strategic, sustained management ($)	13	16	18	19	20	21	22	23	24	25

the rangelands, makes accurate timing of control difficult and precarious. Land managers would need to monitor rabbit density and damage closely and be able to drop other land management tasks and switch to rabbit control at the required time. Land managers rarely have this flexibility. Consequently, this approach becomes little different from crisis management, involving sporadic or ad hoc control. It is more cost-effective for land managers to control rabbit populations when they are low, during drought or late summer, and maintain them at low densities through sustained maintenance management.

'It is unlikely that continual use of 1080 poisoning can be relied on for the long term, due to the potential selection of rabbits that are bait-shy. 1080 should only be used for an initial knockdown.'

One-off management may reduce rabbit populations markedly, but usually the effect is short-lived. In some circumstances one-off poisoning can significantly reduce rabbit numbers for several months to several years. However, the remnant population will increase rapidly, and rabbits from surrounding country will usually recolonise the intact warrens (Foran et al. 1985; Williams and Moore, in press).

The introduction of myxomatosis is an example of one-off management that had a long-lasting effect. Rabbit distribution was reduced although the level of control attained decreased a few years after the virus was released (Myers 1962), as genetic resistance developed (Marshall and Fenner 1958). Possible introduction of rabbit calicivirus disease (RCD) (Leon-Vizcaino and Cooke 1991; O'Brien 1991) is an example of further potential oneoff management although we do not have enough information to know whether RCD will persist in wild rabbit populations in Australia. If it does not, RCD may still be useful as a tool for strategic, sustained management. One-off management may be effective where, in the absence of rabbits, the environment changes to one unsuitable for rabbits, for example, where vegetation becomes dense and rank in the absence of heavy grazing by rabbits and stock (Williams 1983; New Zealand Office of Parliamentary Commissioner for the Environment 1987). It may also be successful where predation intervenes and rabbit populations are slow to resurge (Newsome et al. 1989).

Available evidence strongly suggests that strategic, sustained management is the only effective strategy. Strategic, sustained management can contain rabbits to very low levels at minimal cost (Figures 31 and 32). Long-lasting, effective management aims at keeping a rabbit population in the bottom left corner of Figures 31 and 32 so that regular 'maintenance' control is minimal. The propensity of the wild rabbit to recolonise means unsustained effort will achieve only short-lived control (Parer and Parker 1986; Parer and Milkovits 1994; Williams and Moore, in press).

The importance of maintenance control is illustrated by comparing the results of two group control schemes in New South Wales (Figure 33). The Narrandera group coordinated their poisoning campaigns and was committed to follow-up action (Reardon-Smith et al. 1987). For the Hay project, the landholders undertook rabbit control independently with little emphasis on follow-up. In Narrandera, the necessity for poisoning remained low. In Hay, the use of poison did not decline (Figure 33). As discussed in Section 7.4, it is unlikely that continual use of 1080 poisoning can be relied upon for the long term, due to the potential selection of rabbits that are bait-shy or able to detect and avoid 1080 poison, as shown in New Zealand. Poison should be used only as an initial knockdown.

'Rabbit control requires land managers to be committed to a long-term strategy for a successful outcome.'

Strategic, sustained management is also usually the most cost-effective option (Table 19). For example, land managers in the more productive southern areas of Australia respond to rabbit damage in either of two ways.

- Annual treatment. This is a form of sporadic management (usually by poisoning) that gives no long-term benefits. Despite high kills with poisoning, usually only part of the property is treated in any year, mainly because few fenced areas with adequate feed are available to spell stock during poisoning. Consequently recolonisation from untreated areas is rapid.
- Strategic, sustained management. An initial knockdown by poisoning is followed by continued treatment consisting of harbour destruction, warren ripping and fumigating difficult warrens and burrows, giving high long-term benefits.

Initial costs for the latter strategy are higher, but the benefits last longer. The hypothetical example in Table 20 compares the two approaches derived from known costs for aerial poisoning and bulldozer ripping in difficult granite country in central Victoria (Coman and Nolan 1992). In this example, costs of the two strategies intersect after four years, thereafter strategic, sustained management remains cheaper. No allowance, however, is made in this example for the discount rate, which would greatly influence the outcome (Braysher 1993). Choice of strategy will also be influenced by the production returns obtained with each strategy.

The objective of rabbit-free does not imply eradication. Rather, it provides a long-term and unvarying objective which is simple to grasp and of immediate appeal. It is sufficiently flexible to allow changes in control intensity in any one year, in accordance with the landholder's finances and workload. An objective of rabbit-free maximises the likelihood that rabbit control will be incorporated into the annual cycle of management activities.

A goal of reducing rabbit numbers to as close to zero as possible and then maintaining them at that level has the advantage of providing land managers with a clear, readily monitored, long-term goal. This may counter any tendency of land managers to develop tolerance to rabbits which could undermine efficient long-term management. Rabbit control requires land managers to be committed to a long-term strategy for a successful outcome.

The costs and effort involved in aspiring to such an objective are probably less than commonly supposed. For example, a grazier on the daily round inspecting the flock will, as a matter of custom, carry fumigation tablets and a shovel for treating any active warren seen. A common argument against the idea of virtually rabbit-free zones is that cleared country is always susceptible to reinvasion from the perimeter. This is true, and it is why group or district schemes are advocated. When individual landholders independently carry out management to variable levels, rabbit infestations become a 'patchwork quilt', with areas of high density interspersed among areas of low or zero density. In the absence of netted boundaries rabbits can recolonise very rapidly. Areas treated by warren ripping in western New South Wales are recolonised within two years when surrounding country is untreated (Parer and Parker 1986).

Crisis management

'All too often land managers undertake rabbit control when rabbit populations are burgeoning or damage is obvious. There is no clear objective and rabbits quickly return to precontrol levels. Considerable resources are wasted.'

All too often land managers undertake rabbit control when rabbit populations are burgeoning or damage to crops or other resources is obvious. This is sporadic control or crisis management. There is no clear objective, and rabbits quickly return to pre-control levels. Considerable resources can be wasted with little benefit (Braysher 1993; Parkes 1990).

Commercial management and hunting

Commercial management and hunting (Sections 5.2, 5.6 and 7.4.16) do not control wild rabbits effectively. Shooting may kill about 35% of rabbits locally, while effective management requires at least 95% to be removed. Commercial harvesting is usually undertaken where and when financial returns to harvesters are greatest, not where rabbit management is most needed. Financial returns are maximised by abandoning harvest areas when the rabbit population is still high and when damage is also likely to be high. Furthermore, at these high densities rabbits can recover rapidly to the former density.

No management

No management may be the option adopted when terrain, such as densely wooded areas or very steep or rocky slopes, is inaccessible to equipment, or when the land manager lacks funds, staff or equipment, as is the case for many conservation reserves and government land. No management is undesirable because of the deleterious impact of rabbits on land resources, and because of the capacity of rabbits to spread to neighbouring land (Parer and Milkovits 1994). In such situations where ripping is not possible, aerial poisoning may be preferable, especially where rabbits might be prevented from resurging by changes in the vegetation as a result of the removal of rabbit grazing pressure. It may be necessary to remove stock to allow such changes to occur. It should be noted, however, that vegetation responses that inhibit resurgence seem to be restricted to higher rainfall areas.

Some managers may not manage rabbits because they regard rabbit control as uneconomic. Such economic judgments are usually based on short-term accounting and rarely consider the impact on the capital value of the property, or the impact on non-renewable resources such as topsoil.

No management is common in much of the rangelands and in many conservation reserves, usually because of the size of the problem and lack of resources, or failure to recognise the problem and allocate resources. Yet as indicated in Chapter 4, rabbits are likely to be causing major damage. If control over the whole area is not practicable, then land managers need to determine priority areas for action and concentrate control effort there. For conservation areas, an environmental database such as ERIN can help to identify priority areas to target protection of rare or threatened native plants and animals.

9.3.3 Choice of management option

On farms

Strategic, sustained management is nearly always the recommended option for managing rabbits on farms. In some farming situations rabbits may not have a major impact on the economic or environmental resources. Even in these cases, rabbits should be maintained at low densities by routine and inexpensive measures similar to the maintenance procedures involved in strategic, sustained management.

Low production rangelands

Strategic, sustained management is the recommended strategy for minimising rabbit damage in rangelands. With current technology, one-off management is unlikely to succeed in rangelands. Mutze (1991) reported a high level of rabbit control over ten years after a one-off poisoning and ripping campaign associated with permanent destocking in a drought-refuge area. There was no replication of the treatment so the result may have been due to an unusual feature of the treated experimental site.

High grass swards which can develop after rabbit management can deter a build-up of rabbits, but the long-term destocking which is required to develop these swards is usually unacceptable to graziers. The drier pastures in arid and semi-arid regions may not respond sufficiently to oneoff rabbit management and destocking to deter rabbits from recolonising them.

Crisis management of rabbits, when favourable weather conditions would cause rabbit numbers to climb, is not practicable for the rangelands. Because of the extensive areas involved, rabbit numbers would explode well before they could be managed.

No management is often based on the perception that rabbit control is uneconomic in low production rangelands (Section 4.2) or from lack of money available to landholders to implement control. Some studies indicate that rabbit control may be economic for some sheep rangelands (Parker et al. 1976; Wood 1985; Martin and Eveleigh 1979; Cooke and Hunt 1987). However, Foran et al. (1985) believe that rabbit control in cattle rangelands in central Australia is unlikely to be economic if control costs cannot be recovered in the first three years. This issue requires further investigation (Chapter 12).

9.3.4 Performance criteria

The over-riding objective of reducing rabbits to a level where for all practical purposes the land can be regarded as rabbit-free usually means setting a series of intermediate goals which must be realistic. As an example, Landcare groups might set interim goals such as the following:

Interim target	Year of program
Average rabbit densities reduced 95%	2
Average rabbit densities reduced 98%, no warrens in accessible country	4
Average rabbit densities reduced 99%	6
Virtually rabbit-free status	10
Low input maintenance control to maintain virtually rabbit-free status	>10

These targets provide a yardstick against which the performance of the strategic management program might be assessed. Performance criteria depend to a large extent on land use.

On farms

A farmer might set the following performance criteria:

- for cropping units, to eliminate significant damage to crop edges within 1–2 years;
- for improved pastures, to eliminate all warrens and burrows within two years;
- for rough pastures, to eliminate all warrens and burrows over perhaps 25% of the area per year; and

- for remnant vegetation, to initiate regeneration of native vegetation susceptible to rabbit damage on half the area within one year of the next significant rainfall, and to achieve regeneration on the rest of the area during a second major rainfall if it occurs after the first area has been treated and successful regeneration achieved.

Low production rangelands

The primary objective of the land manager may be to increase ecologically sustainable production by 30% within three years, and to ensure that degradation of native pasture from perennials to annuals is halted within the same time frame.

A grazier on the rangelands may aim to:

- rip all warrens in priority areas in the first year, irrespective of weather, and sustain maintenance treatment annually thereafter;
- treat the drought refuges during the first sequence of dry years by ripping 90% of all warrens in three of four drought refuges on the property in one year, then by removing the remaining 10%, and warrens overlooked in the first pass, in follow-up ripping in the following year;
- similarly treat the fourth drought refuge if necessary during the next dry sequence if rainy seasons intervene. As time permits, treat warrens in rocky areas; and
- rip warrens on the extensive drier country extending out from the drought refuges and boundaries within six years while continuing maintenance control in all priority areas and drought refuges.

9.3.5 Allocating management units

If rabbits are present, the first task in a whole-property plan is to determine and map rabbit distribution and abundance (Section 7.3).

Management units are allocated and land management practices for each unit are examined to determine whether changes can reduce rabbit impact and improve production and conservation values. Improvements to land management practices can be implemented while the rabbit management program proceeds. Priorities for treating the different management units can be decided according to the criteria listed in Section 7.3.5

On farms

Often it is not practicable to treat the property all at once. Therefore, the area should be broken into management units (Section 7.3.4) and priority areas identified for initial treatment. The growth stages of crops should be anticipated and taken into account when allocating management units and their priorities for treatment.

Low production rangelands

After mapping, the grazier may divide the property into rabbit management units based on the pattern of rabbit distribution over land types, the areas involved, and intervening areas of low densities. Internal fences should be disregarded unless they are rabbit-proof or can be used to partition stock from poisoned areas. The management units should maximise homogeneity of land type and rabbit density and minimise the potential for recolonisation from adjacent management units following control operations.

9.3.6 Management strategy

Different management strategies may be needed for each management unit. The management units will then require different interim goals, because of the time required to achieve a high level of control over the whole area. Ultimately, all units should have the same objective of effective high-level management.

Factors which influence the management of units are generally the same as those that relate to the impact of rabbits (Section 7.1).

If rabbits are present and shown to be a significant problem, the strategy outlined in the flow diagrams in Figures 34, 35, 36 and 37 should be followed. These flow diagrams employ the following principles:

- Use land management practices that benefit land values, minimise rabbit impact, and minimise rabbit abundance.
- If possible, modify habitat to make it less suitable for rabbits, including modifying pasture consistent with the above, but especially destroying surface shelter and ripping warrens and burrows.
- Implement control when rabbit numbers are lowest in their annual breeding cycle and most concentrated spatially. This low

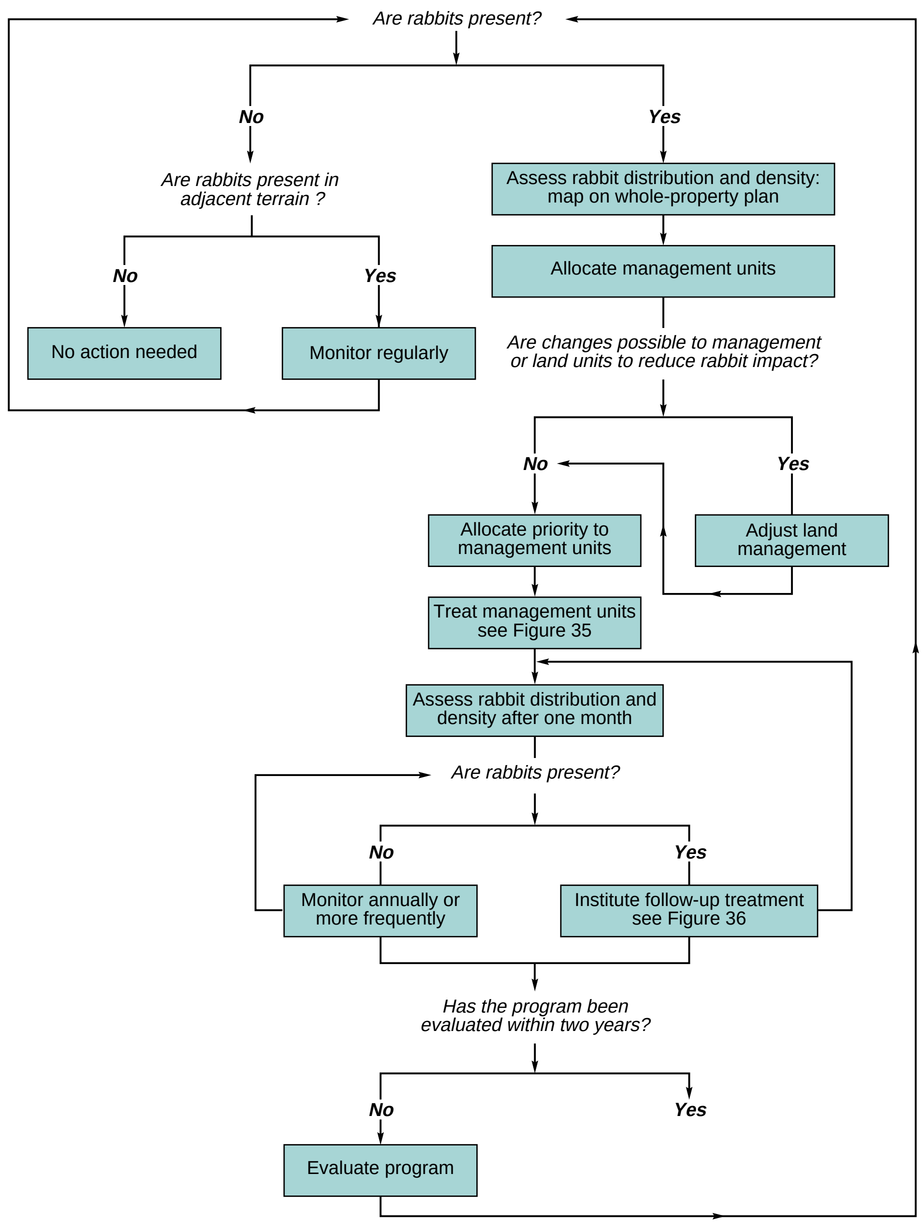

Figure 34: Strategic, sustained rabbit management.

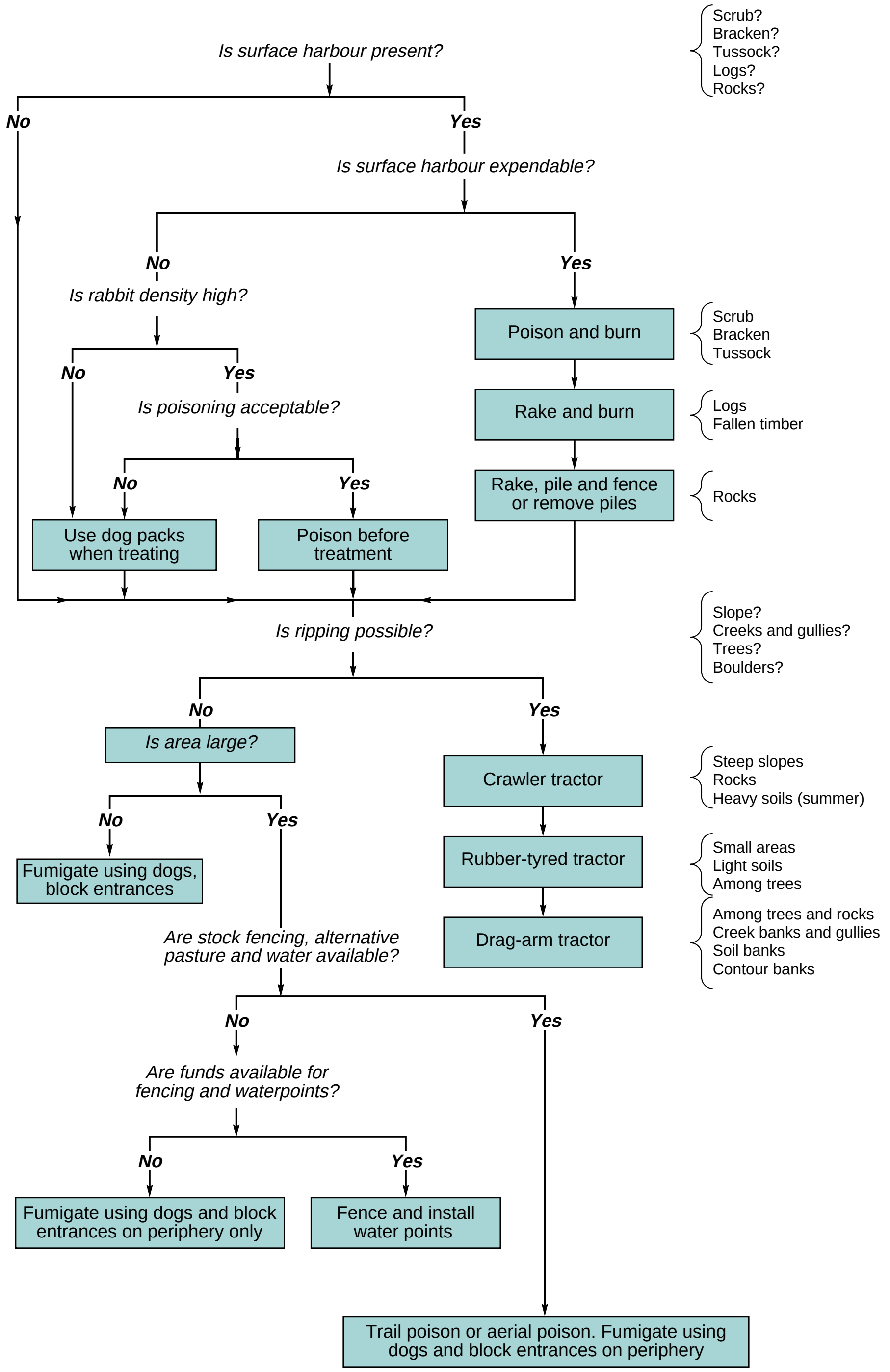

Figure 35: Initial rabbit control treatment.

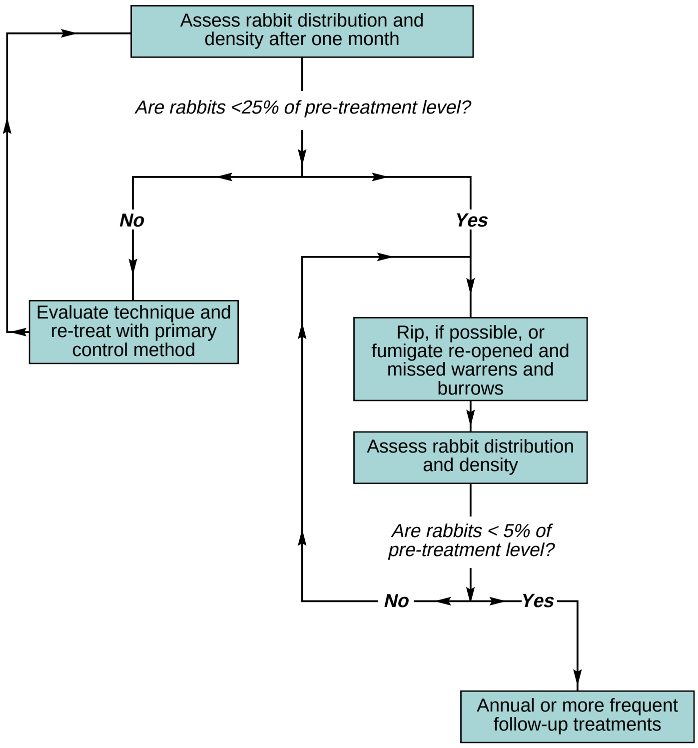

Figure 36: Maintenance rabbit control treatment (one month after initial treatment and annually thereafter).

point in numbers may vary seasonally for different parts of Australia.

- Continue to manipulate habitat and reduce rabbit numbers to the lowest level practicable to minimise rates of population increase.
- Frequently monitor progress by standardised methods, review the program at regular intervals, and adjust it where necessary while continuing to monitor.

'Techniques applied should remove surface harbour, disrupt warrens maximally and regularly re-treat re-openings, new warrens and burrows.'

The choice of techniques for managing rabbits depends mostly on the extent to which rabbits shelter by day in surface cover or in underground warrens or burrows. This in turn depends on the type and extent of available shelter (Section 3.3).

Control techniques are evaluated in Section 7.4 and described in Appendix A. The processes for assessing the need for rabbit management, choosing initial treatment methods and maintenance treatment methods are shown in the flow diagrams Figures 34, 35, 36 and 37.

The best strategy for treating areas which have extensive surface rabbits needs further investigation, particularly the detrimental impact of burning on vegetation and native fauna (Section 12.5.2).

On farms

Special factors that may influence priorities for rabbit management and interim control objectives for each management unit include: (1) accessibility of the terrain to wheeled or tracked vehicles; (2) accessibility

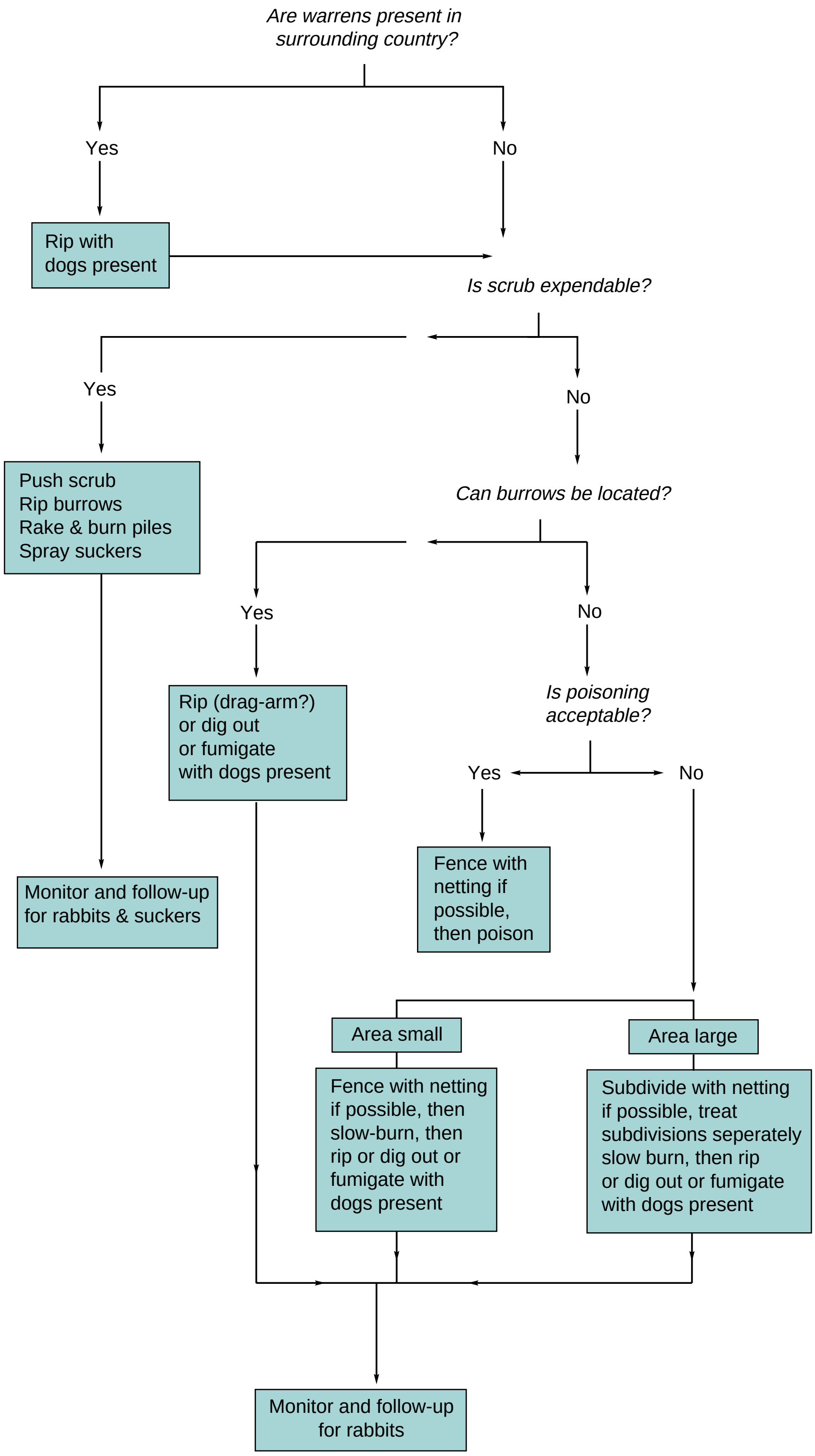

Figure 37: Treatment for scrub-living rabbits.

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of warrens and burrows among creeks, gullies, trees, scrub, rocks and boulders; (3) presence of stock; (4) availability of fenced areas with sufficient pasture to spell stock during poisoning operations; (5) availability of funds which may depend on commodity prices; (6) availability of labour and equipment; (7) convenience of the methods amid other essential tasks and schedules; (8) availability of contract rabbit control services; (9) priorities of tasks with stock, crops and other farm management; (10) the vulnerability of the crop due to its location and growth stage; and (11) the quality, conservation status and representativeness of native vegetation and fauna on the property which will guide priority for action on units containing them.

'Effective management is best undertaken in the rangelands when rabbit populations are low due to myxomatosis or drought. Rabbits in drought refuges should be treated first.'

The choice of techniques will vary depending on the specific situation. Ripping warrens and burrows should be a priority for initial treatment and, if possible, for follow-up treatment. When tractors are purchased, either individually or shared, ideally the machine should include a blade with stick rake for removing briars and pushing logs, four-wheel drive or crawler, hydraulic lift for rippers, and sufficient power for ripping. Other options for ripping include drag-arm rippers (Section 7.4.9).

In summary, the techniques applied should remove surface harbour, disrupt the warrens maximally and regularly retreat reopenings, new warrens and burrows.

Low production rangelands

Special factors which may influence the strategy for rabbit management and the priority for treating management units in the rangeland include: (1) availability of funds; (2) degree of degradation of the management unit; (3) whether the property is part of a group scheme or whether neighbours are controlling rabbits; (4) accessibility of the terrain to wheeled or tracked vehicles; (5) accessibility of warrens and burrows among creeks, trees, rocks and boulders; presence of stock fencing and sufficient alternative pasture and water enabling stock to be moved for poisoning operations; (6) presence of vulnerable or rare plant species or associations; (7) whether the management unit is a drought refuge for rabbits and/or stock; (8) existence of internal and external barrier fences; and (9) the prevailing weather conditions such as drought, abundant rain or average rainfall.

Management of rabbits to virtually rabbit-free status across the entire rangelands is unlikely to be economically feasible. Therefore, managers need to establish priorities for treating land units. These may be the most productive areas of the property, refuge areas for native wildlife and those areas most easily treated, or a combination of these. Initial control campaigns over large areas of rangelands will miss some warrens. Barriers to recolonisation are rare. Therefore, during periods of adequate pasture growth, persistent treatment (strategic, sustained management) on management units is the only way to prevent resurgence of rabbits from the untreated warrens and from untreated management units (Parer and Parker 1986). Effective management in rangelands is best undertaken when rabbit populations are low or contracted due to drought or the occasional outbreak of myxomatosis.

'Inspection and maintenance treatment should continue at least annually.'

Drought refuges should be treated first, with further treatment extending outwards from them. Where possible, rabbit control operations should be coordinated with control activities on adjacent properties, extending inwards from common boundaries and beginning at any shared drought refuges.

Dry times, when predators concentrate on the rabbits living in drought refuges, are the best times for rabbit control in rangelands (Wood 1980). Predatory pressure may delay or even prevent resurgence (Newsome et al. 1989).

Ripping is highly effective in rangelands (Parker et al. 1976; Martin and Eveleigh 1979; Wood 1985; Foran et al. 1985; Parer and Parker 1986; Cooke and Hunt 1987). The methods are discussed in Section 7.4.9 and technical details are shown in Appendix A. Highly efficient large-scale ripping programs are being adopted by Rangecare groups in arid rangelands (Lord 1991; Hams 1991).

Where rangelands are badly degraded it may be necessary to use soil rehabilitation techniques including reseeding with perennial grasses and native shrub species. This can be done in conjunction with ripping (Tatnell 1991). Subsequent control of feral herbivores and kangaroos may be necessary to protect seedlings.

In some refuge areas, it may be difficult to control rabbits by the preferred technique. Ripping, for example, is not possible where the refuge area lies along a river bank lined with river gums (*Eucalyptus camaldulensis*) or a creek lined by Acacia (*Acacia victoriae*) which are important in preventing erosion, as well as for conservation and aesthetic reasons (Tatnell 1991). In such circumstances poisoning, followed by fumigating and blocking remaining warren entrances with stones or balls of wire netting if necessary, may be justified (Section 7.4.11).

If many warrens reopen or if warrens are concentrated, reripping, using the same or smaller tractor may be the most cost-effective maintenance control method. Where reopened warrens are few or at low density, pressure fumigation from a utility vehicle or four-wheeled motorcycle and trailer may be practicable. Alternatively, it may be cheaper and more convenient to use pellet diffusion fumigation with motorcycle transport.

Follow-up control needs to be scheduled within the property management program. Warrens tend to be reopened soon after the initial treatment, and again when population recruits disperse before the following breeding season (Parer 1977, 1982b, 1994). In order to consolidate gains, treated areas should be re-treated within three months. Then inspection and maintenance treatment should continue at least annually.

9.4 Implementation

'Group schemes and cooperative effort provide economies of scale and social benefits that encourage sustained effort.'

Implementation of rabbit management is described in Chapter 11. It is best done in cooperation with managers of adjoining land, preferably in a group scheme.

On farms

Whilst group schemes are preferred, effective management is possible on farms even if rabbit management on neighbouring properties is ineffective. It is also compatible with farm management for cropping and grazing. Pastures can be managed to make them less suitable for rabbits. Cropping exposes some farmland to near annual tillage, generally reducing the area suitable for rabbits. The remaining areas are often unsuited for tillage and more difficult country for rabbit control operations. Nevertheless, cropping operations would reduce the area requiring control.

It may not be economic for a property to be independent in equipment and labour for rabbit management. Group schemes and cooperative effort provide economies of scale and social benefits that encourage sustained effort (Chapter 11). Crops are generally more prone to damage at specific times, such as soon after germination, and rabbit management initially needs to protect crops at those times. Once rabbits are reduced to low levels, there is more flexibility in the timing of rabbit control each year. As a result, farmers can undertake rabbit control themselves or use contract or government services (Section 11.3.2) at times other than when demand on these services is greatest from other farmers in the district with similar crops to protect.

Low production rangelands

The sequence of treating management units should aim to protect vulnerable areas such as drought refuges and to minimise the potential for recolonisation. Management units that are likely to be a source for recolonisation of treated units should be treated next, followed by adjacent units. Neighbouring properties could treat the same management unit on either side of boundary fences so that neither is a source of reinvasion.

In rangelands, rabbit densities vary due to myxomatosis epizootics and seasonal weather conditions. The most effective time and place to control rabbits in the rangelands is in refuge areas during drought. This enables control efforts to be applied much more rapidly, cheaply, effectively and humanely, with less probability of re-opening and recolonisation. Even apparently disused warrens in the drier country should be destroyed as they could be harbouring one or two hardy survivors. It is difficult to detect rabbits at very low densities.

Inadequate finance frequently impedes opportunistic rabbit management during drought. Where practicable, land managers should plan to take advantage of droughts for pest control. Governments can also help by creating suitable financial conditions, such as income equalisation schemes and special loan provisions.

Timing rabbit control to take advantage of rabbit populations which have been reduced by outbreaks of myxomatosis is also advisable. Myxomatosis usually occurs in good seasons when myxomatosis vectors are common and rabbit populations are high. Pasture is likely to be abundant, so rabbits that survive myxomatosis will have good breeding conditions. This could reduce the effectiveness of control, and graziers may find it more effective to commence control in dry times and consider myxomatosis epizootics as an opportunity for improving the effectiveness of maintenance control in good seasons.

9.5 Monitoring and evaluation

9.5.1 Monitoring

Monitoring is an essential, ongoing and often forgotten part of rabbit management (Section 7.5).

'Monitoring assists land managers to develop a better knowledge of the rabbit problem on the property, including changes over time and with treatments.'

There are two forms, operational and performance monitoring. Operational monitoring aims to assess the efficiency of the management operation to determine what was done, where and at what cost. Recording costs for individual management units enable comparisons between similar units and may help to identify potential savings. Information that should be recorded includes time spent on each aspect of the program including monitoring, labour costs (estimated if land manager provides own time), costs of plant and equipment, administration costs and travel time.

Most states and territories have developed, or are developing, Pest Management Information Systems (PMISs) which can assist land managers, whether government or private, to monitor management operations both for operational and performance criteria (Fordham 1991).

Most land managers can readily devise their own operational monitoring system, or state and territory pest management agencies can provide standard forms for monitoring control operations. Examples of operational monitoring are not included in the representative examples discussed later.

Performance monitoring aims to assess the effectiveness of the management operation in meeting the objectives of the program. Ideally the response of the resource being damaged by rabbits should be monitored. When this is difficult or impracticable, rabbit density should be monitored before a control operation, one month after the control operation, and then annually.

Performance monitoring involves:

- measuring or assessing the density of rabbits, and possibly the impact of rabbits on valued resources, using techniques that may include counts, photography, scaled judgments or objective measurements (Sections 7.1 and 7.2);
- recording, tabulating or cataloguing assessments to facilitate comparisons over time and among types of land or management practices (Section 7.3); and
- mapping the assessments on whole-property maps that also include information on topography, roads and water points, soil types, land types, vegetation, management or cultural practices. Property maps may be hand-drawn charts, topographic maps, aerial photographs or computerised interactive geographic information systems (Section 7.3). Property maps carried in the work vehicle allows opportunistic recording of new or untreated warrens as they are encountered, if immediate treatment is impractical.

Besides assessing whether the program is achieving management objectives, monitoring assists land managers to develop a better knowledge of the rabbit problem on the property, including changes over time and with treatments.

Performance monitoring enables land managers to assess progress toward achieving the objective, to identify trouble spots, and to provide information for planning future management action and allocating resources.

On farms

Changes in crop and animal production due to rabbit management can be monitored using the same techniques used to assess the initial rabbit damage (Section 7.1). Long-term changes in production following management are probably the best indicators.

Regular observation or photography of damage to the crops, particularly at the vulnerable stages, and regular inspection of treated warrens, burrows and known places of surface harbour such as patches of scrub, will indicate the effectiveness of rabbit control. Usually however, indices of rabbit density are simpler and cheaper to monitor than damage. Adequate measures could include searching for the presence of crop damage, the presence of open entrances to warrens and burrows and other rabbit-sign such as diggings. Photography also could be included to record regeneration in patches of perennial native vegetation and recovery in pastures using fixed photo points.

Monitoring the effectiveness of rabbit management on mallee regeneration and other conservation objectives is discussed in Appendix C.

In many cases the farmer will reach an intuitive conclusion about the effectiveness of the rabbit management program, although more formal assessments, as indicated above, should be undertaken.

Low production rangelands

The effectiveness of the rabbit management program for each management unit should be monitored using the same techniques that were used to assess damage (Sections 7.1 and 11.2.3).

Annual standardised photographic records, preferably with marker posts, can be used to monitor perennial vegetation and soil loss. Responses of soil and vegetation to rabbit control may not be evident unless grazing pressure by stock and other wild herbivores is regulated and the climatic conditions are favourable to vegetation growth. Suitable climatic conditions may not occur for several years. Indices of rabbit abundance, warrens, burrows and entrances, may be the only guide for several years. Rabbit damage and estimates of rabbit abundance should be mapped (Sections 7.3.3 and 11.2.4) to determine changes in rabbit abundance and to highlight new areas for treatment.

Rabbit-proof exclosure frames allow regeneration of native trees, shrubs and pasture species to be monitored. Large exclosures for stock, rabbits and other wild herbivores allow the impact of grazing on native vegetation to be estimated and provide a valuable reference area. They are also a source of seed for regeneration should native plants be lost from other areas. However, they are costly to construct and require periodic maintenance.

Long-term records that show the response to rabbit control are required so that assessment can be made of the changes in warren distribution and abundance and changes in vegetation and soil. Short-term records are inadequate because of the highly variable nature of the rangeland environment.

Pro-forma kits which are being prepared by state and territory vertebrate pest agencies as part of a national coordinated approach to recording pest management information could help (Fordham 1991). These forms may need to be modified to suit the private land manager who does not need the same level of detail as government.

Changes in animal production due to rabbit management can be monitored by comparing production figures for each management unit before and after rabbit control, or by comparing production with production for similar properties in the district that have controlled rabbits and those that have not. However, care is needed in interpreting this information as factors such as changed management practices and weather can greatly influence production.

9.5.2 Evaluation

Program evaluation, based on monitoring data, assesses the effectiveness of the existing program and the need to vary it. That is, monitoring and evaluation should be used to improve the effectiveness of the program, not just to demonstrate that it is effective. Program evaluations are described in Section 7.6 and in the examples later in this chapter.

For production systems, evaluation is based on the following questions:

- Is net income maintained or increased in the medium to long term?
- Is the land system in which production is based protected from degradation by rabbits?
- Is the impact on neighbouring land minimised?

Where damage remains unacceptably high the management program needs to be changed. It may be that rabbits are not the main cause or that a different or a modified management strategy is required.

For both farms and low production rangelands, the rabbit management program should be evaluated based on monitoring in relation to the stated objectives. The management program needs to be varied or new objectives set if the initial objectives are not met or only partly met.

10. Strategic Management Approach Applied Locally: Some Examples

Summary

The four steps of the strategic approach to rabbit management are: (1) defining the problem; (2) developing a management plan; (3) implementation; and (4) monitoring. Elements of all four steps are found in four existing control schemes — those at: (1) Rankin Springs; (2) Wagga Wagga; (3) Topar; and (4) Pine Creek, all in New South Wales. The first two schemes have been in operation for some years, and both have been successful in achieving effective and sustained management of rabbits. It is too early to assess the outcomes of the Topar or Pine Creek schemes. All four schemes adopted most of the elements of the management planning and implementation stages in the strategic management process. They did not adopt many of the elements of the problem definition or monitoring stages.

A major factor in the success, or potential success, of these schemes was the group approach, particularly the acceptance and ownership of the problem and its solution, by landholders and other stakeholders at the local or regional level. Government involvement was also critically important, including: (1) initiating the schemes; (2) assisting in the development of a management strategy; (3) providing control demonstration trials; (4) providing advice and assistance, such as bait and fumigation equipment; (5) monitoring the rabbit population; (6) advising on maintenance control; and (7) coordinating. Other initiatives involving governments, such as Landcare; the National Resource Management Strategy; and the National Soil Conservation Program, provided funds and other resources. Each scheme developed its own agreed control strategy based on the particular land use in its area. All four schemes adopted strategic, sustained management as the option; in each there was an initial widespread campaign to greatly reduce rabbit numbers, with subsequent population monitoring and maintenance control to reduce and maintain the residual population at easily manageable levels.

None of the schemes undertook an initial assessment of the impact of rabbits on the resource of concern, whether economic or environmental. This is understandable, given difficulties in directly assessing such impacts, and it is expected that projects funded under the Vertebrate Pest Program of the Bureau of Resource Sciences will help overcome this problem. Operational and performance monitoring also were generally neglected in the schemes. The incorporation of these into future schemes would improve the cost-effectiveness and efficiency of the management strategy, and help verify and refine the outcomes expected from the management program.

Economic frameworks need to be developed to assist in the assessment of the relative value of alternative control strategies whenever this is feasible. Such frameworks require: definition of the economic problem; data on relative costs and benefits; an understanding of why the actions of individual landholders may not lead to optimal rabbit management; assessment of means by which governments can overcome identified market failures; and then an assessment of the likely returns from alternative rabbit management strategies.

10.1 Introduction

In recent years several schemes have applied, or are applying, at the local level, major elements of the strategic approach to rabbit management (Chapter 11). This Chapter presents a brief review of some of these schemes, all in New South Wales, and assesses their strengths and weaknesses in the context of strategic management.

Rankin Springs: A group rabbit control scheme was initiated by the New South Wales Department of Agriculture at Rankin Springs in the south-west of New South Wales in 1976. It arose from the continuous high costs of rabbit control work on unoccupied Crown Lands. The scheme covered 250 000 ha, involving 179 extensive sheep grazing properties; private reserves; unoccupied Crown Lands; travelling stock routes and reserves; shire roads; and National Park and Forestry Lands. Cropping was increasing in the area. The information on this scheme is derived from Reardon-Smith et al. (1987).

Wagga Wagga (Lake Albert Catchment Scheme): The Lake Albert cooperative strategic rabbit management scheme was initiated in response to the problem of siltation of Lake Albert on the outskirts of Wagga Wagga. The lake was created by damming a watercourse draining pre-existing marshlands. Being a shallow lake (less than three metres deep), the problem of siltation from run-off in the catchment was soon evident. A Lake Albert Catchment Management Committee (LACMC) was established in 1988 to solve the problem, and the Soil Conservation Service (SCS) of New South Wales became involved from an early stage. The catchment occupies 20 000 ha, and includes 89 landholders, with properties varying in area from medium-sized grazing properties to small hobby farms. The SCS undertook drainage and erosion contour control works using a number of grants and interest-free loans. Extensive rabbit activity in basically unstable, coarse sandy soils was seen as the major initial source of the catchment erosion problem.

Topar: The Topar Area Rangecare Group in far western New South Wales was formed in January 1990 by 21 landholders on adjacent extensive sheep grazing properties. The Group scheme covers some 755 000 ha. Landholders were initially concerned about the extent of the woody weed invasion and the consequent land degradation. Since its inception, the objectives of the Group have tended to move from a single issue, woody weed control, to incorporate rabbit control and pasture reseeding. Information on this scheme has been derived from Topar Area Rangecare Group (Hams 1991).

Pine Creek: The Pine Creek Area Rangecare Group was formed in 1988 by 33 adjacent landholders in the area south of Broken Hill, and covers 988 000 ha. The Group was initially formed to control land degradation and loss of productivity caused by rabbits. As the scheme developed, other land degradation problems have been identified, including woody weed and pasture degradation, and have been incorporated in the activities of the Group. Information on this scheme has been derived from the Pine Creek Area Rangecare Group (Lord 1991).

10.2 The strategic approach

10.2.1 The problem defined

A real or perceived problem? For the Rankin Springs scheme, the problem was identified as the continuing high costs of rabbit control on unoccupied Crown Land. This ranged from $5800 to $7000 annually in the five years before the scheme commenced. This was largely wasted due to rapid reinfestation by rabbits from adjoining landholdings.

Measuring the harmful impact: Whilst all four schemes desired to control the harmful economic and resource degradation impacts of rabbits, the extent of the impact was not measured. All assumed that the density of rabbits indicated the degree of degradation of land or vegetation.

Measuring rabbit abundance: For all four schemes, an initial assessment of rabbit abundance was made by warren counts (Section 7.2.5). Typically, rabbit infestations for each property were graded as none, sparse, medium or heavy. In the case of Wagga Wagga, the extent of the problem was identified by aerial mapping of warrens. This was verified on the following day by a ground survey, which suggested that the mapping was about 97% accurate. For

Rankin Springs and Topar, similar information was collected through ground surveys by noxious animal inspectors.

Assessing impact: Only one scheme, Pine Creek, used photographic records to assess changes in the impact of rabbits. The three others used mapping based on property charts of warren abundance to measure changes in rabbit density and distribution and hence indicate rabbit impact.

10.2.2 Management plan

Objectives: The objective of both the Wagga Wagga and Pine Creek schemes was to reduce the impact of rabbits on the resource. For Rankin Springs and Topar, it was to increase productivity.

Management options: The Rankin Springs scheme aimed to achieve strategic, sustained management, '…with the aim of reducing rabbit infestation levels and the damage these cause to a level of low economic significance'. Although the Wagga Wagga plan discussed the desirability of eradicating rabbits from the catchment, the management option it proposed was based on the principles of strategic, sustained management, such that: 'once this stage is reached only periodic checks and the rare use of advanced maintenance control is all that is necessary to maintain a virtually rabbit-free area'. The Topar scheme also appears to be based on the strategic, sustained management option.

Performance criteria: The performance criterion established in the Rankin Springs scheme was '...to reduce the rabbit population to a very low or "considered free" level within five years'. The criteria set by the Topar and Pine Creek schemes were similar: 'Adoption of rabbit control, woody weed control and pasture reclamation techniques by group members, measured by achievement of strategy plan priorities …' and 'The formulation of other Rangecare groups in the district as a result of the group extension activities'. Pine Creek had an additional performance criterion: 'The extension of "rabbit-free" areas'. The Wagga Wagga scheme had no stated performance criteria.

Management units: Neither the Rankin Springs nor Wagga Wagga schemes established management units but rather based strategies on individual properties. Heavily infested properties were, however, identified and given priority attention in the scheme.

The identification of management units and setting them in priority order for the Topar and Pine Creek schemes were conducted within the individual property management plans which were prepared as part of the scheme. When land system boundaries were superimposed on warren distribution based on property strategy plans, it became evident that while landholder perceptions varied, warren density was related to broader land type boundaries, with heaviest infestations on sandplains and dunefields, and many fewer on rolling downs and lowlands. Accordingly, areas of high rabbit breeding activity were identified, and control was concentrated initially in these areas.

Control strategies: All four schemes had clearly identified control strategies, for both warren and surface-dwelling rabbits, and effective maintenance control. For Pine Creek, this involved coordinated extensive 1080 poisoning on properties with medium to high levels of infestation in the first two years. Fumigation, destruction of warrens by ripping and blasting, and burning of timber stacks were then used to further reduce rabbit populations and harbour, bringing the population down to a sustainable low level. Thereafter, basic routine inspections and control work were to be carried out to suppress infestations to low levels.

For Wagga Wagga, the control strategy was: (1) an initial coordinated large-scale rabbit population reduction based on a 1080 poisoning campaign early in 1990; (2) the early detection of remaining activity and treatment by chasing rabbits into warrens with dogs and gassing with chloropicrin in the winter of 1990; (3) harbour destruction based on ripping warrens in the summer of 1990–91; and (4) the elimination of the few remaining rabbits by spotlight shooting.

The strategy for the Topar scheme was based on warren ripping using crawler tractors pulling three 1-metre-long tines. To increase efficiency, warrens were marked or spotted for the tractor driver. Fumigation using aluminium phosphide tablets was used as a maintenance treatment for warrens which re-opened. Rabbit shooters also operated in the area when numbers were low.

The strategy for Pine Creek was similar to that of Topar.

10.2.3 Implementation

Group action: The Rankin Springs scheme was a large-scale coordinated campaign involving groups of adjacent landholders. Landholders in the Narrandera Pasture Protection Board[1] (PPB) area were divided into six local control groups based on existing bushfire brigade units. The majority of landholders participated and cooperated throughout the project. Three private landholders refused to participate at first, but following the success of the first round of poisoning, realised the benefits of the program and poisoned during the second round. Fourteen meetings between 1975 and 1986 were well attended, although later attendance was approximately 37% less than for earlier meetings.

In the Wagga Wagga scheme, both NSW Agriculture and the PPB soon realised that the rabbit damage could be effectively managed only through the group approach. Accordingly, they called a public meeting of all property owners in May 1989. The meeting was well attended, and the principle of a cooperative approach to the strategic management of the rabbit problem in the catchment was accepted.

It was also agreed that an aerial survey of the catchment was an essential prerequisite to initiate the program. At a subsequent meeting, also very well attended, it was agreed that the catchment should be divided into six groups to facilitate the implementation of the plan. NSW Agriculture suggested the composition of the groups, which was amended slightly to accommodate personal and other factors. For example, one group was amended to enable it to encompass a local bushfire group, with well-established communication and social networks. Each group elected a leader, who was responsible for monitoring and reporting.

The Topar scheme initially encouraged all property owners within the area to participate in the 18-month program. Nineteen out of 28 actively participated. The Group has a five-person committee of landholders who are responsible for coordinating the Group's activities and for reporting on progress. Property holders agreed that they would match any funds received for rabbit control work. In the event, landholders contributed twice the funds received from outside sources.

The Pine Creek scheme is similar to the Topar scheme.

Government agencies: The Rankin Springs scheme was initiated by NSW Agriculture and the Narrandera PPB. The Condobolin and Hay PPBs were invited to cooperate in order to provide a minimum 5–10 kilometre buffer zone of properties along their common boundaries with the Narrandera PPB. Hay PPB agreed, and Condobolin PPB decided to extend their area beyond the proposed buffer zone to treat the area as a control area in its own right. The New South Wales National Parks and Wildlife Service, the New South Wales Forestry Commission, and the Carrathool Shire Council were also involved in the scheme. NSW Agriculture livestock protection officers liaised with the PPBs, advised noxious animal inspectors,

[1] *Pasture Protection Board in New South Wales are now Rural Lands Protection Boards.*

and conducted check inspections for residual rabbits on properties in the project area. The PPB noxious animal inspectors were responsible for conducting preliminary property inspections, coordinating poisoning campaigns, mixing and issuing poison baits, ensuring that effective poisoning and maintenance work was performed, and monitoring changes in rabbit infestation levels on properties. They were required to submit regular reports so that the project could be assessed continually.

In the case of the Wagga Wagga scheme, it was decided at the outset that the plan should be implemented by the Lake Albert Catchment Management Committee using the Wagga PPB, their legal powers and resources. The PPB has the power to inspect properties, and order occupiers to carry out prescribed rabbit control practices. The livestock officer of NSW Agriculture played a key role in initiating the plan, and was a source of continuing advice during its implementation. The appointment early in 1990 by the PPB of another noxious animal inspector had a major impact on the implementation of the plan. The continuing involvement of the Soil Conservation Service of New South Wales (SCS) was also significant, since many rabbit control operations were planned to assist SCS operations. SCS in turn provided numerous services to landholders to facilitate the destruction of rabbit harbour. The implementation of the plan was assisted considerably also by the involvement of Aboriginal trainees employed under the Aboriginal Employment Development Policy (AEDP) program operated by the Bureau of Resource Sciences. The trainees assisted in rabbit control and tree planting operations initially, and several became self-employed in contracted rabbit control operations.

The Topar scheme included active involvement of the New South Wales Department of Conservation and Land Management (CaLM). It encouraged the establishment of the group, helped landholders develop property strategy plans, assisted with the implementation of the program and helped the group with its reporting requirements. CaLM also carried out rabbit warren ripping demonstrations on properties severely affected by rabbits. The development of property strategy plans was facilitated by the provision of funds through the National Resource Management Strategy (NRMS). Funding from the National Landcare Program (NLP) was used to develop property strategy plans, employ a part-time coordinator to organise group activities, and promote the group approach. Funds from both NRMS and NLP were provided to enable demonstrations of rabbit control techniques, including blade ploughing, warren ripping and contour furrowing.

Government involvement in the Pine Creek scheme was similar to that for Topar.

10.2.4 Monitoring

Operational monitoring: Operational monitoring is the recording of the cost, extent and effectiveness of the control operations to enable fine tuning of the control strategy and timely and effective maintenance control operations.

'Whereas nearly 60% of the properties involved in the Rankin Springs scheme had medium or high levels of infestation at the beginning of the project in 1976, less than 2% of properties were so infested by 1984.'

Although landholders in the Rankin Springs project did not maintain records of the costs and effectiveness of their rabbit control operations, CaLM did. In the five years prior to the project, annual Departmental expenditure on rabbit control in unoccupied Crown Lands ranged from \$5780 to \$7019. Following extensive use of 1080 and harbour destruction work in the first few years, costs rose by 5% to an average of \$4210 a year over the years 1976–80. However, in the subsequent five-year maintenance period (1981–85), average costs fell by 87% to \$407 a year and control work was unnecessary in several years due

5

Usage of 1080 and chloropicrin: Wagga Wagga project		
	1080 bait (kg)	**Chloropicrin (bottles)**
1989	na	109
1990	4855	130
1991	5375	134
1992	2904	119
1993	202	14

to low levels of rabbits achieved during the initial phase. After the two-year period of extensive poisoning, greater emphasis was placed on maintenance control work. Private landholders were generally cooperative with the requirement for warren and harbour destruction. However, maintenance control work by the public bodies (National Parks and Wildlife Service; Forestry Commission; and Carrathool Shire Council) was often inadequate for a variety of reasons, mainly lack of funds.

Landholders involved in the Wagga Wagga scheme did not record costs of the rabbit control operations. However, in the first two years, the noxious animal inspector played a key role in inspecting properties and advising on necessary maintenance control action. In addition, a major function of the group leaders was to ensure that occupiers inspected their property for any continuing signs of rabbit activity, implemented correct maintenance procedures, and destroyed harbour.

It is too early to determine whether landholders involved in the Topar scheme are recording the costs of their rabbit control operations. However, estimates of likely costs have been derived from the demonstration projects. These indicate that the cost of ripping a warren varies slightly according to land type, from $4.28/warren in the footslopes, to $7.32/warren in the downs. Thus, the cost of ripping per hectare depends largely on warren density, varying from $7.61 per hectare in heavily infested sandplain country, to $0.45 per hectare in lightly infested alluvial plains country.

Information on the Pine Creek scheme is similar to that for Topar.

Performance monitoring: Performance monitoring aims to assess the effectiveness of the management operation in meeting the objectives of the program. The objectives are usually in terms of a favourable economic–environmental resource outcome. Given the difficulty in establishing a relationship between rabbit density and resource impact, the resource outcome will usually be assumed to be proportional to reductions in rabbit density.

For Rankin Springs, the outcome was highly successful. Rabbit infestations over the whole area were reduced to a very low level. Whereas nearly 60% of properties at the beginning of the scheme in 1976 had medium or high levels of infestation, less than 2% of properties were so infested by 1984. Another commonly used indicator of performance is usage of 1080 over time. In the Rankin Springs project, for the period 1976 to 1985, 43% of total 1080 usage occurred in the first year of extensive poisoning; usage declined steadily, and was only 3% or less of total usage in the final years. This was considered to reflect a successful rabbit management campaign.

'All occupiers commented on a resurgence of subterranean clover in pastures following the initial widespread rabbit poisoning campaign, and noted the return of many plants which had not been seen for some time.'

For the Wagga Wagga project, there are no data on the effect of the management campaign on warren densities. However, records were kept of usage of poisons, 1080 and chloropicrin. The initial poisoning campaign was effective on all properties except one, the occupier of which refused to cooperate. The monitoring and maintenance campaigns succeeded, enabling effective control with minimum cost and effort. This is indicated in the data on usage of 1080 and chloropicrin in the table above.

In addition, although no measurements were taken, all occupiers commented on a resurgence of subterranean clover in pastures following the initial widespread poisoning campaign, and noted the return of many plants which had not been seen for some time.

It is too early to assess the performance of the Topar or Pine Creek schemes in reducing the impact of rabbits on the resources.

10.3 Evaluation of the group schemes

The group schemes embodied many of the features of the strategic approach to rabbit management. The oldest scheme, Rankin Springs, has succeeded in achieving the effective, long-term management of rabbits to a point where resource impacts are minimal, and ongoing management can be effectively carried out at little cost. Indeed, after the first five years, it was decided to make the scheme an ongoing program, with annual general meetings to assess whether further work should be done to bring infestation levels down even further.

'The invasive habits and rapid reproduction of rabbits renders uncoordinated approaches useless in most cases.'

The Wagga Wagga scheme was also successful. The dramatic results obtained after the first widespread poisoning campaign contrasted starkly with previous years of ineffective attempts to manage rabbits by individual occupiers. It was vividly demonstrated that the invasive habits and rapid reproduction of rabbits renders the uncoordinated approach useless in most cases. The cost-effectiveness of maintenance control operations on very low rabbit populations persuaded occupiers to continue sustained management with little outside support.

In the context of the strategic approach to rabbit management advocated in these guidelines, the existing schemes show a number of strengths and some weaknesses.

10.3.1 Strengths

Group action: The major factor underlying the success of the Rankin Springs scheme was the high level of participation and cooperation of landholder groups. For the Wagga Wagga scheme, also, the enthusiastic acceptance of the group approach by the landholders was important. In both Topar and Pine Creek, the schemes are examples of local community groups working to find solutions to their common problems.

The acceptance and ownership of the problem, and its solution, by landholders at the local and regional level is a critical factor in the strategic approach to rabbit management.

Government involvement: Government agencies played key roles in all these schemes, including:

- in some cases, stimulating and organising relevant stakeholders to cooperate;
- assistance in developing a management strategy;
- providing demonstration trials of control techniques;
- ready availability of departmental officers for advice and assistance, such as the provision of bait and fumigation equipment;
- monitoring, by noxious animal inspectors, of the rabbit population during the course of the project, and advice on relevant maintenance control procedures;
- government officers sometimes acting as group coordinators; and
- provision of funds and other resources through Commonwealth initiatives such as Landcare, the National Resource

Management Strategy, and the National Soil Conservation Program (NSCP)[2].

The active involvement of government agencies in a number of roles is a critical factor underpinning the strategic management approach adopted in these schemes.

Control strategy: A major feature of all schemes was the development of a control strategy relevant to the land-use characteristics in each area. Rankin Springs contained a variety of land uses, including unoccupied Crown Lands; grazing properties; private reserves; and national park and forestry lands. The Wagga Wagga scheme was relatively small, consisting entirely of private landholders. Topar and Pine Creek covered extensive areas, consisting of large rangeland grazing properties. The strategies contained many of the features of the approach described in Section 9.3.6, particularly the need for initial widespread control, followed by monitoring and effective maintenance control, and the special control requirements for control of warren-dwelling and surface-dwelling rabbits.

The development of a control strategy suited to the particular land uses of the area was a major factor contributing to all the schemes.

Management option: All four schemes were based on strategic, sustained management and accepted the concept that the most cost-effective management option is to achieve an initial substantial reduction in rabbit numbers, followed by effective maintenance control.

The adoption of strategic, sustained management as the option was very important in the success of the schemes.

10.3.2 Weaknesses

Assessing impact: None of the schemes undertook an initial assessment of the impact of rabbits on the resource outcome of concern, whether economic or environmental. In the case of Rankin Springs, although the initial concern was for the high cost of rabbit control on unoccupied Crown Land, the impact of rabbits on these lands was not measured or assessed. The concern in the Wagga Wagga scheme centred on the perceived impact of the rabbit on land degradation resulting in excessive siltation of Lake Albert. The degree to which the rabbit, rather than stock, feral and native animals, was contributing to this was not assessed. For the Topar and Pine Creek schemes, the concern was the perceived impact of the rabbit in reducing productivity and causing degradation, especially by increasing the woody weed problem. However, the extent to which the rabbit was contributing, rather than other factors, was not measured or assessed.

'Most schemes would have benefited from the development of measurable performance criteria.'

These weaknesses are understandable given the difficulties in directly assessing the impacts of rabbits on resources, and the need for more studies into this problem. It is expected that some of the projects funded under the Vertebrate Pest Program (see Introduction, page 13) will assist in developing a greater understanding of, and better techniques for, assessing the impact of rabbits on resources.

Performance criteria: For all the schemes, except Rankin Springs, the performance criteria were either poorly defined (Topar and Pine Creek) or not developed (Wagga Wagga). To be useful, the performance criteria should establish key indicators or milestones to be accomplished during the control strategy. These should be measurable to provide an indication of the success of the management strategy.

Most schemes would have benefited from the development of measurable performance criteria.

[2] The NRMS and NSCP have now been incorporated into the National Landcare Program (NLP).

Operational monitoring: Operational monitoring, that is the cost and effectiveness of the control operations, was poorly implemented in all four schemes. Only Rankin Springs kept records of the costs of control, and then only for unoccupied Crown Lands. It is very important that the costs and effectiveness of control operations be a part of the whole management process, so that the benefit–cost ratio for an ecologically sustainable production enterprise can be determined and the ratio maximised.

Better operational monitoring would have improved the effectiveness of all four schemes.

Performance monitoring: Performance monitoring, that is the assessment of the impact of the management program on the economic or environmental resource outcome, was also poorly implemented in all four schemes. Only some properties in the Pine Creek scheme maintained standardised photographic records to assess the effect of rabbit management on pastures. However, it is also the case, as for impact assessment, that further studies are required to determine methods to assess the effectiveness of rabbit management on resource outcomes.

11. Implementing Management

Summary

Most successful rabbit management schemes in Australia have involved group action. It was the basis for successful early schemes such as that at Bathurst, New South Wales, in the 1960s and for the more recent initiatives under Landcare and similar community-based programs. The Bathurst Scheme introduced self-imposed levies which are now part of the Rural Lands Protection Board rate. Land managers who achieve a virtually rabbit-free status attract a lower rate, which is a strong incentive for good management. The levy is used to employ rabbit control specialists to 'clean-up' following initial knockdown of rabbit populations by the landowner.

A national approach to managing rabbits must encourage the group approach as the primary mechanism for rabbit management. It is a potent method of promoting the 'stewardship' ethic, a sense of ownership of the problem and of responsibility as a 'good neighbour'. In turn, this approach demands a good knowledge of the scope and nature of the local rabbit damage problem.

Other benefits of a group approach include:

- *group reinforcement and peer pressure;*
- *improved communication;*
- *improved opportunities for broad-scale synchronised action; and*
- *cost savings through economies of scale.*

Within any group, economic circumstances of individuals, and attitudes towards rabbits and other land management issues vary enormously. Consequently, it is important to set clear, unambiguous goals for reducing rabbit damage.

Legislation should clearly state the responsibility of land managers for rabbit management and facilitate appropriate action. Equally important is the ability and commitment to enforce the legislation. Legislation is also needed to regulate use of toxic chemicals.

There are several potential obstacles to successful management of rabbit damage. They include the changing nature of rural communities in many parts of southern Australia, with increasing numbers of 'hobby farms' or part-time farmers, the amalgamation of smaller farms into large, company-owned enterprises and the difficulty of funding rabbit management over large areas of public land.

11.1 Group action — basis of a national approach?

11.1.1 Introduction

'Most successful operations rely on the zeal and motivation of small rural communities to manage rabbit damage.'

Successful rabbit management requires land managers who understand the damage rabbits cause and are committed to effective management of rabbit damage. Although the history of rabbit management in Australia is dominated by administrative and legal procedures operated at the state or local government level upon a 'subject' community, the great bulk of successful operations to manage rabbit damage rely on the zeal and motivation of small rural communities.

In the past, management of rabbits and their damage has been achieved on individual farms without reference to neighbouring properties, but this 'island fortress' approach was generally only possible by a combination of cheap farm labour and cheap rabbit netting.

In 1959, Francis Ratcliffe, one of the early advocates of group action for rabbit control wrote:

'The rabbit's most potent allies in Australia are the extreme individualism that is part and parcel of the man on the land, and the downright indifference of the majority of them … somehow or other the landholders must be persuaded to pocket enough of their individualism to make a regional drive something approaching a genuine community effort'.

He further stated that

'… if effective rabbit control … is to come to Australia, and come in a way that is going to stick and be self-perpetuating, it must spread naturally, from district to district, by the example of success. In other words, I envisage control developing gradually, with money and effort first concentrated in a few districts where the cooperation of the local community was assured. The only practical and satisfactory assurance of cooperation and continuing positive interest on the part of the local landholders that I can see would be a willingness to contribute to the cost of the district organisation through a special rate or levy' (Ratcliffe 1959).

Since 1959, there have been various group schemes in several states, some of which have been successful. Features of the successful schemes include:

- a high degree of understanding in the local community of the nature and extent of the rabbit damage problem;
- group reinforcement through peer pressure and good communication;
- clear, identifiable and shared goals;
- the ability to synchronise the control effort of rabbit damage;
- economies of scale and efficient use of machinery and human resources; and
- strong support from the local and state rabbit management authority.

Although group schemes are now enjoying a revival under Landcare and other initiatives, the long-term success of many of these ventures is uncertain. Problems associated with group approaches include:

- 'multi-task' groups, where it is difficult to focus sufficient attention and resources onto rabbit damage management;
- insufficient field support from government vertebrate pest agencies;
- a lack of knowledge of control and monitoring techniques; and
- coordinators lacking group management skills.

'Community initiatives in rabbit management require strong technical and extension support from the relevant state or territory pest animal authority.'

Community initiatives in rabbit management require strong technical and extension support from the relevant state or territory pest animal authority. While a system of 'user pays' is the inevitable consequence of 'leaner' governments, rabbits must be seen as a cost to the whole community. Governments have an important role in facilitating relevant research and in providing the extension and inspection back-up essential to the success of local rabbit management schemes.

11.1.2 Self-imposed levies

Local levy systems have been employed to great effect in the past. A good example is the 'Bathurst Scheme' in New South Wales, where a landholder levy was used to employ specialist maintenance control workers with appropriate equipment and expertise. As surmised by Ratcliffe (1959), local levies maintain enthusiasm of the participants and provide incentive to achieve the goal of local eradication or a very high level of control. Moreover, the concept of self-imposed levies is consistent with the current government emphasis on 'user-pays'.

11.1.3 The Bathurst Scheme

The Bathurst Scheme originated in 1961 in response to Fennessy (1961) when a group

Table 21: Some costs of rabbit control associated with the Bathurst Scheme in New South Wales, 1962–67 (Bruce 1969).

Year	Person days	Cost ($)	Cost/ha ($)
1962	89	5955	1.66
1963	64	4716	1.25
1964	31	2439	0.63
1965	22	1752	.045
1966	18	1543	0.38
1967	15	1408	0.35

of landholders, in conjunction with the local Pastures Protection Board, decided to alter the way in which they conducted rabbit management. A concept of 'rabbit-free areas' was developed based on the earlier success of the New Zealand 'killer policy'.

Initially, an area containing 43 properties with a total area of 3712.9 hectares (9171 acres) was chosen (Bruce 1969). Small landholder committees were formed to organise the work. Property boundaries were ignored, and the whole area was treated as a single entity, with plant, equipment and labour being pooled. In the first few months, significant gains were made, with some 70% of the area 'almost free' of rabbits. However, because of seasonal work commitments on many of the properties, it was later decided that the PPB take over responsibility for 'mop-up' work. Landholders agreed to contribute 35 cents per acre (87 cents per hectare) per year. This provided enough funds to employ a person with a large pack of dogs for a week each month. The two shire councils controlling the roads in the target area agreed to participate in the scheme. Later, the funding agreement was altered so that any costs incurred on a particular property above the 35 cents per acre would be met by the landowner. This 'cost plus' clause contributed greatly to the success of the scheme, for it provided an added incentive for the landholders to carry out their own control.

By 1975 the area involved in this 'rabbit-free' concept had grown to 83 000 ha. Only about one-tenth of this area was designated 'rabbit-free' at that time. Many other boards followed this early example, most notably the Wagga Wagga Board which claimed an area of some 64 000 hectares as being 'rabbit-free' in 1975 (Kennedy 1975). provides a good example of the progression from an initial higher cost per unit area to a very low 'maintenance' cost.

Although many of these early schemes spoke of eradicating rabbits, it would be more accurate to say that they were aiming for the concept of virtually rabbit-free status, equivalent to strategic, sustained management (Section 9.3.1). At these very low densities, the capacity for rabbit populations to rebound is much reduced and maintenance costs are minimal. Population-limiting factors such as predation, the probability of finding a mate, warren deterioration and severe climatic conditions probably have a major impact on rabbits at these low densities.

The Bathurst Scheme is still operating and further areas are being added to the 'rabbit-free' country. Once a group of landholders enter the scheme, the Rural Lands Protection Board assigns a special rate for the land in question and uses this revenue to carry out initial knockdown. A control area is then subjected to intensive rabbit control. Once Rural Lands Protection Board staff are satisfied that the area is essentially 'rabbit-free', landholders in that area can apply for a rate rebate to compensate for the fact that little or no Board time is required on their properties.

The Bathurst and similar schemes have operated in country where rabbit management is relatively easy. Achieving a virtually rabbit-free status in steep and rocky country, for instance, would be much more difficult. Even so, there is enormous scope for the further use of Bathurst-type schemes or other schemes based on group action. High rabbit numbers are still found in much relatively 'easy' country in southern Australia.

Other group schemes include those where links to government agencies are more formalised. In addition to those discussed in Chapter 11, examples include the Soil Conservation Boards (SCBs) of South Australia, and the Western Australian Land Conservation District Committees.

Importantly, under current nationally-funded programs such as the National Landcare Program (NLP), now incorporating the Save The Bush Program and National Resource Management Strategy, local groups can apply for Commonwealth as well as state assistance in land management matters.

11.1.4 Landcare and similar community-based schemes

The idea of the Decade of Landcare was introduced by the National Farmers' Federation (NFF) and the Australian Conservation Foundation (ACF) in early 1989. The Decade of Landcare was formally initiated when the Australian Soil Conservation Council, with endorsement of the ACF and NFF agreed that 1990 would be declared the Year of Landcare, and the 1990s the Decade of Landcare. The Year and Decade of Landcare were announced in the Prime Minister's Statement on the Environment, *Our Country Our Future,* released in 1989 (Hawke 1989). In the Statement, the Commonwealth made a commitment to provide, during the decade, over $320 million for landcare and related tree planting and remnant vegetation conservation programs. The main objective of the Decade of Landcare is to achieve ecologically sustainable use of Australia's lands by the year 2000.

There has been a dramatic increase in the number of Landcare groups, from 600 groups in 1990 to about 1600 today. In Victoria there are now 87 LandCare groups, covering about 2.6 million hectares (Victoria, Department of Conservation and Environment 1992). Twenty per cent of these groups list rabbit management as one of their major goals, in some cases, the principal goal.

Like the earlier Bathurst Scheme, Landcare relies heavily on community rather than individual action. Unlike the Bathurst Scheme, it relies more on its own organisational structure, and most projects are planned and carried out by Landcare members rather than government or semi-government staff. Landcare groups can attract outside funding, usually on a 'dollar-for-dollar' basis, and have received significant grants from the various Landcare and other Commonwealth and state government initiatives. Generally, Landcare tends to concentrate on long-term environmental problems such as salinity, erosion and tree decline, and is less concerned with improving immediate farm productivity. Nonetheless, in the longer term, the concept of ecologically sustainable development espoused by Landcare will influence the productivity of degraded land.

Some Landcare groups employ a 'coordinator' or 'facilitator' — usually part-time — to assist in planning, keeping group members informed on progress and problems, liaising with government and other agencies, and generally providing a focus and contact point. Decisions are made either at full meetings or meetings of the executive. The liaison, negotiation and people-management skills of the coordinator are an important element in the success of the Landcare group.

All states, territories and the Commonwealth have prepared 'Decade of Landcare Plans'. Elements of community-based action in the plans are:

- community education;
- resource appraisal and monitoring;
- establishing clear roles and responsibilities for both government and local community;
- research; and
- evaluation and review.

It is too early to comment on the long-term success of the Landcare initiative for management of rabbit damage. However, the Landcare concept has helped to link rabbit damage to other environmental issues, particularly the establishment of trees and programs of natural revegetation. Landcare has set new community standards for levels of rabbit control, for example, that rabbit damage should be low enough to prevent damage to trees. One other important element of the Landcare philosophy has been the development of strategy plans, both at the property and district level. This allows landholders to see their own property management in the context of a whole land system, and provides clear goals and means of assessing progress. Landcare has also developed higher local awareness and ownership of land management problems by bringing the individual managers together to share responsibilities.

11.2 Requirements for effective local action

11.2.1 Group or district approach

Group action for the effective management of rabbit damage is important. Groups should be relatively small, from 10–50 landholders. Where the nature of the rabbit problem or the land-type or land use varies markedly within the target area, it is advisable to consider the formation of sub-groups so that each smaller group shares a common approach and a common goal.

'The impetus for formation of a rabbit group should come from the community and not from the pest management authority.'

The impetus for formation of a 'rabbit group' should come from the community and not from the pest management authority. The latter should encourage and facilitate group formation but not impose it, otherwise local landholders will not have ownership of the problem or of the proposed solution.

11.2.2 Ownership of the problem and the good neighbour code

The damage caused by rabbits must be seen as a community problem, not a problem to be solved by governments or the next-door neighbour. Community ownership of the rabbit problem involves more than just the landholders themselves: rabbit damage is a cost to the whole community. Hence, although the costs of control are attributable to the landholder as the primary beneficiary, indirect costs such as provision of extension, research and technical advice are, to some degree, the responsibility of the wider community.

In a small country town the local shopkeepers will, indirectly, be adversely influenced by rabbit damage to productive lands in the district. Those with a purely aesthetic interest in the district, the field naturalists and bushwalkers, will have an interest in the management of rabbit damage.

The fear of fire and the knowledge of its disastrous consequences transcends all special interest groups and serves to unite a rural community in a common purpose. Often, the fire brigade will serve as the primary 'social unit' in a district and this, in itself, helps to reinforce the purpose of the group. In one sense, rabbit damage can be considered a slow form of bushfire. In both cases there is loss of production and damage to the environment. It is only the time scale that differs.

'Owning the problem' can be 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. Yet, failure to adequately manage rabbits certainly represents a threat to neighbouring properties and, by inference, a threat to the livelihood of others.

11.2.3 Knowledge of the scope and nature of rabbit impact

The management of rabbit damage requires an understanding of the scope and nature of the problem. Individual landholders have little knowledge of the extent of rabbit damage, since it can often occur in a slow and insidious manner. This is often the case where damage has been incremental over a long time and, more particularly, where it is exacerbated by overstocking.

Thus, one of the first requirements for successful group action is a knowledge of rabbit densities in the district, their association with particular habitats or land-use systems and the areas requiring treatment.

Mapping of the area is the simplest way to convey this information. Many Landcare groups prepare composite aerial photographs of their territory and, by using overlays, delineate various classes of 'rabbit country'. Some of these groups are now interested in digitised mapping and linking into a computerised geographic information system (GIS) (Section 7.3). This approach can accommodate a wide range and quantity of useful information. Maps can be produced at any required scale and the particular features varied at will. For instance, a rabbit management group may require a map which combines a particular land type or land-use pattern with cadastral data and information on the type of boundary fencing. One of the principal benefits of this approach is the capacity for individual farmers to supply information to the databank and to obtain detailed maps of individual farms showing required features. Under these types of mapping schemes the landholder becomes the provider, as well as the receiver, of the mapping information.

11.2.4 Whole-farm and district plans

Farm plans are a useful aid in planning for rabbit management and form the last and most important link in the whole planning process from national and state objectives downwards. The process of planning often forces a radical re-think on such things as location of internal fences, paddock size and type, and timing of various farming operations. The plans also enable a more accurate estimate of the materials, equipment and labour needed for the control works and the timing of various control operations. Farm or project plans for rabbit management must be coordinated with other conservation activities, especially reclamation programs such as tree-planting and erosion control.

Whole-farm planning is now a focus of Landcare and similar schemes through the Property Management Planning Program, and courses are available to assist in the production of these plans.

'The process of planning often forces a radical re-think on such things as location of internal fences, paddock size and type, and timing of various farming operations.'

Farm plans should reflect the wider aims and objectives of the regional, state and national plans. Some states have made progress in this area. As an example, the Victorian Department of Conservation and Natural Resources has a Victorian Rabbit Control Plan (1987) outlining the government's objectives and priorities for rabbit management. The regional arms of the Department provide the basic framework for district plans. The latter include mapping (1:50 000), and delineate control 'zones' on the basis of land value, whether for agriculture or conservation, and susceptibility to rabbit infestation. These district plans detail the distribution and density of rabbits and provide a history of past management.

11.2.5 A clear, unambiguous goal

All plans need to set realistic goals for the management of rabbit damage. Ideally, goals are based on a cost–benefit approach. Strategic, sustained management (SSM) to reduce and maintain rabbits at minimum densities is most likely to be profitable in higher rainfall areas and places where uncontrolled rabbit densities would usually be moderate or high (greater than three rabbits per hectare). Rabbit control to minimum densities is also likely to be profitable in conservation reserves where a high value is placed on the resources being protected from rabbit damage. In the sheep rangelands there are likely to be high benefits from rabbit control, in terms of increased wool clip and land values, but because of the large land areas involved, control costs may be high and land managers may lack sufficient funds. Rabbit control to increase production may not be profitable at times of low wool values or in areas which naturally have low rabbit densities (less than one rabbit per hectare). In the rangelands, the high cost of maintaining rabbits at very low densities might prevent this from being a feasible goal. More information on the relationship between rabbit density, damage and control costs will be needed before clearer assessments on the most effective strategy for rabbit management can be made for different areas and land uses, and on the best approaches for integrating rabbit management with other farm operations.

Rabbit control is technically complex and land managers need to be committed to a long-term strategy and clearly defined goal for a successful outcome. The authors believe the most effective goal is one of minimum rabbit densities where this is economically practical.

11.2.6 Integration of rabbit control with general land management operations

Too often, rabbit management is seen as an 'add-on' activity to be fitted in if time allows. It needs to be as integrated into farm and other land management as is drenching of sheep and cattle or blowfly control.

It needs also to be integrated into the normal farming routine. For instance, using 1080 for poisoning rabbits requires stock to be removed from the targeted paddocks. In south-eastern Australia, the poisoning operation might then fit in with the summer drenching program since the latter requires that newly drenched sheep be shifted to a 'clean' paddock.

'Rabbit management needs to be as integrated into farm and other land management as is drenching of sheep and cattle or blowfly control.'

Once rabbit management has been reduced to the maintenance level the farming routine should be sufficiently flexible to deal with a potential rabbit problem as soon as it becomes evident. Highly motivated farmers will nearly always carry a tin of fumigant tablets and a shovel in the back of the farm vehicle so that any new rabbit warren seen can be treated immediately.

'Highly motivated farmers will nearly always carry a tin of fumigant tablets and a shovel in the back of the truck so that any new rabbit warren can be treated immediately.'

11.2.7 Training, extension and technical advice

Adequate techniques are available to manage rabbit damage. More effective extension and technical advice is the major requirement (Section 6.3).

11.2.8 Role of legislation

While governments now emphasise facilitation of pest management rather than a legislative approach, the success of any rabbit strategy will be dependent on unambiguous legislation that states the responsibilities of all land managers including public land administrators. Equally important is the ability and commitment to enforce the legislation.

Legislation in most states and territories is adequate, but enforcement is often lacking or undertaken to different degrees. In New South Wales the suppression and destruction of rabbits under the *Rural Lands Protection Act 1989* is administered by the Rural Land Protection Boards (RLPBs). Although each board is obliged to administer the Act, it is not compelled to enforce it. There are 57 boards, each with a high degree of autonomy. The result is lack of uniformity in policy or administration. Needless to say, the commitment to rabbit management varies within and between boards (Korn 1991).

State and territory legislation must contain the opportunity for punitive action, including fines, 'forced entry' work and the ability to charge costs against title. Punitive powers should be used only as a last resort, but their existence provides a strong psychological support for rabbit management.

Legislation can be effective in other ways. For example, the *Land Agents, Brokers and Vendors Act 1973* in South Australia requires a vendor or prospective vendor to provide detailed information on a range of issues including any notices issued under the *Animal and Plant Control Act 1986*. Any notice to control rabbits or other pest animals on the vendor's land must be disclosed to the buyer. Other possible initiatives include issue of compulsory 'rabbit clearance certificates' before land in rabbit-prone country can change ownership.

Strong enforceable legislation and regulation is important to ensure the responsible use of toxic chemicals in rabbit control, and to discourage the use of poisoning as a long-term solution to rabbit management. The policy of the Animal and Plant Control Commission (APCC) in South Australia provides a good example. Here, landholders who wish to obtain poisoned rabbit bait must make a written commitment to attempt removal of rabbit harbour, particularly the warrens.

Economic frameworks need to be developed to assist in the assessment of the relative value of alternative control strategies whenever this is feasible. Such frameworks require: definition of the economic problem; data on relative costs and benefits; an understanding of why the actions of individual landholders may not lead to optimal rabbit management; assessment of means by which governments can overcome identified market failures; and then an assessment of the likely returns from alternative rabbit management strategies.

11.3 Implementation at the national, state and local level

11.3.1 Coordination or independence?

Coordinated management minimises recolonisation from untreated adjoining properties (Parer and Milkovits 1994) and offers economies of scale, shared hire or purchase of equipment including economies of overhead costs (Reardon-Smith et al. 1987), and perhaps most importantly, engenders and maintains enthusiasm through enhanced effectiveness, greater cost-effectiveness, peer support, encouragement, and camaraderie.

'Coordinated management minimises recolonisation from untreated adjoining properties and offers economies of scale, including shared hire or purchase of equipment.'

Nevertheless, where coordinated action is not immediately practicable, independent management programs are preferable to delaying control. However, rates of recolonisation could be so high that little benefit is obtained from the effort and expenditure on control.

Coordinated management programs may take different forms, including those organised by government, shire councils (Reardon-Smith et al. 1987) or self-organised groups such as Landcare groups (Coman 1991; Pine Creek Area Rangecare Group 1991; Topar Area Rangecare Group 1991). The different forms of organisation will be reflected in the size of the area involved. Recolonisation is less likely the greater the areas over which management is coordinated, because edge effects are minimised.

Coordinated management programs are usually effective in reducing rabbit damage to low levels (Bruce 1969), but they tend to falter in the maintenance stage when required inputs are small and potential gains are greatest (McKillop 1988; Reardon-Smith et al. 1987; Williams 1991). Sociological and human behaviour studies are required to determine (1) organisational structures that will persist beyond the more dramatic phase of rabbit reduction; (2) effective means of informing land managers of the future value of current low-level maintenance rabbit action to maintain virtually rabbit-free status; and (3) the means of permanently incorporating regular maintenance rabbit control within land management.

The image of rabbit management needs to be raised. This might be achieved best by quantification and revelation of the real cost of rabbit damage.

11.3.2 Who implements management?

Many rabbit control operations are intimidating, and dangerous if performed incorrectly. Nevertheless, legislation in all states obliges landholders owning rabbit-infested land, including the Crown, to control rabbits. Apart from the necessary commitment of funds, time and personnel, effective rabbit management requires individual landholders or government officers, implementers, and specialised contractors with the knowledge and skills to undertake effective rabbit management. Few people meet these requirements. State vertebrate pest agencies such as those in South Australia and Western Australia could undertake the necessary training on a cost-recovery basis. TAFE colleges could also contribute, especially for private individuals.

Contract services for rabbit control could expand as demand grows, which will happen only when rabbit management achieves a much higher public profile. Governments could promote a competitive rabbit-control industry by competing with private contractors and by keeping prices to realistic levels so that the use of either private or government services by production enterprises is encouraged. Governments might also use private contractors to control rabbits on conservation lands and Crown Lands where control is currently neglected.

Land managers can choose to employ government services or private contractors, or undertake the task of learning effective methodology themselves and training any staff to be involved. The choice will depend on factors including: (1) the nature of the problem; (2) the area to be treated; (3) the availability of services; (4) the availability of funds; (5) the capacity to borrow, hire or buy the implements; and (6) the availability of time.

Some government contractual operations have proven very successful. One such scheme involving poisoning, ripping and clearance of surface harbour was run by the Tamworth RLPB on a cost-recovery basis. The scheme evolved to a total contractual service provided by a spotter on horseback, a pack of dogs, and a bulldozer and driver. Ripping and clearance of surface harbour followed a 1080 poisoning operation if necessary. The landholder paid an hourly rate and supplied fuel from on-farm storage. The success of the scheme was indicated by the demand for the service which grew to the extent that a second bulldozer was purchased, and when one contract was completed, mostly over the entire property, the operators usually moved onto a neighbouring property. Participants claimed to have recovered their carrying capacity and doubled their stocking rates over a period of three years. The scheme reduced the usage of 1080 poison within the boundaries of the Board by 95% and effected a long-term solution, unlike the previous repetition of 1080 poisoning every two to three years (Dekkers, RLPB, NSW, pers. comm.).

11.3.3 Private contractors

Private contractors can undertake rabbit control operations for landholders who do not have the necessary skills and equipment. Absentee landholders who might otherwise neglect rabbit management especially benefit from the services of these contractors. Legislation is required to prevent unscrupulous contractors thwarting effective rabbit management by leaving some rabbits to maintain the need for their services. Suitable legislation would ensure that private contractors are appropriately qualified and experienced, and would provide a means to monitor their effectiveness.

11.3.4 Public lands under a 'group scheme' approach

Group schemes do not address the problem of rabbit management on public land. The government should be regarded as another landowner in the district and should take the initiative and provide an example of responsible land management at the local level. This could be a powerful means of extension. Farmers and other landowners cannot be expected to manage rabbits if the government, as a landowner, does not.

'Government land managers should take the initiative and provide an example of responsible land management at the local level.'

The position on more extensive areas of public land such as larger national parks is more difficult. Here, high-level rabbit management over large areas is constrained by limited finances. The initial costs of effective rabbit control often need to be spread over a period of years in relation to benefits achieved. The managers of public land operate within annual budgets and do not have the financial flexibility that might apply to the management of private land. For instance, on public land the annual 'maintenance' budget might need to be apportioned over a range of management requirements, only one of which is the management of rabbit damage.

Wise management in this situation requires a detailed knowledge of the extent and severity of each management problem, knowledge that is rarely available. Nonetheless, in apportioning resources to the various management issues, some special consideration needs to be given to rabbit management.

In general, where rabbit damage is identified as a major problem, it is better to spend limited resources on those areas requiring priority action and achieve high-level management rather than to treat the whole area at some lesser intensity. The latter achieves no long-term gain. It should be possible to select particularly sensitive areas and treat these using either barrier fencing or some form of buffer zone to protect the investment. As an example, the ERIN and various state and territory conservation databases can often help to pinpoint priority areas (Section 7.3). These areas may be the habitat of rare species or of rare or endangered vegetation associations.

It is strongly recommended that, in dealing with rabbit infestations on public lands, governments consider the provision of large capital grants for initial measures rather than smaller, annual allocations over the longer term.

11.3.5 Size of the problem

The magnitude of the rabbit problem in Australia is a psychological barrier to large-scale government investment in rabbit management. The perceived costs may be overestimated. It is instructive to consider a case study.

In the Western Division of New South Wales, there are some 877 000 hectares of national parks and reserves. Not all of the area is badly infested with rabbits and, allowing some $2 per hectare for initial ripping, the maximum cost of initial ripping would be $1.75 million. Annual maintenance costs thereafter might start at about $150 000 and decrease over time.

Of the grazing land of the Western Division, some 31 million ha, a little over half is badly infested. Allowing a 40–50% government subsidy on ripping, which would be sufficient incentive for most graziers to carry out control, the cost to government would not exceed $20 million. Maintenance control would be the responsibility of the land manager.

Those graziers who could not afford this initial expense are already able to obtain low interest loans for rabbit control.

Pilot schemes, such as that of the Pine Creek Rangecare Group (Chapter 10), have already demonstrated that rabbit management in the rangelands is possible and economic. We lack only the willpower and vision to meet the problem head on and to break it up into manageable units.

11.3.6 Changing nature of rural communities

In southern Australia, there have been major changes in the structure of rural communities over the last two decades: there has been a proliferation of small hobby farms and weekend blocks, and smaller family farms have been aggregated into larger units resulting in an increase in absentee owners. The available farm work force has also declined. These changes have militated against effective rabbit management.

Many owners of hobby farms and weekenders visit their properties only infrequently and know little about the nature of the land they have acquired and the techniques of effective rabbit management. The land is likely to be the most rabbit-prone in the district because the first land to be sold for subdivision is usually the 'rough country' which is of little grazing value.

At the other end of the scale, many smaller family farms have been swallowed up in larger company runs, again with absentee ownership being common. Traditional close ties between the farmer and the land are often destroyed and the single objective is short-term company profit. In addition, high costs of farm labour often mean that these large holdings do not have sufficient labour to tackle rabbit damage.

A possible solution for rabbit management in these circumstances is for local and state government to place tighter controls on the transfer of land. As an example, subdivision land could be subject to a title restriction such that sale could not proceed before certification of 'rabbit clearance' or, at least, evidence that some demonstrable and effective effort had been made to bring rabbits under proper management (Section 11.2.8).

PART SIX

FUTURE DIRECTIONS

12. Deficiencies in Knowledge, Techniques and Legislation

Summary

Biology and impact — *The biology of rabbits in Australia is well known. The economic and environmental damage rabbits cause, particularly in the rangelands, is less well known. The impact of rabbits on native vegetation and pastoral production needs to be measured in the rangelands. In order to determine the most cost-effective level of management, the relationship between damage and rabbit density needs to be quantified for both rangelands and cropping areas. The potential impact of foxes and feral cats on native animals following rabbit management also needs to be assessed.*

Management techniques — *Studies designed to develop or enhance biological control of rabbits should continue, including an assessment of the effectiveness of rabbit calicivirus disease (RCD), the use of the myxoma virus to deliver a sterilising agent to rabbits, and an assessment of the effectiveness of arid-adapted rabbit fleas in transmitting myxomatosis in arid lands.*

The long-term effectiveness of 1080 for rabbit management is uncertain, especially given the New Zealand experience of rabbits avoiding both 1080 poison and baits. Cost-effective humane alternatives need to be identified. Anticoagulants and cholecalciferol show promise.

Monitoring — *Low-cost techniques need to be developed for rapid assessment of: (1) rabbit impact on crops, native vegetation, native fauna and soil; and (2) rabbit abundance where warrens and burrows are little used by rabbits.*

Economics — *Cost–benefit analyses are needed for different levels of rabbit control for both cropping and grazing lands. The cost-effectiveness of various combinations of control techniques and prescriptions for rabbit management, including no control, need to be examined.*

Animal welfare — *The fumigants chloropicrin, and to a lesser extent phosphine, are considered inhumane. A replacement is required. Carbon monoxide is a potential substitute.*

Legislation and other policy instruments — *There is considerable variation between states and territories in policies, legislation and institutional arrangements for the formulation and delivery of rabbit and other pest animal management. The variation needs to be assessed to determine the most effective elements.*

Awareness and training — *Pest control officers, land managers and the public need to be aware of and understand the damage rabbits cause so that they can make judgments about rabbits and their management. Better training, decision-support systems and information brochures based on the information presented in this report are required.*

12.1 Introduction

Australian research has provided much of our understanding of rabbit biology, and the nature and action of the disease myxomatosis. It has also assessed the effectiveness of rabbit control techniques, particularly poisoning with 1080 and warren ripping.

Nonetheless, rabbits are still Australia's principal animal pest, particularly in the arid and semi-arid interior. This is despite the enormous impact of the disease myxomatosis and, at least for the more highly productive lands of the south-west and south-east of Australia, the high annual expenditure on rabbit control.

Some of the reasons why rabbits are inadequately managed are often more to do with human perceptions and communication problems than with ignorance of the basic biology of the animal. Further research into the impact of rabbits in Australia is required to validate or improve upon the vast amount of anecdotal and other evidence which establishes the rabbit as the most damaging vertebrate pest species in Australia.

Resources required for research proposals vary considerably and will influence which proposals are taken up.

12.2 Biology of the rabbit

12.2.1 Biological control

Future use of biological control agents against the rabbit requires a better understanding of the interaction between host and disease. As an example, the possible use of myxoma virus as a vector for contraception (Section 7.4.14) will require that disease epizootiology is much better understood, particularly in the rangelands. This would include a careful evaluation of agents for carrying myxomatosis — in particular, arid-adapted vectors.

Developments required: biological control

- Long-term studies of the relationships between the host, vector and disease, with particular emphasis on disease transmission. A primary aim is to identify suitable strains of the myxoma virus to act as carriers for the immunosterilant messenger.
- Research to isolate strains of the virus combining high virulence with long survival times which increase the effectiveness of myxomatosis. Research is also required to develop techniques of producing large amounts of 'pure strain' virus cheaply and to improve the techniques of initial 'seeding' of such viruses into rabbit populations.
- Research to increase the effectiveness of myxomatosis vectors, with particular emphasis on arid-adapted rabbit fleas.
- Continued investigations into the effectiveness and target specificity of rabbit calicivirus disease (RCD) as a possible biological control agent in Australia.
- Research on the evolution of resistance to biological control agents and approaches to overcome this.

12.3 Impact in non-agricultural areas

12.3.1 Rangelands

Management of vast areas of the Australian rangelands requires knowledge of the effects of rabbits on perennial vegetation. Of particular importance is a knowledge of the long-term effects of different densities of rabbits and other herbivores on native vegetation. This would be a very complex study requiring broadacre study sites and a large number of variables. Investigations need to include pastoral land, national parks and unalienated Crown Land. Such investigations would assist decision making by Aboriginal communities regarding rabbits on their land.

Developments required: impacts on rangelands

- Assessment of the relationship between rabbit density and impact upon pastoralism and tree and shrub regeneration in the rangelands. This must include a study of the cost of rabbit impact during drought and therefore needs to be of sufficient duration to cover at least one drought period.

12.3.2 Conservation areas

The impact of rabbits on conservation areas, including parks and reserves, is a neglected issue. Many weed problems in national parks are in fact due to the suppression of native vegetation by rabbits.

Developments required: impacts on conservation areas

- Assessment of the impact of rabbits on native vegetation. Particular emphasis on rare or threatened species associations and ways of ensuring their natural regeneration. Because of the large number of variables involved, initial work should concentrate on the relationship between rabbit density and regeneration of trees and shrubs over a range of seasonal conditions.

12.4 Impact in agricultural areas

12.4.1 Pastures and stock

The cost of rabbit damage in Australia has been poorly documented despite 140 years of rabbit damage to pastures and agricultural production. Most estimates are based on 'dry sheep equivalents' (DSE) with a range of 9–16 rabbits claimed as being equal to one DSE. The estimate does not allow for possible selective grazing by rabbits which may lead to increasing weediness and the loss of valuable pasture species. The costs of rabbits at various densities and for a range of farm situations need to be quantified. Cost estimates need to include control costs and, if possible, costs of 'environmental' factors such as soil erosion and weed invasion. Long-term studies are required to cover the range of seasonal conditions including drought years. Such studies might be best carried out in conjunction with broad-scale community initiatives such as Landcare and Rangecare.

Developments required: impacts on agricultural areas

- Quantification of the relationship between rabbit density and rabbit impact, and the costs and benefits of control for cropping and grazing land.

12.5 Management and monitoring techniques

For most of Australia, the basis for long-term rabbit management is destruction of warrens and the removal of above-ground harbour. Technology is improving rapidly, with larger, more efficient machinery and safer, more cost-effective herbicides. Only a small number of studies have investigated the most cost-effective combination of control activities preceding warren and harbour destruction, and even fewer have looked at long-term maintenance costs necessary to hold rabbit populations at very low levels.

12.5.1 Technique comparisons

Comparative studies are required to determine the cost-effectiveness of various control techniques. This applies particularly to comparisons of warren ripping techniques, such as bulldozer versus tractor use, time for cost-recovery of various techniques, and the most appropriate sequence of applying these techniques.

Developments required: comparison of control techniques

- Assessment of the cost-effectiveness of various rabbit control techniques used alone or in combination with other techniques, for a range of land types including both agricultural and conservation lands. Priority techniques to be assessed are ripping and harbour destruction with prior poisoning and follow-up fumigation. The study should include a detailed evaluation of the various machines available for warren ripping.

12.5.2 Control of surface rabbits

There are few techniques for managing surface-dwelling rabbits.

Developments required: control of surface rabbits

- Determination of optimal methods for managing rabbits that live in scrub or wooded habitats. The effectiveness of burning scrub by various prescriptions as a component technique of managing rabbits in scrub, and the effect of such practices on native flora and fauna populations, needs to be evaluated. Techniques for managing rabbits in rocky areas and in areas of steep slopes need to be developed and evaluated.

12.5.3 Alternative poisons, particularly anticoagulants and cholecalciferol

A major concern with current control technology is the high costs of anticoagulant poisons. These chemicals are used where domestic animals and some native wildlife species are potentially at risk from 1080 poisoning. The principal anticoagulant used for rabbit control, pindone, is over 50 times more expensive than 1080. Also, the heavy reliance on 1080 as the principal rabbit poison in Australia requires that we have some suitable substitute should this poison no longer be available or efficacious. Currently 1080 is available from few sources and the long-term future of this chemical is not assured.

Cholecalciferol is a chemical with considerable potential for rabbit control. Further research on its suitability is needed, especially on the sensitivity of non-target species, on its persistence in stock after ingestion, and its degradation in the field. Cholecalciferol is approximately 16 times more expensive than pindone, so further research is required on reducing its cost, such as the addition of calcium carbonate to baits.

Research is required on alternating the use of poisons to minimise the development of poison aversion and poison tolerance and to reduce costs.

Developments required: alternative poisons

- Evaluation of the range of poisons available for rabbit control, particularly anticoagulants and cholecalciferol, with particular emphasis on cost-effectiveness, non-target dangers, persistence in livestock, and ease of application on carrot, oat and pellet baits.

12.5.4 Improvements to control techniques

Of major concern, particularly in southern Australia, is the reliance on ‘knockdown’ poisoning as the primary control method. Recent experiences in New Zealand suggest that neophobia and bait shyness are likely to occur in Australia if we continue to rely on poisoning. The main areas requiring poisoning as the primary technique are inaccessible areas where treatment of rabbit harbour and destruction of warrens is difficult if not impossible. To this must be added large areas of public land where the relevant authority does not have the resources to carry out fully integrated management of rabbits in the short term.

Developments required: control techniques

- Re-appraisal of the (1) ‘tarbaby’ technique using different toxins and carriers; (2) effectiveness of long-term bait stations; (3) feasibility of slow release fumigant chemicals; (4) effectiveness of explosives to collapse warrens; and (5) the sealing of ’difficult’ warren entrances with a combined fumigant and expanded foam mix.

12.5.5 Non-target wildlife

The impact of current control techniques upon non-target species (including introduced predators) requires further study. This applies particularly to the use of poison baits. Despite a number of published studies in this area, there has been little attempt to improve the target-specificity of baiting.

Developments required: protecting non-target wildlife

- Improving target-specificity of baits and poisons to minimise potential 'off-target' losses. Investigations should include alternative toxins, use of dyed baits, value of specific chemical lures or deterrents, and the method of bait presentation.
- Development of baiting techniques which allow rapid return of farm livestock to treated paddocks. Loss of grazing is often cited by farmers as a major reason for failing to carry out adequate poisoning operations.
- Investigation of use of rabbit warrens by non-target species. Non-target wildlife using warrens are vulnerable to warren ripping and fumigation.

12.5.6 Predator–prey relationships

Developments required: understanding predator–prey relationships

- Assessing the long-term effectiveness of non-native predators, foxes and feral cats in managing rabbit populations and determining how best to use predators in rabbit management. This study must be linked with that assessing the impact of foxes and feral cats on native wildlife following rabbit management.
- Field experiments to determine the impact on native prey of rabbit predators due to effective management of rabbits. Studies should concentrate on areas with rare or threatened native species.

12.6 Administrative procedures and incentives

While legislation alone cannot ensure effective rabbit management, effective and enforceable legislation is a necessary adjunct to successful management.

The structure and process by which states and territories coordinate rabbit and other pest animal management varies considerably. In some it is vested mainly in local or district authorities while in others it is more centralised. No one state has a perfect system. The effectiveness of each needs to be assessed (Braysher 1993).

Governments and pest control authorities also need to review the effectiveness of current initiatives and administrative procedures in the areas of rural finance, incentives, subsidies and penalties. Current incentives, such as the National Landcare Program (NLP) grants for land rehabilitation, often fail to recognise rabbit damage as an important contributor to land degradation.

Particular care is needed regarding guidelines for subdivision of rabbit-prone country. In many instances, the subdivision of such country into small 'weekender' or hobby blocks has increased the rabbit problem. Many of the new tenants are absentee owners who have little or no knowledge of rabbit management.

12.6.1 Identification of pest, animal and weed management in land tenure and financing agreements

The South Australian *Land Agents, Brokers and Vendors Act 1973* requires a vendor to provide information on the status of their land to a purchaser at least ten days prior to settlement. Information includes any notice to control pest plants or animals. This provision helps prevent transfer of pest-infested land. It also may encourage brokers to incorporate previous rabbit management into the value of the property. General applicability of these provisions needs to be investigated.

12.7 Training and extension

12.7.1 Training

A recent workshop on rabbit control in Australia (Coman and Arundel 1991) highlighted deficiencies in extension and training with respect to rabbit management, and recommended that an

Developments required: administrative procedures

- All levels of government should (1) review and assess the adequacy of existing legislation, policies and institutional arrangements for the formulation and delivery of programs for managing rabbits and other vertebrate pests; (2) investigate the introduction of special clauses or 'caveats' upon land titles such that land rental or sale is contingent upon the removal of animal pests and weed problems to the satisfaction of the responsible authority; and (3) investigate with financial and real estate institutions, the means by which effective rabbit management can be seen as a capital improvement and, as such, the value of the work adequately reflected in property values.

extension and training package on rabbit biology and management techniques be prepared.

The move toward multi-skilling of pest management staff is commendable. It links rabbit management with other aspects of land management. There is, however, a risk that too little emphasis will be placed on rabbit management, especially with the recent decline in resources available to train field staff. Rabbit management should be given special emphasis by state and territory pest control authorities. It should be part of a generic training package on vertebrate pest management that is based on a broad land management approach.

Developments required: training

- These guidelines should be used by each state and territory where appropriate to prepare or update their training manuals on rabbit management.
- There is scope for the development of a national or interstate training scheme. While techniques and approaches may vary between states, territories and regions, basic information (rabbit biology, control techniques and damage assessment) is common. South Australia and Western Australia could develop and run these schemes on a cost-recovery basis.

12.7.2 Increased public awareness of the rabbit problem

So that the public can make a better and more informed judgment about rabbits, information needs to be packaged and presented with the aim of developing an awareness and understanding of rabbits, their biology, the damage they cause and what can be done about them.

Developments required: public awareness

- Production of a simple education package suitable for schools, and similar to recent successful initiatives regarding salinity, tree decline and other environmental issues.

12.7.3 Increased extension and advisory services

Landcare and similar community-based groups are an essential element in the planning and implementation of successful rabbit management. They are an effective means for developing ownership of the problem at the local level and provide a cost-effective means for governments to distribute advice and other resources. Groups require coordinators with the necessary personal or technical skills. There is also concern that many Landcare groups may fail when funds cease at the end of the

Developments required: advisory services

- The effectiveness of Landcare and similar community-based groups as a means for achieving long-term management of rabbit damage should continue to be reviewed. The review should determine the essential elements for successful management of rabbit damage, including the level of support required from pest management authorities.

Decade of Landcare. The organisation, programs and strategies of successful groups, especially rabbit management groups, need to be examined.

12.8 Animal welfare

12.8.1 Control techniques

The two fumigant chemicals currently used for rabbit control, chloropicrin, and to a lesser extent, phosphine, cause suffering to rabbits (Section 5.5.1). A new fumigant chemical is needed which is more humane but reasonably cheap and effective, enabling chloropicrin and phosphine to be phased out.

Trapping is not an effective rabbit control technique. Steel-jawed traps are inhumane and, importantly, other and more effective alternative control techniques are available.

Developments required: animal welfare

- Critically review available information to identify possible replacement fumigants for chloropicrin and phosphine, particularly carbon monoxide. It would be advantageous if the replacement chemical was able to be used in power fumigating machines designed for the application of chloropicrin.
- Those states and territories which allow the use of steel-jawed, leghold traps should ban the devices for rabbit control.

6

General Reading

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Appendix A
Control Techniques

This Appendix should be read in conjunction with Section 5.5, which assesses the animal welfare concerns associated with each technique, Section 7.4 which outlines the advantages and disadvantages of each technique and how the technique should be used, and Chapter 10 and Appendices B and C which illustrate the combined use of a variety of techniques for four land management examples.

A1 Poisoning

Introduction

When follow-up harbour removal and warren destruction are possible, the aim of poisoning is to increase the effectiveness of maintenance control action. Poisoning should aim for a 90% kill or better. Poisoning alone will provide only short-term relief from rabbit damage.

Where rabbits do not form warrens, or where warrens cannot be destroyed, such as in parts of Western Australia, poisoning may be the only practical means of suppressing rabbit numbers. Bait shyness and poison aversion are likely to be serious problems.

A1.1 Equipment (Table A1)

A variety of specialised bait-laying equipment has been developed to make the distribution of bait more economical and effective. Bait can also be distributed manually using any simple system for measuring it out.

Baitlayers can be towed by conventional, four-wheel drive or all-terrain vehicles or mounted on the three-point linkage of a tractor.

Specialised baitlayers usually have the following features:

- a storage bin for the bait;
- a feed mechanism to regulate and in many cases to alter the rate that bait is laid; and
- a disc or single tine to form a furrow. (The role of the furrow in encouraging rabbits to feed on the bait is unknown but the furrow provides a clear path for subsequent pre-feeds and poison bait

Table A1: Materials and services needed for poisoning.

Materials and services	Available from	Further information
Mechanical baitlayers	Purchase from engineering manufacturers; hire from local or state vertebrate pest control agencies	Local or state and territory vertebrate pest control agencies
Bait materials (oats, carrots and cereal pellets)	Stock feed or grain merchants or stock agents; other farmers	Suppliers
Poisons	Mixing or baiting service available from local or state and territory vertebrate pest control agencies	Local or state and territory vertebrate pest control agencies
Contract poisoning service	Local or state and territory vertebrate pest control agencies. Private contractors operate in some areas	Local or state and territory vertebrate pest control agencies

Table A2: Choice of technique for poisoning.

	1080	Pindone
Under what conditions should the poison be used?	Agricultural and conservation lands with rainfall greater than or equal to 250 mm, and which are: • areas of relatively high rabbit abundance requiring reduction in numbers prior to control by other methods; OR • areas with high rabbit numbers where no other control methods are practicable. Areas of infestation situated away from human settlement and areas where dogs and livestock can be denied access to the bait.	Agricultural and conservation lands with rainfall greater than or equal to 250 mm, and which would otherwise be treated with 1080 poisoning but are: • areas of infestation close to human settlement; OR • areas where dogs and livestock are likely to be at risk if 1080 poison is used.
When should the poison be used?	Outside of the main breeding season. When the availability of other feed is low.	Outside of the main breeding season. When the availability of other feed is low.

trails and assists subsequent covering or removal of unused bait).

Other devices rely on broadcasting the bait over a larger swathe rather than placing it in or beside a furrow. This can be as effective but it is virtually impossible to cover poison bait trails so that stock can be returned sooner to poisoned areas.

Light-weight baitlayers are a recent innovation. They can be towed behind all-terrain vehicles (four-wheeled motor 'bikes') and have the following advantages over conventional equipment: low operating costs; minimal environmental impact; and high manoeuvrability enabling effective poisoning in environmentally sensitive areas.

In some states, carrot or oat baits may be applied from aircraft, but the state vertebrate pest control authority must be consulted for approval.

A1.2 Bait

Baits always must be clean and attractive. Contaminated baits can discourage rabbits from eating a lethal dose or reduce the potency of the baits. If oats are used, where practicable, landholders should use oats grown on their property to minimise the risk of weed infestation.

There is no evidence that chemical attractants encourage rabbits to eat more bait material. Dyeing baits is advisable in order to distinguish between poisoned and unpoisoned baits. This helps prevent accidental feeding of poisoned baits to livestock, and accidental dosing of bait with a second lot of poison.

A1.3 Procedures

The following points need to be addressed when laying a trail:

1. Encircle all warrens and all major areas of rabbit activity with the bait trail (Figure A1).

2. Follow the same trail for both free-feeds and for the poison trail.

3. Place bait in the activity areas of all groups of rabbits.

4. Include property boundaries and scrub fringes in the treatment.

5. Avoid crossing trails as this creates confusion when subsequent trails are laid. When there is no alternative, the trail should be crossed at right angles so that the appropriate direction is obvious when the trail is re-laid.

6. Use a grid trail pattern in areas of thick vegetation, when feeding areas cannot be discerned or when it is otherwise impossible to follow a winding trail.

Use sufficient bait for all the rabbits in the area. Scrimping on bait is false economy and can greatly reduce success.

In Western Australia, pindone impregnated oats may be laid. A packet of poisoned oats is mixed with 6 kg of clean oats then laid at a rate of 17 kg/km. State and territory authorities differ considerably on the number of free-feeds required. We recommend the number of free-feeds shown in Table A3, with 2–3 days between feeds.

1. In areas where all bait was eaten lay more bait on the subsequent free-feeds.

2. In subsequent feeds cover areas that were discovered but missed on the first free-feed.

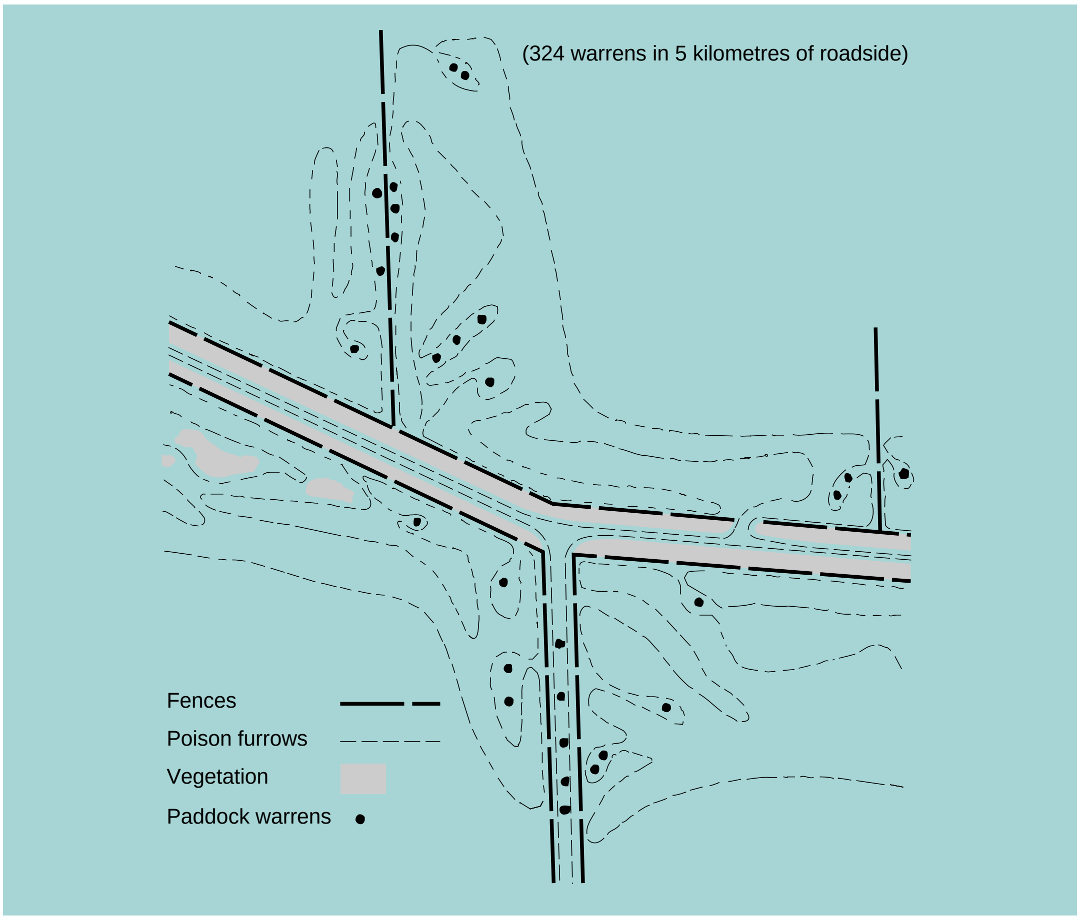

Figure A1: Map showing adequate trail placement to cater for a substantial rabbit infestation, Murray Mallee district, South Australia.

Table A3: Recommended free-feeding rates.

	Free-feeding for 1080 poisoning			Free-feeding for pindone poisoning*
	Oats	Carrots	Cereal pellets	Carrots
Number of free-feeds	3	2	2	2
Rate of trail laid (km / 100 ha) in infested areas	≥24	≥24	≥24	16
Rate of feed laid (kg / km of trail)	4.2	4–8	4–8	4–8

* Free-feeding may not be required for pindone in all states (see Table 16)

Table A4: Legal restrictions on the use of poisons.

Legal requirements	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Can private land managers use prepared baits for conventional 1080 poisoning?	Yes(a)	Yes	No	Yes	Yes	Yes	Yes	Yes
Can conventional 1080 baiting be used by qualified personnel?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Are warning notices required when using 1080?	No(b)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Must neighbours be warned that 1080 is being used?	No(b)	Yes	Yes	Yes	No	Yes	Yes	Yes
Can prepared 'one-shot' 1080 be used by qualified personnel?	Yes	No	Yes	Yes(c)	No	No	No	Yes
Can prepared pindone baits be used by private land managers?	No	Yes	na(d)	Yes	No	Yes	Yes	Yes
Are warning notices required when using pindone?	No(b)	Yes	na	Yes	na	Yes	Yes	Yes
Must neighbours be warned that pindone is being used?	No(b)	Yes	na	Yes	na	Yes	Yes	No

(a) Laying of prepared baits by private landholders are permitted subject to supervision by the ACT Parks and Conservation Service.
(b) There is no legal requirement to display notices to warn neighbours when 1080 or pindone is used, but it is ACT Government policy to do so.
(c) Permitted but not recommended.
(d) Pindone is not used in the Northern Territory.
na not applicable.

Longer intervals between free-feeds, or between the last free-feed and the poison feed, do not influence the effectiveness of the control program.

A1.4 1080 poison

1080 poison is supplied only to authorised vertebrate control agencies (Table A4). The most dangerous part of handling 1080 is the mixing of the raw powder with water to form a 5% stock solution. Mixing and handling of raw 1080 must be undertaken only by staff trained and nominated by the relevant authority in each state or territory. The facilities, conditions and qualifications for this process are set by the relevant state or territory authority, which can provide further information if required.

Preparation of 1080 stock solution

Requirements for recording the mixing, supply and storage of 1080 may vary between states and territories.

- Mixing and handling of 1080 powder should take place in well-ventilated but draught-free conditions at a site which is isolated from animals and people not involved in the mixing process.
- All mixing and handling equipment should be clearly labelled 'POISON 1080' and not used for any other purpose.
- Operators must wear the following protective clothing: overalls and rubber boots; heavy duty rubber gloves; full-face respirator with RC224 canister for handling 1080 poison, plus a supply of refill cartridges (consult the state or territory vertebrate pest control authority for more details); and a washable hat and face visor.
- Other necessary equipment includes: a calibrated device such as a drench gun for measuring and distributing the 1080 solution onto the bait material; watertight storage containers and measuring flasks, including 1 x graduated 100 mL measure, 1 x 15 to 20 L translucent plastic container, 1 x plastic jug (about 1500 mL size) and a 1 x 3 L plastic bottle; a mixing device such as a cement-mixer; 2 x 55 L storage drums with lids for the bait; 1 x 4 L plastic water bottle; 1 x spring balance; and a carrot chopper if using carrots.

Conventional oats

- Mix 50 mL of 1080 stock solution (5% 1080) with 6 kg of dry oats. Five 'mixes' at a time can be handled by a small cement mixer (i.e. 250 mL in 30 kg). One kilogram of 1080 powder is enough to treat 2400 kg of oats. Ensure that the solution is spread evenly through the oats and continue to mix the oats until the solution has been absorbed.
- Use only clean oats. Impurities such as straw, or awns on the oats, can absorb 1080, reducing the concentration of 1080 available to rabbits.
- The recommended concentration of 1080 in the final poisoned bait material is 0.04%.

Cereal pellets

- Dilute the 'standard' or stock solution by adding 1500 mL of water to 1000 mL of poison solution. The dry and absorbent nature of this bait material requires more water in the poison solution to ensure a satisfactory coverage.
- Only small quantities can be mixed at a time. Care must be taken to squirt the solution with a coarse spray onto the bait while the mixer is revolving. This is because the dry, absorbent nature of the bait results in little transference of poison from one pellet to another during mixing.
- Spray 310 mL of 'pellet' solution onto 10 kg of pellets to give a concentration of 0.06% pure 1080 (i.e. 5.4 g of 90% pure 1080 poison in 10 kg of pellets).
- A rabbit needs to eat 1.63 g of pellets to ingest a lethal dose (approximately two average-sized pellets). At a poisoning rate

Table A5: Recommended poison feeding rates.

Recommended poison feeding rates	1080 poisoning			Pindone poisoning
	Oats	Carrots	Pellets	Carrots
Rate of trail laid (km / 100 ha) in infested areas	≥24	≥24	≥24	16
Rate of poison feed laid (kg / km of trail)	2.8	4–8	4–8	4–8

of 4 kg/km a lethal dose would be contained in about 40 cm of furrow.

Carrots

- Carrots are more palatable so rabbits will usually consume more carrots than other baits.
- Dilute the 'standard' or stock solution by adding 500 mL of water to 1 L of solution.
- Apply 50 mL of the diluted solution to 6 kg of chopped carrots. (Batches of five such 'mixes' can be prepared in a cement mixer.)
- There is 1.7 g of 90% pure 1080 in 6 kg of treated carrots, which is a poison concentration of 0.026% pure 1080 in the bait.
- A rabbit needs to consume 3.8 g of treated carrot to ingest a lethal dose. This is the amount of bait in just under one metre of trail at a poison bait-laying rate of 4 kg/km.

One-shot oats

The Agriculture Protection Board (APB) in Western Australia supplies its officers with packets of oats containing the appropriate concentration of 1080. These packets are then mixed with unpoisoned oats to form the one-shot mixture. Officers using one-shot oats should consult the APB for further information.

A1.5 Pindone

Methods used for preparing pindone baits vary between states and territories. Consult the appropriate state or territory vertebrate pest control authority.

A1.6 Laying poison bait

The same trail should be followed as used for the free-feeds. Warrens, rabbit grazing areas and the trails themselves should be inspected after a poisoning program so that rabbit carcasses can be collected and disposed of by burial or burning.

A1.7 Precautions

Risk to people

People are highly susceptible to 1080 poison, less so for pindone, but if the following guidelines are followed, risks are minimal:

- ensure that bait material is mixed, transported and used in accordance with the requirements of the relevant state or territory vertebrate control authority;
- dye or otherwise mark poison bait to show that it has been poisoned;
- use intact rubber gloves when handling the poison bait; and
- do not inhale dust from poisoned oats or pellets.

Only persons who are trained and supervised by the state or territory authorities should handle raw 1080 or pindone. Consult the relevant authority for further information.

Risk to stock

Stock can be poisoned by both 1080 and, to a lesser extent, pindone. Most losses have been due to either poisoned bait being accidentally fed to stock or stock being prematurely allowed into a poisoned paddock.

The risk of accidental feeding can be minimised by closely adhering to state and territory restrictions on the transport and storage of poison, and by identifying poisoned baits with dye. All containers used to store poison baits must be clearly labelled.

The risk of poisoning stock can be minimised by:

1. Removing stock before free-feeding for 1080 poisoning begins.
2. Using oats where practicable. Stock are more likely to take carrots or pellets. Even dried 1080 carrot bait can become attractive to stock in heavy dew or rain.
3. Keeping stock out of the paddocks where 1080 poison has been laid until:
   - the trail is covered, for example by dragging a chain over it or by using the disk or tine in the bait-layer; or
   - the oats have germinated: poisoned oats can contain up to 50% of the original concentration of 1080 until they have germinated.

Pindone can be used in paddocks containing stock, but it is generally recommended that stock be withheld from pindone-poisoned paddocks as an added safety precaution. The relevant state or territory authority should be consulted for further information.

Risk of secondary poisoning

Dogs are extremely susceptible to 1080 and can be poisoned through eating the stomach and intestines of poisoned rabbits or through eating poisoned pellets. Domestic dogs and cats should be kept away from any areas used for mixing 1080 baits, and where baits have been distributed. There is no antidote for 1080 but there is for pindone. Any domestic animal suspected of being poisoned with pindone should be treated with vitamin K or phytomenadione as prescribed by a veterinary practitioner.

Risk to wildlife

The risk to non-target wildlife can be minimised by following the recommendations for poisoning outlined in these guidelines. Effective rabbit control through follow-up ripping and ongoing maintenance will minimise the need for repeated poisoning and hence the possibility of non-target wildlife kills. Choice of bait is also important. Where practicable, choose bait that is least attractive to wildlife most at risk. For example, oats are safe where parrots are abundant. In addition, birds are less susceptible than rabbits to 1080 bait, and the 1080 is mainly concentrated in the husks of oats which birds usually discard. Covering the trail the morning after laying the poison and collecting dead rabbits will also reduce risks (Section 7.4.8).

First aid

There is no known antidote to 1080 poison. Medical help should be sought immadiately for any person suspected of being poisoned with 1080.

Symptoms include vomiting, numbness, twitching of the face and excitation of the central nervous system progressing to epileptic-like convulsions.

If poisoning is suspected, induce vomiting by taking the appropriate dose of Ipecac syrup, drinking 60–115 mL (2–4 oz) of a strong saline solution of table salt in warm water (dissolve as much table salt in water as will readily dissolve), or stimulating the back of the throat with a spoon or padded stick.

Following the inducement of vomiting, the patient should be left completely quiet and rested. Note, induction of vomiting is of little use after the symptoms of 1080 poisoning are observed. By this time, the poison has already been absorbed. Moacetin may be given if the patient is conscious and not convulsing.

Immediate medical attention should be sought for any persons suspected of being poisoned with pindone so that the antidote (vitamin K) can be administered.

A2 Warren destruction

Introduction

Warren destruction is the most effective way of reducing rabbit density (Section 7.4.9). There are two recommended methods of warren destruction: deep ripping and disc cultivation.

A2.1 Deep ripping

The aim of ripping is to destroy the warren structure to a depth of at least 50 cm and to fill deeper burrows with loose soil. The ripped warren should be smoothed so that it is not attractive to rabbits looking for a suitable place to dig. The most appropriate time to rip and the advantages and disadvantages of this method are discussed in Section 7.4.9.

Equipment

The availability of equipment will often be the most important determining factor (Table A6). Specialised tines are manufactured by some agricultural engineering companies. Earth-moving contractors will often undertake ripping programs. The

Table A6: Suitability of equipment for ripping.

Type of vehicle	Suitability
Two-wheel-drive tractor, ≥ 40 kW	Flat or gently sloping land, for small total areas
Four-wheel-drive tractor	Sloping land, loose sandy soils, larger areas
Crawler tractor	Steeply sloping land, heavy soils and rocky ground, very large areas
Drag-arm tractor (back-hoe or excavator)	Areas requiring minimal disturbance to surface vegetation or where other equipment cannot gain access without unacceptable disturbance, e.g., creek banks, gullies, contour banks, under trees or fence lines
Type of ripper	
Single tine	Small or difficult areas, especially suited to low-powered, two-wheel drive tractors or drag-arm tractors
Multiple tine	Larger areas, especially with more powerful wheeled tractors and with crawler tractors. In general, the more powerful the tractor and the greater its traction, the more tines can be pulled under certain soil conditions
Blade plough or similar	Heavy soils or large complex warrens

appropriate state or territory vertebrate pest control authority can provide relevant details.

Methods

The property map showing rabbit density and distribution, and rabbit management units can be used to plan the ripping program (Section 7.3).

- Allow dog packs to roam the area to be ripped, both before and during the operation, to drive surface-living rabbits underground.
- 'Cross-rip', that is, rip in one direction and then again at 90 degrees to the original ripping to completely destroy the warren complex.
- Keep tine rip-lines ≤50 cm apart and extend to about 50 cm depth; the deeper the rip, the greater the destruction of the warren.
- Extend rip lines at least 4 metres past the outermost holes. This approach may be modified where the soil is particularly susceptible to erosion or where there is a danger of damaging native vegetation.
- Smooth and compact the surface either with a blade, or by driving over raised parts of the ripped area, or by dragging a roller or other heavy object.
- On sloping ground, ensure that the final rip lines are at right angles to the direction of slope to reduce the risk of erosion.

Operator safety

General precautions for using agricultural machinery must be followed. Tractors should be fitted with appropriate safety cages or roll bars, especially when ripping in steep country. The relevant state or territory authority for occupational health and safety can provide further advice on safety.

A2.2 Disc cultivation

Disc cultivation can be used to destroy warrens where land is cultivated regularly, rabbit numbers are low and soils are light or sandy. Its major advantage is that it is relatively quick and can be readily incorporated into normal farming practices. Its major disadvantage is that it does not destroy the structure of deep warrens.

Equipment

Equipment consists of a wheeled or crawler tractor with a disc cultivator mounted on a 3-point linkage.

Methods

Thoroughly cultivate all warren entrances when the soil is dry. Re-treat areas as required or as part of normal paddock preparation. Follow-up fumigation can increase the efficiency of this technique. General precautions for using agricultural machinery should be followed.

A3 Removal of surface harbour

Destruction of surface harbour is especially important where rabbits do not use warrens, such as in some parts of Western Australia, but it can greatly increase the effectiveness of most rabbit control programs. Its use must be carefully evaluated where native fauna are present, or where the harbour comprises valued native vegetation (Section 7.4.6).

The approach used will depend upon the nature of the surface harbour and the sensitivity of the land system to disturbance. In general, dead vegetation such as fallen trees and branches, should be piled in clear areas and burnt. Briars, bracken, blackberries and other vegetation which provides rabbit harbour should be poisoned with an appropriate herbicide and burnt when dead. Alternatively, vegetation can be slashed, although the benefits are unlikely to be permanent.

Stone heaps, rubble and debris from road construction, old fencing material and discarded machinery should be crushed, burned, buried or removed. Hay storage areas and other valuable commodities that may harbour rabbits should be surrounded by rabbit-proof fencing. Cracks and crevices in rocky areas should be closed using balls of wire netting or rocks.

As a general principle, landholders, road constructors and other land users in rabbit-prone areas should be aware of the potential to create more rabbit harbour by their operations.

A4 Fumigation

Fumigation is usually used as a follow-up to warren ripping to treat reopened burrows, or to treat small isolated warrens in areas where ripping is not practicable. Both pressure and diffusion fumigation are best when soil is moist and, as for most techniques, when rabbit density is low (Section 7.4.11 and Figure 35).

Choice of pressure or diffusion fumigation is often determined by the availability of equipment, with diffusion being simpler and requiring less equipment. However, although the use of smoke to detect burrow entrances is a major advantage of the pressure techniques, costs of each technique are approximately the same. In general, pressure fumigation is preferred when an area has not been ripped, the warren area is extensive with several open entrances, the burrow entrances are thickly vegetated and easily missed or if more than one operator is available.

Diffusion fumigation with aluminium phosphide is usually preferred when there are only a few, isolated burrow entrances to treat, entrances are easily found, and if fumigation can be carried out during regular farm operations whenever isolated open entrances are found.

There are concerns about the humaneness and worker safety of the fumigants chloropicrin and, to a lesser extent, aluminium phosphide (Section 5.5.1). Alternatives are required, with carbon monoxide being a possible replacement.

The legal restriction on use of fumigants is shown in Table A7 and the materials and services required are shown in Table A8.

A4.1 Pressure fumigation

The following equipment is required for pressure fumigation:

Table A7: Legal restrictions on the use of fumigants.

Legal restrictions	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Can chloropicrin be used in pressure fumigators?	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Are there legal restrictions on the use of chloropicrin (e.g. warning notices, notification of neighbours)?	No	No	No	No	No	na	No	na
Can aluminium phosphide be used as a rabbit fumigant ?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Are there legal restrictions on the use of aluminium phosphide (e.g. warning notices, notification of neighbours)?	No	No	No	No	No	No	No	No

na not applicable.

- power fumigator, appropriate fuel and diesel oil for smoke generation and kerosene for cleaning of fumigator;
- extension hose for fumigator (up to 4 m length);
- full-face respirator with RC224 canister plus spare canisters;
- heavy duty rubber gloves, coveralls, rubber boots and cloth hat;
- long-handled shovels;
- chloropicrin, trade names: Larvacide® or Double-R®; and
- water to wash off any spill of fumigant.

Method

- Use a dog pack both before and during the operation to drive all surface-living rabbits underground. Care is required to ensure that the dogs are kept away from treated warrens and the fumigant.
- Follow manufacturer's instructions to load fuel and diesel into the appropriate tanks of the pressure fumigator.
- Start the machine and ensure that it is working smoothly before filling the fumigant tank. Adjust the diesel gravity feed so that a thick white smoke is produced. Turn the machine off.
- Wearing the protective clothing and full-face respirator outlined above, carefully decant the fumigant from its storage bottle into the appropriate tank in the fumigator.

Adhere to the safety precautions outlined in this Appendix before handling the fumigant. In some states and territories operators are required to wear appropriate protective gear throughout the fumigation operation. The relevant authority should be consulted before using pressure fumigation.

- Cut each burrow entrance down for about 0.3 m. Pile the excavated soil on the upwind side of the burrow to use later to seal the entrance.
- Restart the fumigator and insert the hose from the machine down the burrow entrance.
- Seal the entrance with the soil that has been removed. Adjust the outlet rate from the chloropicrin tank to the rate suggested by the manufacturer of the fumigator, usually about one drop per second. Approximately 5 cc of fumigant is required per entrance.
- A mixture of chloropicrin, diesel smoke and exhaust gases will now be forced through the warren structure.

Table A8: Materials and services needed for fumigation.

Equipment and services	Availability	Further information
Pressure fumigators	Purchase from engineering manufacturers; hire from local or state and territory vertebrate pest control agencies	Local or state and territory vertebrate pest control agencies
Chemical fumigants	Stock agents	Suppliers, local or state and territory vertebrate pest control agencies
Contract fumigation service	Local or state and territory vertebrate pest control agencies. Private contactors operate in some areas	Local or state and territory vertebrate pest control agencies

- Working upwind from the warren to avoid inhaling toxic fumes, dig back each entrance as described above and seal each entrance and seepage hole in the warren complex after the smoke mixture issues freely from the hole.
- The surface should be tamped down and the area smoothed off so that there is no indication that an entrance existed at the site and no mound or depression attracts a wandering rabbit to dig at the site.
- Pay particular attention to places where smoke may appear beneath dense vegetation or among tree roots. Clearance of some vegetation may be needed to seal entrances thoroughly.
- If some entrances fail to issue smoke, place the hose in each entrance in turn until all known entrances have been fumigated and sealed.
- After all entrances have been sealed, turn off the supply of fumigant and remove the hose, thoroughly re-sealing the first hole.
- The fumigator may be kept running while it is moved to the next warren to be treated. A longer hose will mean that several warrens may be treated without having to move the machine.
- Repeat the process at the next set of entrances. Note: all entrances may not interconnect in some warrens: Do not fill in holes unless smoke issues from them. Each set of interconnecting holes should be treated separately.
- At the completion of each day's work, remove any chloropicrin remaining in the storage tank of the fumigator. Flush out the tank and associated feed lines with kerosene. Chloropicrin should not be left in the machine because it is corrosive and dangerous.
- Reinspect the warrens one week after treatment and re-treat as necessary. Annual inspections should then be made. For isolated reopened holes, diffusion fumigation may be a more appropriate means of re-treatment.

A4.2 Diffusion fumigation

Equipment

The following equipment is required for diffusion fumigation:

- rubber gloves and coveralls;
- long-handled shovels;
- aluminium phosphide tablets, trade names: Phostoxine®, Gastoxine® or Fumitoxine®. The amount of chemical in each tablet varies according to the formulation of different products. The product label will indicate the amount required for each burrow entrance;
- a long-handled ladle or other device for placing the fumigant at least 1 m down the warren;
- 2 L of water and several rolls of paper; and
- a bundle of newspapers.

Method

- Use a dog to drive rabbits into their burrows, both before and during the operation. Be careful to keep dogs away from treated warrens.

> Adhere to the safety precautions outlined in this Appendix before handling the fumigant.

- Cut each burrow entrance down for about 0.3 m. Stack the excavated soil on the upwind side of the burrow to be used later to seal the entrance.
- While wearing rubber gloves, wrap the required dose of fumigant as specified by the manufacturer in tissue or toilet paper. Moisten the paper with water.
- Place the tablet(s) in the toilet paper at least 1 m down the burrow using the ladle or other delivery device. Ensure that the tablets are not accidentally buried when the burrow is closed.

- Seal the entrance with the soil that has been removed. A large sod of soil or crumpled newspaper should be put down the hole first so that the fumigant is not covered with loose soil.
- Tamp down the surface, smooth it off so that there is no mound or depression to attract a wandering rabbit to dig at the site.
- Repeat the process for all holes in the warren, working towards the windward side of the warren.
- Reinspect the warrens one week after treatment and re-treat as necessary. Then annual inspections should be made.

A4.3 Precautions

Operator safety

Do not carry fumigants inside an enclosed vehicle, especially after the seals on the containers have been broken.

Chloropicrin

- Chloropicrin is highly corrosive and toxic: Avoid skin contact and inhalation of the fumes. A concentration of 2 mg/L may be fatal if inhaled for ten minutes.
- Wear protective clothing and full-face respirator whenever handling the liquid fumigant.
- For safety, work in teams of at least two when undertaking pressure fumigation.
- Fumigate only on windy days so that there is no build-up of gases in the air around the warren. Do not fumigate in small sheltered gullies.
- Avoid any skin contact with liquid chloropicrin. Wash any contaminated parts of the body immediately with lots of water. Clothing contaminated with the liquid should be removed immediately.
- Cease operations as soon as any symptoms of exposure to chloropicrin are detected (see Section A4.4, first aid).

Aluminium phosphide

- An exposure of 1000 ppm for half an hour may be fatal.
- A contaminant has been added to the formulations so that an odour is detected when aluminium phosphide reacts with water to form phosphine gas. However, the concentration at which the odour can be detected is little different from the maximum safe concentration, so do not rely upon smelling the gas as a safety measure.
- Fumigation should be conducted only on windy days so that gases do not build-up in the air around the warren. Avoid small, sheltered gullies.
- Avoid breathing any fumes from the tablets, especially after they have been moistened.
- Avoid any skin contact with the aluminium phosphide tablets. Wash any contaminated parts of the body immediately with lots of water. Clothing contaminated with powder from the tablets should be removed immediately.
- Cease operations as soon as any symptoms of exposure to aluminium phosphide are detected (see Section A4.4, first aid).
- Open canisters of tablets only in open, well-ventilated situations.

Effect on wildlife

Native wildlife may use rabbit warrens. Where use of a warren by wildlife is suspected, the warrens should be monitored before treatment to determine which animals are using the burrows. Areas of soil in front of the entrances should be smoothed, and any tracks identified. The presence of large animals such as wombats can be determined by placing sticks at least 30 cm apart at the burrow entrances. Wombats will knock these down whereas rabbits will move between them.

If monitoring shows that native fauna are using the warrens, these warrens should not be fumigated.

A4.4 First aid

First aid

Chloropicrin

Symptoms of poisoning include tears, headache and shortness of breath. Pulmonary oedema may follow causing difficulty in breathing. The tear-provoking qualities of the gas normally allow the person affected to be removed from the cause of exposure before serious respiratory damage can occur.

The patient should be removed from the contaminated atmosphere. Contaminated clothing should be removed, and affected body parts washed with plenty of water. Wash the patient's eyes, rinse mouth and, if the patient is able, have them gargle with water or dilute aqueous sodium bicarbonate. Keep the patient lying down and monitor any signs of respiratory problems. Seek urgent medical attention.

Aluminium phosphide

Symptoms of poisoning include breathing difficulties or unusual bowel discharge.

The patient should be removed from the contaminated atmosphere. Lay the patient down and check for signs of breathing difficulty. Administer artificial respiration if required. Seek urgent medical attention.

Appendix B Strategic Rabbit Management in Plantation Forests

B1 Defining the problem

B1.1 Economic impact

Rabbits kill or damage young plantings and, to a lesser extent, dig under the roots of growing trees. Damage is most significant in plantations established on previously unforested sites, such as pastures. Yield losses can be calculated with reasonable accuracy and translated into monetary values. Losses can be calculated as potential yield loss at the time of final harvest and replanting, plus any additional loss through rabbit damage. Economic losses fall into three main categories, information on which should be available from coupe records or compartment registers: the number of planted trees damaged; the age at which they are damaged, which is a measure of the growth forgone; and the cost of maintaining the trees to the age at which they were damaged.

B1.2 Environmental impact

Rabbit browsing may result in treeless, erodable patches in plantations. Management may compensate for actual or anticipated browsing losses by increasing the areas of plantations or by recultivation, both of which may increase soil erosion. The environmental impact would be adverse if additional native or vegetated land were cleared for plantations, but it could be mitigated if the plantations used land already degraded.

B1.3 Measuring impact

Special factors affecting rabbit impact in plantation forests are: (1) areas of native and exotic vegetation; (2) rabbit-proof fences; (3) age of planting; (4) fertiliser and weedicide use; (5) windrows and debris; and (6) the presence of rabbits on adjacent land.

In plantation forests, an indication of the potential for browsing damage by rabbits can be gauged before trees are planted by inspecting for rabbit scats in prepared sites. The presence and abundance of nearby warrens and burrows would also be a good indicator. An estimate of potential damage can be obtained using sacrificial plots, planted one or two months before planting the main crop (Clunie and Becker 1991). This method can be expensive and rabbit damage caused to an earlier planted sacrificial plot may not accurately reflect what will happen later to the main planting, due to factors such as seasonal variation in alternative food. If it is used, sacrificial planting of 1% of the number of trees intended for the main crop (N) at 100 plants per plot in $N(0.01)^2$ plots is recommended (Clunie and Becker 1991).

For planted tree crops, rabbit damage can be estimated by sampling the crops to determine the number of trees damaged and the type of damage; whether the tree was killed, its growth retarded or the tree made less valuable. Losses can be computed to the next available planting period.

The long-term susceptibility of land units within the forestry plantation to rabbits can be determined by estimating and mapping warrens, burrows and entrances at points assigned by the sampling design, using two line transects at right angles, one along contours, and the other across them. This estimate is less affected by seasonal variations. Standardised walk or vehicle spot-light transects may be easier but seasons greatly influence estimates. Spotlight counts from vehicles are the preferred assessment method of the Department of Conservation and Natural Resources in Victoria. Permanent reference sample lines are established and monitored at three-monthly intervals to provide data on rabbit population trends which are then taken as indicative of the population for the overall area. Counts of rabbit dung (Wood 1988) or rabbit tracks across smoothed sections of roadway may be used where vegetation height limits visibility. Forestry roads can assist access for sampling, but their location should not determine sampling.

Where rabbit damage and rabbit abundance are not highly correlated, other browsers may be the primary cause of damage. Conversely, rabbit impact may be more prevalent in particular environmental situations or where some cultural practices have been implemented.

B1.4 Mapping

Forestry plantations are usually extensive, often covering a variety of terrain types and complex topography, and a variety of cultural techniques may be used. Mapping, especially in geographic information system (GIS) form, would assist in interpreting this high degree of complexity for a rabbit management program (Section 9.2.4). The critical period for rabbit damage is after harvesting is completed and during preparation and replanting operations. This presents an opportunity for significant increases in rabbit numbers. Thus, site-specific surveys mapping these operations will be of considerable value in planning management programs.

Interactive GISs would be the best means of detecting correlations between the rabbit damage and rabbit abundance and environmental or cultural variables. Where present, the distribution, density and damage caused by other browsers such as hares and wallabies should also be determined and mapped.

B1.5 Assessing impact

Other tree-browsing species such as wallabies and hares damage plantation forests. It may be possible to assign the percentage loss due to each species by recording the distinctive signs of their damage. Night observations of each species within the plantation may help to determine the type of damage each species causes. If damage patterns are not distinctive, the amount of damage may be attributed to each species by regular monitoring of footprints and sign in prepared smoothed sand patches around randomly selected trees. Animal presence around browsed and unbrowsed trees can be used to apportion the damage to each species.

Other possible methods for assessing damage due to each species are using fences or tree-guard filters that select species based on body size, and inspection or analysis of stomach contents of shot animals (Statham 1983). Damage due to each species may vary between seasons and with time since planting, hence monitoring should be designed to detect these variations. The cost of the damage can be calculated from the numbers of trees damaged by each species and the total costs of growing the damaged trees to their age at the next available planting. This cost figure can be used to determine the maximum economic expenditure on rabbit control.

B2 Management plan

B2.1 Objectives

The objective of forestry plantations is to maximise ecologically sustainable profit. Even fast-growing crops such as *Pinus radiata* will not give a return for ten years, so rabbit management costs and returns must be assessed and discounted over at least a decade or more.

Commercial rabbit harvesting is unlikely to be effective in managing rabbit damage in forestry plantations. No management might be seen as the best option if the cost of rabbit damage is small. No management might also become an option in management units where appropriate changes in cultural practices such as ploughing for site preparation reduce rabbit abundance and damage to low levels. However, this strategy might allow recolonisation of areas of recent planting or adjacent properties.

A major objective in forestry management is to prevent rabbit population increase through cultivation and weed control in the plantation establishment phase. This can be integrated into normal forest cultural practices.

B2.2 Performance criteria

The plantation manager has two major goals for managing rabbit damage, namely to:

- maximise ecologically sustainable profit; and
- prevent rabbits from the plantations adversely affecting adjoining land.

If the assessment of impact shows that rabbits are present but causing little or no economic impact, the primary goal is to ensure that adjacent land is not affected.

B2.3 Allocating management units

After mapping, the plantation should be divided into separate management units. The division will be influenced by features including concentrations of rabbits, vegetation and stages of tree crops, soils, aspect and proximity to neighbouring land. Forestry roads and slopes may be used to determine management units, unlike sampling points (see above). The management units should enable the same treatments to be applied within the unit, minimise recolonisation between units, and assist assignment of priority for sequential treatment.

B2.4 Control strategy

Control strategies for each of the identified land management units may differ with regard to: (1) tree species and genetic variety chosen for planting; (2) growth rates and palatability of trees planted or proposed; (3) age of trees to be planted; (4) age of existing plantings; (5) intended seasons of planting; (6) existence and distribution of rabbit-proof fences; (7) effectiveness of tree guards; (8) effectiveness of repellents; (9) amount and distribution of areas of native vegetation; (10) amount and distribution of areas of weeds, bracken and brambles; (11) ploughing patterns of past cultivation; (12) fertiliser applications of past cultivation; (13) abundance of other species which damage tree plantings; (14) abundance of rabbits on adjacent land; (15) prevalence of predators; and (16) availability of staff and machinery for rabbit control.

Strategies to manage rabbit damage on plantation forests can be based on the outcome of monitoring before planting the crop. Clunie and Becker (1991) indicate a sampling strategy and suggest scoring browsed trees in five categories of increasing severity:

1. Minimal damage (side leaves).
2. Apical bud(s) removed.
3. Approximately 50% crown damage.
4. Severe damage (whole seedling chewed or total defoliation).
5. Seedling pulled out.

Erection of a rabbit-proof fence and eradication of rabbits within the enclosed area may be feasible and cost-effective while plantings are vulnerable, especially if it is necessary to protect trees from other species such as hares and wallabies. Such fences are costly to construct and maintain. Plantations may become progressively more inhospitable to rabbits as the trees grow and shade the undergrowth. The need for fencing is often minimised by using herbicides during the establishment phase, a normal part of forest establishment practice. Fencing has been trialed successfully in native forests but mainly to control wallaby browsing.

Strategic, sustained management is the most cost-effective option and it may remove the need for rabbit-proof fencing. Rabbits will attempt to recolonise treated areas while the trees are still vulnerable, whether or not rabbit-proof fencing is used. The frequency of repeated followup control could be varied according to the extent that the surviving rabbits damage new plantings. Strategic management maintains rabbits at low densities and severely restricts their rates of increase, thus reducing subsequent control costs. It also minimises damage to recent plantings of young trees by rabbits from nearby older planting areas or areas of native vegetation. Strategic management near boundaries of the plantation would minimise damage to adjacent land.

Forestry managers may be inclined to manage rabbits only when tree crops are vulnerable to rabbit damage during their early growth stages, although this may last several months. Such management is likely to be less cost-effective than continuous strategic management because the planting season usually coincides with the time when rabbit numbers and their rate of increase are high. Tree crops are likely to sustain greater damage than if strategic management were adopted, because rabbits may resurge before the trees are mature enough to be safe from rabbit damage.

There are several current or potential management practices which can decrease damage by rabbits to tree plantings. The suitability of any practice or combination of practices will depend on tree species, local conditions and size of the rabbit population (Clunie and Becker 1991):

- Cultivation is necessary for successful establishment. Large-scale ploughing is encouraged, together with ripping. This has a two-fold effect, that of destroying warrens and removing foci of disturbance for rabbits to exploit.
- Warren destruction, fumigation and baiting should be part of site preparation prior to planting.
- Seedlings should be hardened-off in nurseries rather than under shelter, to make them less palatable.
- Tree guards in plantations should be avoided due to the risk of distorting and reducing growth and also because they are expensive.
- Species or varieties that are relatively unpalatable to browsers during juvenile stages could be used. If these are not available they may need to be developed by plant breeding. This is a long-term strategy and must not be at the expense of the primary objectives; quality and quantity of timber.
- Early growth can be increased by using fast-growing varieties.
- Trees can be fertilised and irrigated at the base (although for some tree varieties this may make them more palatable to rabbits).
- Weeds and brambles could be controlled and removed, especially around the base of trees to maximise growth.
- Patches of native vegetation throughout the plantations could be retained to encourage birds of prey and to shelter and enhance growth of seedlings. Rabbits must be controlled in these areas.
- Early research is showing promising results with repellents, particularly if applied to the outer rows of trees most at risk, or alternatively strip sprayed on the ground.
- Trash from previous pruning and harvests could be removed or fragmented.
- Cooperation with adjacent landholders to manage rabbits could be encouraged.

For highly palatable species such as *Acacia melanoxylon* (Blackwood) the only option may be to remove all cover and windrow and burn trash so that there is no shelter for rabbits, prior to enclosing the plantation within a rabbit-proof fence (M. Statham, Department of Primary Industry and Fisheries, pers. comm. 1994).

Combined use of some of these practices can assist rabbit management while other combinations may increase rabbit damage. For example, fertilising and irrigating trees only and not the surrounding vegetation may increase the nutrient status of the trees, making them more attractive to rabbits. If fertiliser is used, other techniques should be used to protect the trees at the same time, either rabbit-proof fencing, tree guards, repellents or effective rabbit control. An alternative strategy is to plant seed directly without fertilising the seedlings, so that the growing trees have lower nutrient status and thereby are less attractive as browse (Clunie and Becker 1991). The benefits from this method need to be weighed against the losses due to slower growth.

The effectiveness of many of the management practices discussed has not been tested. For example, there is little agreement on the potential value of some repellents now being developed. Field research is required to determine the most cost-effective combinations of management practices.

Forestry operations usually have machine operators and powerful machinery suitable for ripping warrens and destroying surface harbour, but it may be more practicable to use other techniques. Rabbit warrens may be located amongst dense native vegetation which should be protected to control erosion, conserve native species and shelter commercial tree plantings. In cases where ripping is not possible, poisoning or fumigation can be used to kill rabbits before the warrens are blocked or dug out.

Chemical repellents also may have a role, although effective repellents for rabbits are not yet available (Parer and Milkovits unpub.). Combined egg powder and acrylic resin gave good protection to planted trees in New Zealand (Crozier 1988), but did not work in Victoria (Clunie and Becker 1991). Another alternative is to erect rabbit-proof fences around areas intended for tree planting and remove rabbits from within the enclosures before planting begins. The cost-effectiveness of tree guards and rabbit-proof fences compared with the cost of rabbit damage and the cost-effectiveness of rabbit management programs has yet to be assessed. Follow-up treatments could include repeated ripping of reopened entrances, new burrows and warrens, or pellet fumigation if few openings need to be re-treated (Williams and Moore, in press).

Where rabbit impact is minor, the plantation could be enclosed by well-maintained rabbit-proof fencing. Alternatively, the peripheral half kilometre of the plantation could be kept inhospitable to rabbits by clearing surface harbour, ripping any warrens or burrows and fumigating and blocking inaccessible warrens. It may be possible to plant the periphery with species that are unpalatable in juvenile stages and promote an environment inhospitable to rabbits, such as dense shading. These peripheral barriers may require less maintenance, and will yield income when harvested and replaced, although other methods for controlling rabbits and preventing their dispersal would be needed until the barrier is re-established.

B3 Implementation

The following actions increase the effectiveness of the strategy:

- Treat the most valuable and most threatened management units first. The age at which plantings are no longer susceptible to rabbit damage can be determined from coupe records or compartment registers.
- Thereafter, sequentially treat adjacent management units to minimise the rate of recolonisation. Work from edges not prone to recolonisation such as those within rabbit-proof fences or those containing few or no rabbits.
- Schedule follow-up treatments on treated management units within three months of the initial treatment and annually thereafter.
- Begin rabbit control when rabbit density is low, such as in mid or late summer after progeny from the previous breeding season have declined but before the autumn dispersal (Parer 1977, 1982b). During droughts and after myxomatosis outbreaks are also opportune times for implementing rabbit management.
- Rabbits should be controlled just prior to the best time to plant the trees. The most

cost-effective strategy will depend on local conditions and may vary from year to year. Trial plantings could help. Trees may be planted at the most opportune times for establishment and growth with little danger of serious damage by rabbits if the effective control strategy is adopted.

B4 Monitoring

Monitoring damage caused by rabbits and other browsers, and monitoring rabbit and other pest distribution and density should be undertaken during the vulnerable growth stages of the trees. Estimates should be made one month after management action, using the techniques adopted to assess the initial problem. Ongoing monitoring may be reduced to annual monitoring depending upon the success of the management program. Data should be recorded on maps or GIS databases to help interpret the effectiveness of the management regime(s).

Monitoring should include an assessment of the costs and effectiveness of the management operations, as well as an assessment of the effectiveness of the program in achieving established objectives.

B5 Evaluation

Evaluation of the program should determine:

- the value of the browsing damage compared to the cost of the management program;
- the effectiveness of the program in minimising rabbit damage; and
- the degree to which adjacent lands are protected from recolonisation by rabbits from the plantation site.

Ideally the cost-effectiveness of the rabbit management program should be assessed by comparing treated areas with untreated matched reference areas. However, the losses in the untreated areas may be intolerable. Comparisons before and after treatment are usually used, although factors such as seasonal variation due to weather or changed management practices can influence the result.

The increased profit due to rabbit management can be computed by comparing projected production and profit from each management unit before and after rabbit control. The full costs of the management program need to be determined, including planning and monitoring costs. Conversely, the benefits need to include the reduced plantation management costs due to rabbit management (including savings, adjusted to net present value, of replacing damaged trees and growing them to the stage at which the damage occurred), and projected to the next available time for replanting.

The minimum period over which the costs and benefits of rabbit management are assessed should be greater than the period over which the relevant tree species are vulnerable. The ideal assessment interval is the duration of rotation of the tree crop. From the perspective of rabbit management, the minimum period should be four years. Values should be projected to the rotation interval. All costs need to be adjusted to net present value using the appropriate discount rate.

The costs of rabbit management are not linear. Initial costs are highest and they decline sharply during the ongoing maintenance phase (Bruce 1969 and Figure 30).

The benefit–cost comparison will show the effectiveness of the program or indicate that the program needs to be modified in order to deal with some other factor(s) that may be causing tree damage or loss.

The impact of plantation rabbits on adjoining lands could be assessed by neighbouring landholders and by monitoring rabbit distribution and abundance in the buffer zone, the peripheral half kilometre of the plantation.

Appendix C
Strategic Rabbit Management in Conservation Areas

C1 Defining the problem

C1.1 Economic impact

Conservation areas are rarely seen as economic entities although many contribute to the economy through tourism. Rabbits can reduce or prevent regeneration of perennial plants, cause soil erosion and deplete populations of native animals. This can result in degraded values of the conserved resources, expenditure on control and recovery programs, and a loss of tourism income.

C1.2 Environmental impact

The rabbit is the main vertebrate pest in relation to conservation. Its damage is greatest in the arid and semi-arid regions where rabbits prevent regeneration of trees and shrubs by killing seedlings. Most mature trees and shrubs in these regions either grew before the rabbit was introduced, or in the years immediately following the introduction of myxomatosis. In many areas no tree seedlings have survived for many decades (Friedel 1985) (Section 4.3). If rabbit control to a level that allows tree regeneration is not achieved in the limited time before the remaining reproductively viable trees are lost, the stability of arid land soils and the associated flora and fauna will be at risk. The necessary technology is available (Hams 1991; Lord 1991; Tatnell 1991), and the cost is known or can be calculated. Government assistance, both Commonwealth, state and territory, is necessary to protect some of Australia's unique rangeland flora and its associated fauna. Sections 11.3.4 and 11.3.5 outline the position of public land and how available resources might best be allocated.

C1.3 Measuring impact

Factors likely to affect rabbit impact include: (1) reserve size; (2) frequency of droughts; (3) accessibility; (4) existence of rabbit-proof fences; (5) presence of rare species of flora and fauna, alliances, communities or sensitive landscape features; (6) other management practices such as the burning of vegetation; and (7) availability of staff and resources.

Known rabbit damage to native flora and fauna is documented in Section 4.3. In most cases experiments will be necessary to quantify rabbit damage. A suitable study would compare the composition of biota and soil variables between matched, replicated, stratified, randomly-chosen sites before and after rabbits are managed on half of the sites. The experimental treatments, possibly factorial, should be: (1) changes in management practices to reduce suitability of habitat for rabbits, and a non-treatment area with no such management changes; and/or (2) direct treatments for effective control by warren ripping and maintenance control within three months and then annually, and a non-treatment area with no rabbit control. Before being assigned to experimental treatments, prior to rabbit control, both untreated and experimental sites could be surveyed and monitored for abundance, species composition and age structure of both animals and plants, plant biomass and soil variables. Depending on seasonal conditions, the survey would need to cover two or more growth seasons. The sites should be as large as practicable to minimise the impact of rabbit recolonisation and site variables. Kangaroos and other wild herbivores may respond to vegetation changes which occur as a result of rabbit management. Determination of effects due to these other animals if they are abundant may need to be incorporated into the experimental design.

Native vegetation susceptible to rabbits may respond in two ways to rabbit management: (i) an early response demonstrating the impact of rabbits, such as on conservation lands where rainfall is reliable; and (ii) a delayed response which may be rapid when it occurs, such as in more arid conservation lands where rainfall is erratic, and vegetation and fauna regenerate in response to relatively rare favourable climatic events. Until these events occur, rabbits may seem to have little or no impact on conservation values although the true impact may be massive. Consequently, in the rangelands, experiments to demonstrate rabbit damage to native flora and fauna may need to continue until the occurrence of conditions favourable to regeneration.

C1.4 Mapping

Geographic information systems (GISs) that facilitate manipulation of large and complex databases such as ERIN and NRIC assist the planning and management of large conservation reserves. The data maps, especially if analysed using GISs, will indicate correlations between rabbit abundance and the physical environment and the biota. This will show which land systems or units are more vulnerable to rabbit damage. Similarly, the distributions of vulnerable plant species or associations in relation to rabbit distribution and abundance will be evident. Areas of high rabbit abundance can then be assigned to individual rabbit management units that are separated from other areas of high rabbit density by habitat less favourable to rabbits. Control operations can work to or from these boundaries. The units with vulnerable or rare plant associations should be treated first.

C1.5 Assessing impact

As well as: (1) a survey of rabbit warrens and burrows, other relevant factors should be recorded, including (2) other feral pests; (3) wombat burrows; (4) kangaroo groups; (5) plant species thought to be particularly susceptible to rabbit grazing or browsing; and (6) major features of the environment such as slope, soil type and dominant overstorey and understorey species or major associations. These data refine information on the land system or unit classification for purposes of seeking correlations between distributions of rabbits and species of conservation value. Survey information should be recorded on maps, either based on GISs, or on paper.

The survey methods should enable rapid assessment of the variables at each site, with more sites included rather than more detailed observations for the chosen variables. If many sites are included, rapid assessment of presence or absence of species and impact variables is sufficient, or they may be given an abundance score such as none, few or many. The same sites should be assessed over the main seasons of the year and over more than one year, preferably including years of good rainfall when species abundances are likely to be high and the chances of their detection improved. The survey of Kakadu National Park provides a model for such surveys (Braithwaite 1985). The model adopted would need to be tailored to local conditions and available resources.

C2 Management plan

C2.1 Objectives

The objective in a conservation area may be to ensure the long-term conservation of a particular plant species such as mulga (*Acacia aneura*), to protect certain species associations, or to protect a historic building which is being undermined by rabbit burrowings. Different goals may be set for the various management units identified in the assessment and mapping process outlined above.

C2.2 Performance criteria

The performance criteria should be specific and time limited, for example ‘Successful regeneration of mulga seedlings to a patch-density of ‘x’ per hectare within three years (or, for example, in the first year of above average rainfall) on 50% of the management units that contain mature mulga trees’.

C2.3 Management options

The management options for managing rabbit damage include: (1) local eradication; (2) strategic, sustained management; (3) one-off management; and (4) no management. Eradication is practical only within areas that are isolated by natural or constructed barriers, such as islands, or within areas subdivided by rabbit-proof fences as in Hattah-Kulkyne National Park (Ward and Cooke 1987; Cooke et al. 1991), although eradication was not attempted in the latter. Rabbits also might be eradicated locally from rabbit management units that are marginal habitats for rabbits. Manipulating habitat in such units may eliminate the rabbit and deter subsequent recolonisation.

One-off management might be of value in conservation reserves if grazing by other herbivores is limited and dense grass swards or shrub overstorey can develop, thus making the reserves unsuitable for rabbits. However, feral and native herbivores may influence the success of this strategy. Ideally they should be managed either beforehand or simultaneously with rabbits. In many situations this may not be achievable. In order to preclude conditions suitable for rabbits, fire may need to be excluded from the area until rabbit numbers are reduced. Given these qualifications, the strategy of one-off management is of limited value for managing rabbits on conservation reserves.

No management is the default option for lower priority rabbit management units, especially when resources are inadequate. It may also be used on land systems or units that are not amenable to effective management, such as densely wooded ecotones that support fauna that would be vulnerable to poisoning, as in Kosciusko National Park. For such areas, ecological and environmental changes caused by rabbits are probably inevitable.

C2.4 Control strategy

Factors influencing the control strategy in conservation areas include: (1) presence and abundance of rare, endangered or vulnerable species or associations; (2) proneness of slopes or soils to erosion; (3) whether or not the management unit is a drought survival area for rabbits and for valued species and associations; (4) accessibility to equipment essential for rabbit control; and (5) presence and extent of natural barriers and rabbit-proof fences.

Rabbit management in conservation reserves must use combinations of techniques that minimise harm to conservation values. The techniques outlined for other land uses, if applied judiciously, are suitable for conservation reserves. The best solution is to manage habitats to make them unsuitable for rabbits. This may involve increasing the grass-sward height, or promoting growth of shrub layers, by careful management of fire and grazing by other herbivores, both native and non-native. The main direct method of rabbit control involves removal of surface shelter, ripping warrens, and ongoing maintenance control by re-ripping or fumigation. Control is timed best to coincide with seasonal low densities of rabbits (end of summer in temperate and arid southern Australia), and when rabbit numbers are low during drought or after outbreaks of myxomatosis.

The negative impacts of rabbit management on native flora and fauna must be weighed against the impact of rabbits on conservation values. Poisoning to reduce rabbit density may kill non-target species, and clearing surface harbour and ripping warrens may destroy habitat or kill native animals sheltering there. Of special concern are rare or endangered species such as some of the potoroos and bandicoots, especially where accidental 1080 poisoning may occur (Section 4.3.5). In general the authors believe that the effects of rabbits on native vegetation and its regeneration, on soil stability, and in maintaining high levels of predators, greatly outweigh the loss of native flora and fauna in the course of rabbit management. In most cases only a fraction of the habitat will need to be treated, and the populations of native species will recover quickly from any losses, especially after rabbit densities are reduced to low levels.

Non-target kills by poisoning can be reduced by: (1) free-feeding; (2) dyeing the bait to make it unattractive to non-target species; (3) using bait preferred by rabbits; (4) using minimal concentrations of poisons; (5) using the appropriate poison (1080 or pindone); (6) ensuring that bait is distributed in the main areas of rabbit activity; and (7) collecting carcasses and removing residual poison bait (Section 7.4.8). Ripping also can be implemented with care to minimise the impact on surrounding vegetation, and hydraulic-arm rippers can be used to advantage in some fragile or awkward areas. Managers must balance the likely consequences to flora and fauna of using the various techniques.

The extent to which surface harbour can be removed largely determines the effectiveness of a ripping program. Areas of weeds, briars and brambles can be sprayed, pulled up and burnt. Areas of rocks and boulder piles are especially difficult to treat. Rabbits can be fenced into such areas and then poisoned, using appropriate precautions. Fallen trees, limbs and logs can be piled and burned. Bracken fern may be slashed. Dense scrub can be burned in weather conditions that promote cool creeping fires. After surface shelter has been reduced, surviving rabbits are likely to shelter in warrens and burrows where they may be killed by a warren ripping or fumigation program.

Where rabbits inhabit warrens, warren ripping is the most effective and long-lasting method for managing rabbits (Williams and Moore, in press). It destroys warrens more quickly and completely than other methods and it enables large areas to be treated rapidly. Recent developments in rabbit control techniques, such as ripping with powerful wheeled and crawler tractors, concurrent seeding to stabilise soil, and the use of global positioning systems linked to tractor-mounted computers to determine optimal ripping paths, have improved the speed, cost-efficiency and the practicality of treating extensive areas by ripping, especially in the rangelands.

Areas where local access is difficult, such as among large boulders or trees, or in areas sensitive to erosion, such as creek banks and erosion gullies, may be ripped using a mobile hydraulic ripping arm, or destroyed with explosives. Fumigation is less effective than ripping because, although it kills rabbits, warrens are disrupted at the entrances only (Williams and Moore, in press). The long-term effectiveness of ripping requires follow-up treatment sustained over at least two years. The number of burrow entrances used by rabbits are approximately halved by each repeated treatment (Williams and Moore, in press). In the absence of comparative information on costs and effectiveness, the choice of follow-up method, ripping or fumigation, can depend on convenience or local assessments.

Fencing boundaries of conservation reserves with rabbit-proof netting, or subdividing management units to make them more manageable, is expensive initially, and requires an ongoing commitment of labour and funds. Fences can be effective, but are difficult to keep rabbit-proof where kangaroos, wombats and feral pigs occur.

C3 Implementation

As a first step to minimising rabbit damage in conservation reserves, managers can review and modify, where advantageous, land management practices such as burning and control of grazing by other herbivores, especially feral species, to develop a higher grass sward which is unsuitable for rabbits. This is likely to be a practical management option only in higher rainfall areas.

Previously determined rabbit management units should be treated according to priority. Policy and politics may influence the order, but much weight should be given to the likelihood of recolonisation of the areas once treated. Rabbit management will be ineffective if treatments do not provide long-term protection from rabbits. Recolonisation can be minimised by treating adjacent management units in sequence, working from barriers, such as water bodies, rabbit-proof fences, land types inhospitable to rabbits, or areas of low rabbit abundance. Initial campaigns for rabbit management should coincide with periods of low rabbit abundance, such as late summer and during droughts. This minimises the reopening of ripped or fumigated warrens and recolonisation from adjacent management units.

In the semi-arid and arid areas, emphasis should be placed on managing rabbits in the moister drought survival areas to which rabbits retreat in dry times (Myers and Parker 1975b; Wood 1980). Once survival areas are treated, further control action can extend outwards, eliminating all warrens, whether occupied or not.

Where practicable, conservation managers should work cooperatively with neighbours. Poor rabbit management on conservation reserves has often led to bad relations with neighbouring land managers. The government should set an example to other managers and adhere to the good-neighbour principle. Where there are insufficient funds for across-the-reserve management, an adequate buffer zone should be treated and maintained.

C4 Monitoring

The effectiveness of the management program should be monitored using the same survey design, methods and sites as used for assessing rabbit damage. This includes (1) mapping and assessing the desired outcome, for example, the degree to which mulga regenerates; estimating numbers of reopened or new warrens, burrows and rabbit entrances; (2) monitoring aspects of rabbit damage such as changes in the distribution, abundance and age structure of selected components of native flora and fauna; and (3) estimating soil loss. Monitoring should continue for several years, or at least until after native vegetation has had a chance to regenerate following a favourable sequence of weather and seasons, and through a subsequent drought to ensure seedlings are not destroyed when alternative sources of food and moisture are not available to rabbits.

C5 Evaluation

For nature conservation, evaluation is based on the questions:

- Is there a sustained recovery of native flora and fauna?
- Is the impact on neighbouring land minimised?

In Figure 34 an evaluation frequency of at least two years is suggested, although this may vary in different situations.

The monitoring data can then be used to assess and evaluate the effectiveness of the program, specifically whether:

- the monitored conservation values are being protected in the long term;
- direct suppression of rabbits and changes in land management implemented to suppress rabbits indirectly contribute substantially towards the protection of the conservation values; and
- the priorities for protection of conservation values from rabbit impact need to be changed.

The monitoring program and design are crucial for successful objective evaluation. The design of the monitoring program will enable statistical analysis of whether the management program is achieving its conservation objectives. Analysis of the monitoring data from areas treated to reduce rabbits and from the matched, untreated control areas, will show whether the rabbit management program is protecting monitored conservation values.

Many factors influence the extent to which the desired outcomes of rabbit management are achieved. For example, the primary conservation objective may be achieved, but the response may be short-lived due to a continued decline in other essential features, such as loss of fertile topsoil. This may occur with or without a significant reduction in rabbit density. Further analysis of the monitoring data may provide insight into the circumstances operating and the need to modify the management program. There are three factors: the main conservation problem, other damage inflicted by rabbits on the conservation reserve, and rabbit abundance; all are quantified to some degree by the monitoring of the management program.

The following outlines some possible management interpretations and responses — all possible outcomes of the management program.

A. Primary conservation objective not achieved

(i) Rabbit damage not reduced, rabbit abundance not reduced

Rabbit impact should decline if rabbit abundance is reduced. Changes to other management practices may be necessary, such as burning regimes, managing of other herbivores or reassessing rabbit control techniques.

(ii) Rabbit damage not reduced, rabbit abundance reduced

The impact of rabbits may be similar for both low and high densities of rabbits. For example, rabbits at very low densities may suppress regeneration of some arid-land tree species due to high palatability of these species. To conserve the threatened resource, it may be necessary to reduce rabbit density further, or even to aim for local eradication within rabbit-proof enclosures.

(iii) Rabbit damage reduced, rabbit abundance not reduced

It is possible that damage was not caused by rabbits but by some other process, for example other pest species or an inappropriate burning regime that was changed by the management program. The treated and untreated plots need to be re-evaluated to determine the cause of damage. Alternatively, the management program may have diverted rabbit damage to other parts of the ecosystem that are affected but as yet unnoticed.

The conservation objective may not have been achieved because of irreversible changes such as loss of components of the soil seed bank or changes in soil structure. Alternatively, reducing rabbit damage may be required as well as changes in other management practices such as reintroduction of plant species, treatment of soil surfaces, modifying burning regimes, or control of grazing or trampling by other species. Further research would be needed, using the existing database or data collected in further field studies, to determine the appropriate management changes required.

(iv) Rabbit damage reduced, rabbit abundance reduced

As in (iii), changes may have occurred which cannot be reversed without additional management input. Further research would be needed to determine what kind of additional management is required.

B. Primary conservation objective achieved

(i) Rabbit damage not reduced, rabbit abundance not reduced

The damage due to rabbits is not as originally perceived. Rabbits may be affecting other elements of the ecosystem. For example, valued plant species may have regenerated when the appropriate weather sequences occurred, but the rabbits continued to cause soils to erode. The targeted conservation values were not threatened by rabbits, although they may have been at risk from other causes which were removed by the management program or natural events. It would be necessary to re-assess the problem. If action is needed to manage rabbit impact, different strategic objectives, management practices, implementation strategies or control techniques are needed.

(ii) Rabbit damage reduced, rabbit abundance not reduced

Processes or elements other than rabbits may have damaged the resource until the management program intervened. Alternatively, the management program may have diverted rabbit damage to more resilient plants of the ecosystem, or to unnoticed sensitive elements. Further investigation would be needed to find the focus of the impact, initially using the existing database, or by examining the problem on the ground, and to determine whether a modified rabbit management program was required to conserve the system in the longer term. If no further high priority problems due to rabbits are found, the original program may be extended to other parts of the conservation reserve.

(iii) Rabbit damage not reduced, rabbit abundance reduced

Rabbits continue to affect important elements of the ecosystem other than those originally thought threatened. The priority conservation element is protected by management changes of the program or by natural events. The damage caused by rabbits to other elements of the ecosystem remains, despite the reduction in rabbit abundance. The problem needs to be re-assessed to determine whether or not there is a threat from continued rabbit damage and if so, what action is required.

(iv) Rabbit impact reduced, rabbit abundance reduced

Rabbits were the primary source of damage to the valued resource. Management practices and strategic objectives were appropriate to manage the problem and conserve the valued elements. At this stage, management may consider whether the management program should be extended. First priority should be given to retaining the gains already made in the treatment areas, by continuing the maintenance control program. Thereafter, preference should be given to extending the program to land types of high priority that are not part of the no-treatment control group so that monitoring and statistical analysis may continue. No-treatment controls should be retained while doubts remain about the most appropriate form of management program.

Appendix D
Criteria for Eradication

The primary criterion which must be met for eradication is that the rate of population increase is negative at all densities (Bomford and O'Brien, in press). Whether this can be achieved for a rabbit population can be determined by five subsidiary criteria, which all need to be met.

- Rabbits must be killed at a rate faster than replacement rate at all densities. This is often difficult because of the high rate of increase of rabbits. As the density declines it usually becomes progressively more difficult and costly to locate and remove the last few animals.
- Immigration must be zero. This is possible (1) on offshore islands; (2) where completely effective barriers can be erected and maintained such as well-maintained rabbit-proof fences; or (3) where rabbit control on the margins of the eradication area is 100% effective.
- All individuals in the population must be at risk from the control technique(s) used. If animals become trap shy or bait shy, then a subset may no longer be at risk.
- Rabbits must be able to be monitored at very low densities. If this is not possible, survivors may not be detected.
- The socio-political environment must be suitable. For example, if certain groups object strongly to the eradication of rabbits they can directly thwart or politically influence the program.
- Discounted cost–benefit analysis favours eradication over control. Discount rates are used to compare the value of future benefits with the current and future costs of actions. This criterion is difficult to meet because the high cost of eradication occurs in the present and benefits accrue over a long period. For example, at a discount rate of 8%, it is unlikely that eradication will ever be cost-effective. Eradication has a large initial outlay but, if it can be achieved, there are no ongoing costs apart from maintaining the outer protective boundary. For cost-effective eradication, each situation should be assessed to determine whether eradication costs are less than discounted benefits for the discount rate selected. However, eradication has been achieved mainly for the protection of conservation values to which it is difficult to assign a monetary value.

Index