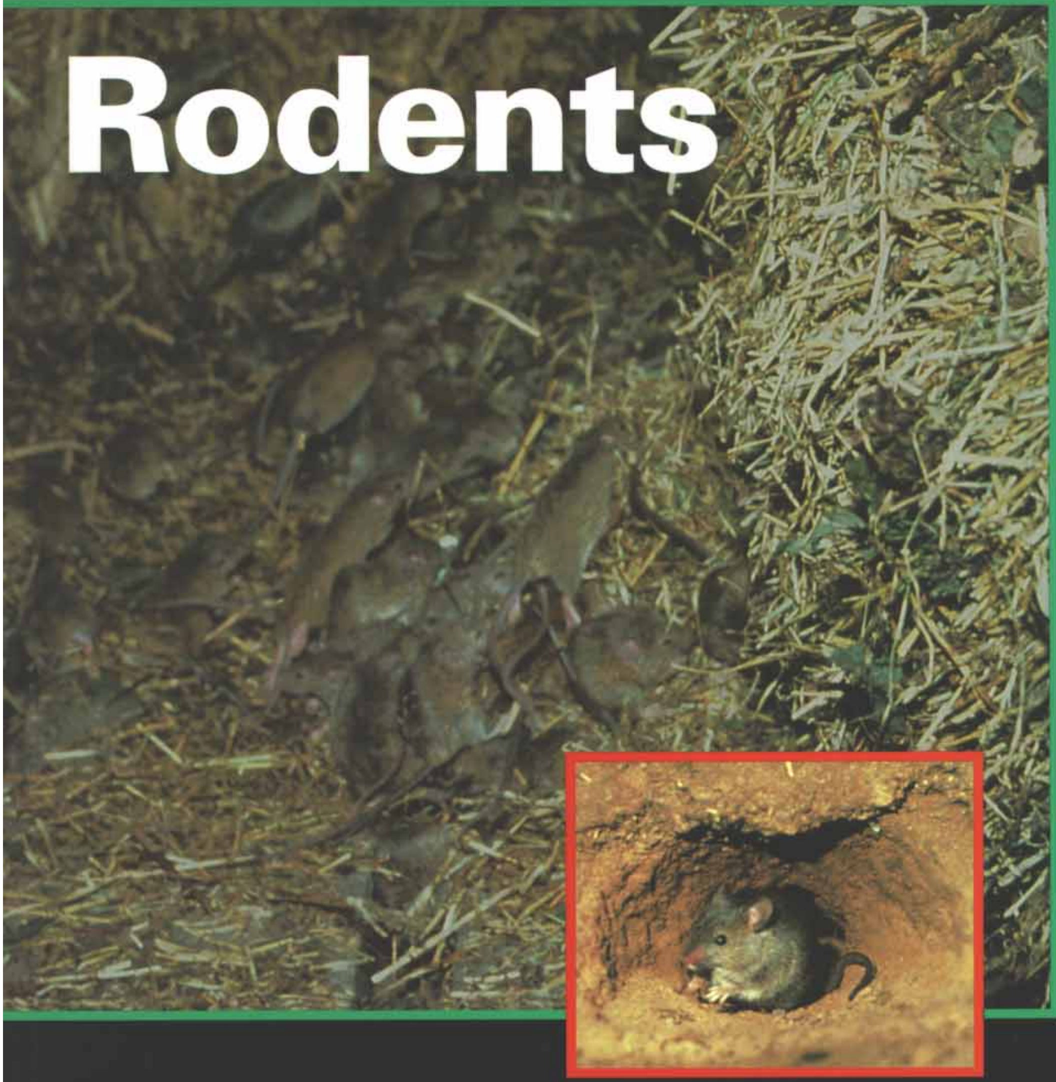
Managing Vertebrate Pests

Rodents



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Managing Vertebrate Pests: Rodents

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FOREWORD

Rodents are a problem because they cause millions of dollars worth of damage to Australian crops each year. There has been a mouse plague somewhere in the Australian grain belt every four years on average since 1900. In the last twenty years plagues have increased to one every year or two. The 1993–94 plague in south-east Australia cost the grains industry an estimated $65 million.

Rats also inflict significant damage to fruit and sugarcane. Rat damage to Queensland sugarcane crops amounts to $2–9 million annually. In addition, mice and rats have significant social and environmental impacts and can spread disease to people and livestock.

Landholders are not always aware when rodent numbers are building up so action to prevent crop damage can be delayed. Once numbers are high, managing the problem can be extremely difficult and not always successful. The key to successful rodent management is regular monitoring, so that signs of an impending build-up in numbers are recognized, and prompt action is taken to limit damage.

This book is one in a series produced by the Bureau of Resource Sciences to provide land managers with national guidelines for managing the damage caused by pest animals in Australia. Others in the series include guidelines for managing feral horses, rabbits, foxes, feral goats, feral pigs, wild dogs and carp. 'Best practice' approaches are examined for controlling the damage caused by pests following the principles for the strategic management of vertebrate pests described in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993). The emphasis is on the management of damage rather than on simply reducing pest numbers. To ensure that the guidelines are accepted as a basis for pest rodent management, comment has been sought from State, Territory and Commonwealth Government agencies and from land managers and community and research organisations. The Standing Committee on Agriculture and Resource Management has approved publication of these guidelines.

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

Peter O'Brien
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Bureau of Resource Sciences

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All dollar values have been converted to 1996–97 Australian dollars unless otherwise stated in the text.

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- Standing Committee on Agriculture and Resource Management
- Vertebrate Pests Committee
- Australia and New Zealand Environment and Conservation Council
  - Standing Committee on Conservation
  - Standing Committee on the Environment
- Land and Water Resources Research and Development Corporation
- Meat Research Corporation
- Rural Industries Research and Development Corporation
- International Wool Secretariat
- Australian Conservation Foundation
- National Consultative Committee on Animal Welfare
- Australian and New Zealand Federation of Animal Societies
- National Farmers' Federation
- Australian Veterinary Association
- Northern Land Council
- Murray-Darling Basin Commission
- National Registration Authority for Agricultural and Veterinary Chemicals

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INTRODUCTION

These guidelines for the management of pest rodents in Australia are one in a series of publications developed by the Bureau of Resource Sciences (BRS) in conjunction with the Vertebrate Pests Committee (VPC) of the Standing Committee on Agriculture and Resource Management (SCARM). Others in the series include management guidelines for feral horses, rabbits, foxes, feral goats, feral pigs, wild dogs and carp. Each aims to bring together the best available information for managing the impact of the particular pest species.

The guidelines are principally for state and territory agencies to assist them with effective management of pest damage through coordination, planning and implementation of regional and local management programs.

The guidelines follow the philosophy outlined in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993). The central principle is that effective management will need to focus on controlling the damage caused by the pest rather than the pest itself. For example, poisoning during a mouse plague may kill many mice, but it may do little to reduce crop damage if mice rapidly reinvade the area. Damage control must be the goal of all rodent management strategies. All guidelines have the following process in common (see Figure 1):

- defining the problem in terms of impact;
- determining management objectives and evaluating various options;
- implementing chosen management options; and
- monitoring and evaluating effectiveness of chosen options in meeting objectives.

Defining the problem

Rodents are pests in urban and rural environments throughout the world. These guidelines focus on managing them in rural environments. In Australia, the problem species are:

- introduced house mouse (*Mus domesticus*) which can build up to plague densities in cereal-growing areas of eastern Australia and cause damage worth millions of dollars to crops and stored grain, intensive livestock industries, horticulture and vine and tree crops;
- introduced black rat (*Rattus rattus*), a pest of orchards and stored produce; and
- several native rodents in tropical and subtropical areas, including the canefield rat (*R. sordidus*) and the grassland melomys (*Melomys burtoni*) that damage sugarcane, and the pale field-rat (*R. tunneyi*) that causes damage in hoop pine plantations.

In addition to the impact on agriculture and silviculture, rodents act as vectors for numerous diseases. Potentially they represent a serious health hazard to humans and to stock, especially when the animals are contained (for example, in piggeries and poultry sheds).

Further details on problems posed by pest rodents are outlined in the subsequent chapters. The first two chapters examine why rodents are pests and include a description of relevant aspects of their biology and population dynamics. Chapters 3 to 5 specify the extent and types of impact they have on agriculture and the environment in Australia. Control methods that have been used in the past and current government policies are described in Chapter 6.

Generally, rodents only cause problems in some years and then only at certain times of the year. Because rodent outbreaks are often episodic, farmers are frequently unaware populations have increased until they notice the damage. Consequently, their management tends to be too late to be truly effective.

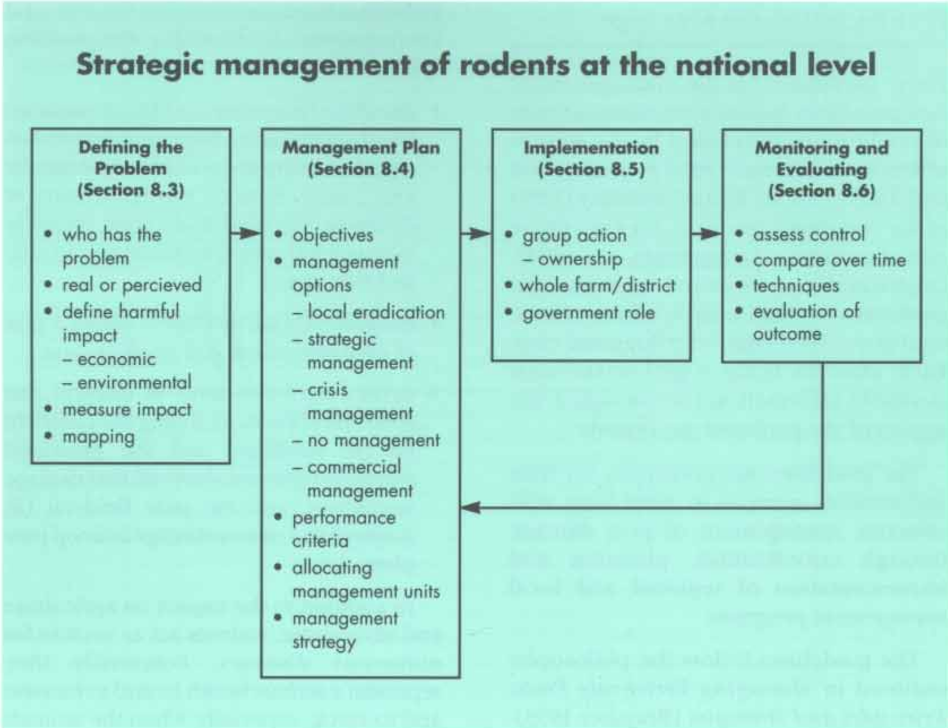

Figure 1: Strategic approach to managing rodent damage (after Braysher 1993).

Management objectives

In some rural areas, the damage from rodents is sufficiently small that it can be ignored. In other areas, damage can seriously reduce the profitability of enterprises in some years and needs to be factored into farm planning. The primary aim of all pest management is to use practical and cost-effective methods that will limit the impact of the pest species on production and conservation goals without degrading the soil and other resources on which the long-term sustainability of the land depends. Managing rodents is just one small component of pest management and landuse planning.

One objective of these guidelines is to seek out appropriate best practice management to restrict rodent damage. Ideally, the aim of management will be to reduce damage wherever it is cost-effective for land managers to do so. To achieve this aim for mice, it will usually be necessary to restrict the build-up in mouse numbers. That goal may only be attainable through the adoption of systematic checking, whole property planning and local cooperative action amongst neighbours or local groups such as Landcare or TOPCROP groups (see Chapters 8 and 9).

The guidelines will have met their purpose if the strategic approach they advocate is accepted and implemented by a significant number of agencies and individuals in the areas where rodents are a problem. If the adoption rate is sufficiently extensive, it will be possible to evaluate its effectiveness over time and the strategy can be adapted as more information becomes available. The aim is to have a strategy that is flexible enough to incorporate changes arising from feedback or new research.

Options for limiting damage

Management options can vary from 'doing nothing' to extensive use of acute rodenticides during rodent outbreaks. In between these management extremes are various techniques that may restrict the amount of damage. These are discussed in detail in Chapter 7. However, these techniques have not been subjected to rigorous scientific testing and for this reason the guidelines represent a stage in the evolution of best practice management for pest rodents. It is likely that some techniques will succeed beyond our expectations and others may prove to be a waste of time. It is also likely that it will be not one technique that achieves the desired goal but a suite of actions. It is important to maintain multi-faceted approaches at this stage.

Implementing the options

The present Commonwealth Government approach is to encourage self-reliance and the adoption of risk management strategies by landholders. These guidelines have followed this policy by:

- presenting a strategy that allows landholders to take responsibility for regular checking of rodent numbers;
- providing information on management options that landholders may undertake to minimise damage by limiting any population increase or by protecting crops when populations increase uncontrollably; and
- describing a structure for government agency support.

Monitoring and evaluation

To be successful, the proposed management strategy requires cooperation and coordination between landholders and supporting agencies at a local level as described in Chapters 8 and 9. Since the techniques it recommends are largely untested, landholders will need to assess their effectiveness and provide feedback through the local groups' organisational structure. However, for maximum benefit, the testing should not be haphazard. Good coordination between landholders in monitoring the effectiveness of techniques is vital. Government agencies are ideally placed to coordinate and collate the data, provide feedback to landholders and support when necessary.

The future

Chapter 10 outlines the developments required for improving rodent management. It describes the research required and the benefits this will bring.

1. Species, distribution and abundance

Summary

In Australia, two species of introduced rodents are significant agricultural pests — the house mouse (Mus domesticus) *and the black rat* (Rattus rattus). *House mice are found throughout Australia. When conditions are good, their numbers can increase dramatically. Black rats are found in temperate and tropical regions, especially in areas of human habitation. They do not plague like house mice, but occur in large numbers under favourable conditions.*

Four species of native rodents are also pests. The canefield rat (Rattus sordidus) *and grassland melomys* (Melomys burtoni), *whose natural habitat is tall coastal grassland in tropical and subtropical areas, have become serious pests in sugarcane. The pale field-rat* (Rattus tunneyi) *occasionally reaches high densities in hoop pine plantations. The long-haired rat* (Rattus villosissimus) *forms plagues during good seasons in arid areas of northern Australia, but between plagues they are rare.*

1.1 Introduction

Rodents are pests of agriculture throughout the world, causing damage worth millions of dollars annually to stored grain, pastures, crops, orchards and forests in many countries (Prakash 1988; Wood 1994). Each country has a suite of problem species. In Australia, they are all in the Family Muridae and include the introduced house mouse, the black rat[1] and several native species. The native species are in tropical and subtropical areas and include the canefield rat, the grassland melomys, the pale field-rat and the long-haired rat.

1.2 House mice

House mice (*Mus domesticus*, also called *M. musculus* or *M. musculus domesticus*) probably arrived in Australia at the time of European settlement (Singleton and Redhead 1989) and are now widespread. They usually occur in very low densities in natural habitats except after disturbances such as fire. They occur in all agricultural regions and are usually found in disturbed areas of long grass (for example, along roadsides, fencelines or channel banks) or around sheds and houses. When conditions are favourable, their numbers can increase to such a level that they reach plague densities. Plagues of mice occur primarily in the grain belts of southern and central Queensland, New South Wales, Victoria and South Australia (Figure 2).

'Plagues of mice occur primarily in the grain belts of southern Queensland, New South Wales, Victoria and South Australia.'

The frequency of mouse plagues varies considerably in different parts of the grain belt (for example, see Figure 3). Based on the data in Saunders and Giles (1977), Mutze (1989a) and Singleton and Redhead (1989), there has been a mouse plague somewhere in the grain belt every four years on average since 1900. In the last 20 years, mouse plagues in eastern Australia have increased in frequency to one every year or two. Infrequent plagues also occur in the Western Australian grain belt (Chapman 1981). In years when mice plague in agricultural areas, their numbers can also be high in semi-arid and arid pastoral country.

Plagues vary considerably in extent, severity and duration. Consequently, there is no quantitative definition of a plague. Generally the term implies mice at very high densities; however, it is difficult to determine their density during a plague because they are so abundant and normal methods of estimation fail. An attempt by Saunders and Robards (1983) using the 'frequency of capture' technique (Section 7.1) estimated a density of 2716 mice per

1 A third introduced species, the brown rat or Norway rat (*Rattus norvegicus*) has not spread much beyond human habitation in coastal cities and ports, and is not a significant pest in agricultural areas.

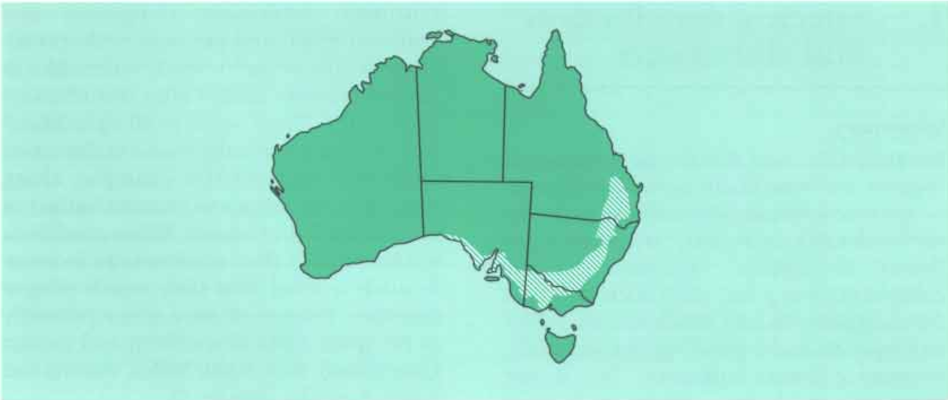

Figure 2: Distribution of the house mouse (*Mus domesticus*) in Australia. The striped areas indicate where plagues of house mice cause agricultural damage (after Redhead 1988).

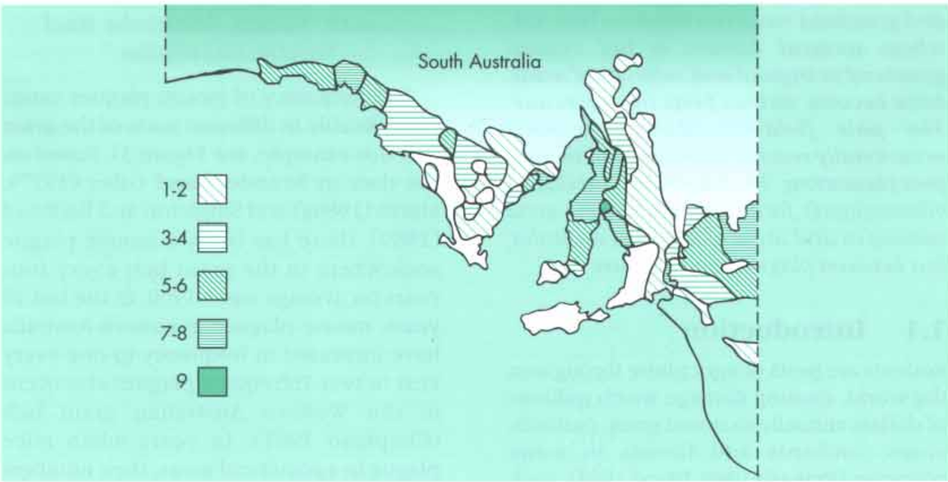

Figure 3: Number of mouse plagues in different areas of South Australia's cereal-growing region from 1916 to 1985 (after Mutze 1989a).

hectare in a sunflower crop. Saunders later checked the technique on an enclosed population and found that it underestimated numbers by 33%. He suggested the density was probably closer to 3530 mice per hectare (Saunders 1986). By comparison, in non-plague years, mouse numbers can be less than 60 per hectare, depending on location and season.

1.3 Black rats

Black rats (sometimes called plague rats, ship rats or roof rats) were introduced around the time of European settlement and are now found throughout temperate and tropical Australian environments (Figure 4). They are usually found adjacent to human habitations or in highly modified environments. They are a pest particularly in macadamia, banana and avocado plantations where they eat maturing fruits (Loebel 1995). In the riverland of South Australia, they cause significant damage in citrus orchards and, in years when house mice plague, have been known to establish large colonies in cereal grain paddocks. They are rarely found in natural habitats

Figure 4: Distribution of the black rat (*Rattus rattus*) in Australia according to Strahan (1995).

although it appears they can establish in areas where native rodents are absent (for example, Bowen Island in Jervis Bay National Park).

1.4 Native rats

Australia has many species of native rodents but few have a significant impact on agriculture. The three species that have become serious pests are those whose natural habitat is tall grassland — namely the pale field-rat, the canefield rat and the grassland melomys. The pale field-rat causes problems in young hoop pine plantations where densities can frequently exceed 100 per hectare (Kehl 1987). The canefield rat is common throughout sugarcane crops on large alluvial river flats and occasionally causes problems in grain crops in south-east Queensland. Grassland melomys are found in highly dissected, narrow valleys in sugarcane areas and mostly inflict damage within 15–20 metres from the edge of the crop.

'The native species which have become agricultural pests are the pale field-rat, canefield rat, grassland melomys and long-haired rat.'

A fourth species, the long-haired rat, can cause crop damage during plagues in the Ord River area of Western Australia, but between plagues they are rare (King 1994). The distributions of these four native pest species are shown in Figure 5.

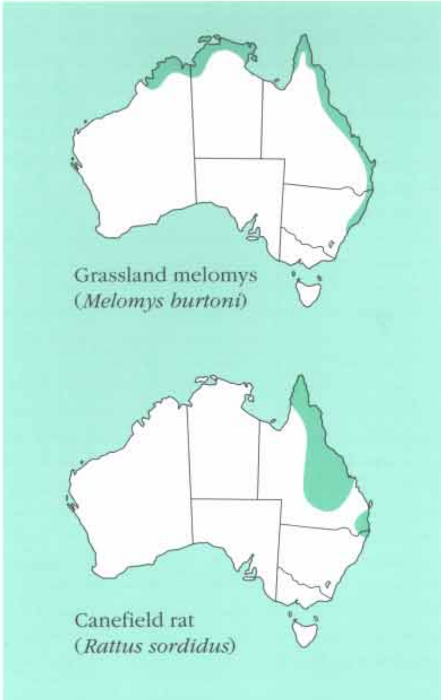

Figure 5: Distribution of native rodents that cause damage to crops and plantations in Australia (after Strahan 1995).

2. Biology

Summary

Rodents generally have poor sight but acute senses of smell, hearing, touch and taste. Social odours are an important means of communication.

The major pest species in Australia all tend to be opportunistic feeders, with their diet reflecting the food available in their environment. They feed mainly on seeds, the pith of stems and other plant material. A house mouse eats 3–4 grams of grain per day and the larger rats eat 20–30 grams of food per day.

Rodents are typically highly fecund. The young grow rapidly and reach sexual maturity early. They are also good dispersers and quickly colonise new areas when conditions are good. Mortality is usually high and life spans are short.

Breeding generally varies with environmental conditions. Reproduction is correlated with rainfall, presumably through its effect on food availability. Pest rats in tropical and subtropical areas typically breed in late summer and autumn after the start of the wet season. Breeding by mice is mostly in spring and early summer but can extend to any time of year when conditions are favourable. Young rodents reach sexual maturity well within the span of a breeding season. Female mice can produce a litter per month and the doubling time for a population can be as short as three to four weeks.

Numbers fluctuate annually in all species with peak density at the end of the breeding season in late autumn. In sugarcane, the numbers in any one year depend on the timing of the arrival of the wet season and its strength and duration.

2.1 Introduction

Some relevant aspects of the biology of rodents are briefly described in this chapter as these are important in determining which strategies might be successful in reducing their impacts. A salient aspect of the pest status of rodents is their diet and feeding behaviour because it is these that determine the type of impact. Another important characteristic is the reproductive capacity of pest rodents (Conway 1976). In ecological terms they are termed *r*-strategists, the term *r* standing for *rate of increase*. That is, they grow rapidly, reach sexual maturity early and are highly fecund. They are also good dispersers and quickly colonise new areas when conditions are favourable. Conversely, mortality is often high and the life span short.

2.2 Species description and biology

Table 1 gives a general description of each of the five major pest rodent species, including a physical description and relevant aspects of their biology, reproductive potential, diet and behaviour.

2.2.1 Reproduction

Breeding generally varies with environmental conditions. For example, house mice and black rats living in buildings may breed throughout the year. With mice, the start of the breeding season is usually triggered by an increase in fresh seed and insect availability in spring (Bomford 1987a; Tann et al. 1991). The proportion of females breeding at any time depends on the quality and quantity of the food available (Bomford and Redhead 1987) which is largely determined by rainfall. If a summer is hot and dry, breeding ceases; if rain falls in late summer or early autumn, breeding will resume. Few mice breed in winter in the field.

'The proportion of females breeding at any time depends on the quality and quantity of food.'

Reproduction in the other pest rodents is also correlated with rainfall, presumably through its effect on food availability. Rodents in tropical and subtropical areas

Table 1: Description of major pest rodents in rural Australia.

Scientific name	*Mus domesticus* [1]	*Rattus rattus* [2]	*Rattus sordidus* [3]	*Rattus tunneyi* [4]	*Melomys burtoni* [5]
Common name	House mouse; field mouse	Black rat; roof rat; ship rat; tree rat	Canefield rat; field rat	Pale field-rat	Grassland melomys; banana rat; climbing rat; khaki rat; small mosaic-tailed rat
Adult size head+body (mm) tail (mm) weight (g)	 60–95 75–100 10–25	 160–205 185–245 95–340	 135–210m; 110–160f Shorter than head+body 50–260m; 50–150f	 118–194 78–151 42–165	 130–140m; 125–130f 130–140m; 125–130f 50–65m; 45–50f
Description	Yellow-brown to dark grey above; white, pale yellow or grey below. Fur soft, short. Distinguished from similar native species by notched upper incisors and musty smell.	Body slender and elongated, snout pointed, tail longer than head+body. Ears large and thin, reaching past middle of eye when bent forward. Colour usually grey to light brown (its name is a misnomer although black individuals do occur).	Grizzled grey-brown above with long guard hairs, grey below. Tail dark, always shorter than head+body. Females usually smaller than males.	Yellow-brown to grey above, grey or cream below. Tail always shorter than head+body. Eyes large and protruding.	Short, soft, thick fur, grey to rich tan above, slightly paler below with variable white or pale cream patches on throat and belly. Tail same length as head+body. Scales on the tail do not overlap but form a mosaic.
Breeding season	Mostly between spring and autumn, but can breed throughout the year.	Can breed throughout the year; commonly pregnant in late summer and autumn in Queensland (normally 3 litters per year but can produce up to 6).	Capable of breeding throughout the year but proportion of females breeding strongly influenced by rainfall; most births between March and May.	Mainly autumn.	Mainly in autumn and winter; onset and duration influenced by rainfall.
Litter size **Number of nipples**	1–10 10	5–10 10	3–10 10	2–10 10	2–4 4
Diet	Principally seeds but omnivorous and highly opportunistic (insects, earthworms, leaves, stems, roots, fruits and fungus).	Omnivorous but principally herbivorous. Often digs for fungi. Diet also includes fruit and snails. Can raid bird nests.	Omnivorous preferring the stems and seed of grasses and some broad-leafed herbs. Insects are commonly eaten.	Mainly grass stems, seeds and roots.	Mainly grass stems and seeds. Also eats bananas and berries. Remains of insects have been found in stomachs.

Table 1 (continued): Description of major pest rodents in rural Australia.

Scientific name	*Mus domesticus* [1]	*Rattus rattus* [2]	*Rattus sordidus* [3]	*Rattus tunneyi* [4]	*Melomys burtoni* [5]
Habitat	Australia-wide where food is available, particularly cereal crops, but also in semi-arid and desert areas.	Around the entire Australian coast, in forests and some inland areas, but rare in semi-arid and desert areas.	Tropical grasslands and open forests with a dense grass cover and friable soils. Invades sugarcane when the crop provides a complete canopy of leaves.	Open forest with a dense grass understorey, usually adjacent to a watercourse or swampy area.	Wide range of tropical and sub-tropical coastal tall grasslands and swampy areas.
Behaviour	Predominantly nocturnal except when population density is high. Social, living in small groups of related individuals, usually within a home range that appears to be defended at certain times or at certain population densities. Most young disperse often before reaching adulthood. During plagues, dig deep (up to 0.5m) burrow systems in crops with extensive runways. More than 40 mice can be found in a single burrow at these times.	Predominantly nocturnal. Highly social with communal nests; often digs extensive, relatively shallow burrow systems around the edges of sheds but also nests in cavity walls, roofs and trees. An agile climber and good swimmer. Occasionally builds burrows in cereal crops.	Generally nocturnal but may be seen on overcast days if population densities are high. Poor climber. Damages cane at ground level. Constructs long, shallow burrows, no more than 40 centimetres deep. Large discrete colonies are formed, with networks of runways between burrows. During the breeding season burrows are usually occupied by a single individual or a female with young. In the non-breeding season as many as 23 rats may occupy a single burrow.	Nocturnal, spending the day in a shallow burrow dug in loose, friable soil. Solitary, one adult per burrow, but from the distribution of burrows, appears to live in patchy colonies. Runways between burrows are usually conspicuous.	Nocturnal. Solitary (one adult per nest), aggressive. When disturbed in nest, female will flee with young attached to nipples. Sometimes digs short burrows but usually constructs a spherical nest of leaves and grasses, 20 to 50 centimetres in diameter, woven around two or three erect stems up to 2 metres above the ground. Tail partially prehensile, climbs with great agility.

1 Watts and Aslin 1981; Bomford 1985; Singleton 1995.
2 Covacevich and Easton 1974; Watts 1995.
3 Watts and Aslin 1981; Redhead 1995.
4 Watts and Aslin 1981; Braithwaite and Baverstock 1995.
5 Watts and Aslin 1981; Kerle 1995.

typically breed in late summer after the start of the wet season. Reproductive output in a season depends on how early the wet season begins, its duration and the total rainfall.

Table 2 shows the reproductive potential of each of the five main pest species. Except for grassland melomys, females are capable of mating immediately after they give birth and a new litter is born as the previous litter is weaned. The young grow rapidly and reach sexual maturity well within the span of a breeding season.

2.2.2 Diet

All five species in Table 1 tend to be opportunistic feeders, their diet at any time reflecting the availability of food in their environment. Generally, they feed on seeds, the pith of stems, other plant material and stored produce such as cereals, sugars, pulses and processed food. They also take insects and other animal matter, including gnawing on live animals in intensive rearing units (Meyer 1994). A house mouse consumes 3–4 grams of grain per day (Bomford 1985) and the larger rats consume 20–30 grams of food (Meyer 1994). Mice can survive without access to water but black rats cannot.

The upper and lower incisors of all rodents grow continuously and they regularly gnaw on hard surfaces or grind their teeth to keep them short and sharp.

2.2.3 Behaviour

All rodents in Australia are primarily nocturnal although they can be active during the day when numbers are high. Mostly they spend the days in burrows or nests constructed in natural cavities or in clumps of vegetation.

Except for grassland melomys, the pest rodents tend to live in small colonies which are probably loose aggregations of family units. Burrows used by the group are clumped and distinct runways may be visible between entrances. When populations are high, frequent use makes these runways more obvious.

2.2.4 Home ranges and movement between habitats

According to Meehan (1984), rodents move to find food, water, shelter and to find and protect breeding partners and young. A study by Krebs et al. (1995) found that male mice had average home ranges of 0.035 hectares and females 0.015 hectares during the breeding season. These ranges increased in the non-breeding season to

Table 2: Reproductive potential of the major pest rodents in Australia (after Watts and Aslin 1981; Strahan 1995).

Species	Gestation length (days)	Mean litter size	Weaned (days)	Age at first * breeding (weeks)
House mouse *(Mus domesticus)*	19–20	6	18–21	5
Black rat *(Rattus rattus)*	21–22	7	20	12–16
Canefield rat *(Rattus sordidus)*	21–22	6	20	9–10
Pale field-rat *(Rattus tunneyi)*	21–22	4	21	5
Grassland melomys *(Melomys burtoni)*	—	2.5	21	—

* Onset and duration of breeding is influenced by rainfall.

— Unknown.

Source: G. Singleton, CSIRO

Mice use a wide range of refugia during the day including burrows along fencelines.

0.199 hectares, regardless of sex. Krebs et al. (1995) also found that population density did not seem to affect home range size. Dispersal over greater distances can occur as rodents are readily transported in goods and vehicles.

Rodents move between donor and receptor habitat patches, for example, from roadside verges or fencelines into crops. Dispersal to new habitats occurs particularly when numbers are high and when sub-adults enter the population following breeding. A trapping study conducted by Mutze (1991) in cereal-growing areas in South Australia found that roadside verges were occupied almost continuously, with mouse populations peaking in late autumn or early winter and declining in spring even though mice were breeding. Cereal crops were unoccupied during midwinter, and colonised in late winter or spring, presumably from donor habitats.

Donor habitats favoured by rodents are those with abundant resources, such as fencelines, which provide shelter and a good supply of grass seeds. Undisturbed sites for burrowing are important for mice and large populations are found in sandy banks and perennial vegetation.

2.2.5 Sensory capabilities

Rodents generally have poor sight but acute senses of smell, hearing, touch and taste. In the majority of species, social odours are an important means of communication. For example, an individual mouse will recognise the odours of members in its social group. These odours are produced by specific glands and secreted in urine and faeces (Macdonald and Fenn 1994). All mice mark with urine to the extent that most objects in their environment are coated. They can negotiate their way in total darkness by smell.

2.3 Population dynamics

The population dynamics of all species are a function of the number born and the number dying. In rodents the number born in any year depends on how early breeding starts and how long the breeding season continues. In addition, the quality and quantity of food available during the breeding season affects litter size (Bomford 1985, 1987a, b; Wilson and Whisson 1990), and possibly litter frequency. When conditions are good, mice in particular are highly prolific and capable of rapid population growth. Female mice can produce a litter per month during the

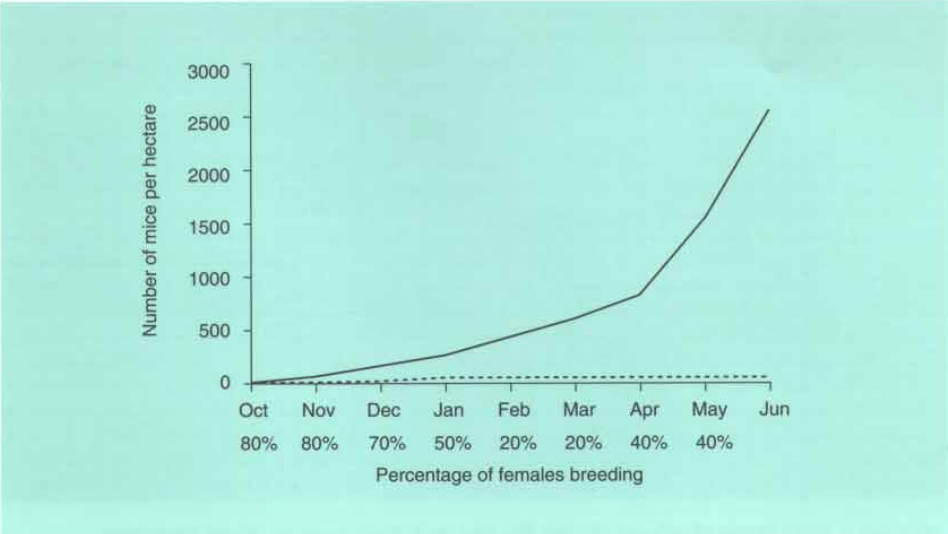

Figure 6: Hypothetical mouse population growth curves. The solid line represents a hypothetical mouse population build-up, based on a starting density of 20 mice per hectare breeding from spring through to late autumn (October to May) with the percentage of females breeding in each month as shown (Table 3). The dotted line presents for comparison the trend in numbers of a population of mice where starting density is four per hectare, the breeding season lasting only three months (October to December), and with 80%, 70% and 60% of females participating in breeding respectively.

breeding season and the doubling time for a population can be as short as three to four weeks. If the breeding season starts early in spring, extends well into summer and the proportion of females breeding remains high, then numbers can reach plague proportions by autumn. Figure 6 presents a hypothetical curve of such a plague build-up (solid line). Plotted on the same graph is a population trend (the dotted line) for a more 'normal' year (that is, low population density and breeding season limited to spring and early summer). The data represented in this graph is also presented in Table 3.

'The doubling time for mice populations can be as short as three to four weeks.'

A characteristic of plague build-up is that population growth is almost exponential. Simultaneously, the food requirements of the population grows exponentially. For example, the amount of grain eaten by the mice per month in Figure 6 would be 76 kilograms per hectare in April and 140 kilograms per hectare in May. If mice exhaust the food sources in their vicinity, they must disperse and find other sources or starve. If resources are depleted over a large area, then the population can crash very quickly.

The trigger for a mouse plague is considered to be above average autumn rainfall — particularly if the rain follows one or two years of drought (Figure 7). Saunders and Giles (1977) suggest that this relationship arises because populations of mice and their natural predators, pathogens and parasites[2], decline during a drought, and then when conditions again become favourable, mouse populations can increase unchecked by these normal agents of mortality which take more time to become re-established. Redhead et al. (1985),

2 Pathogens and parasites have the potential to affect rodent numbers through their impact on breeding success and mortality (Singleton and McCallum 1990; Singleton et al. 1993; Smith et al. 1993).

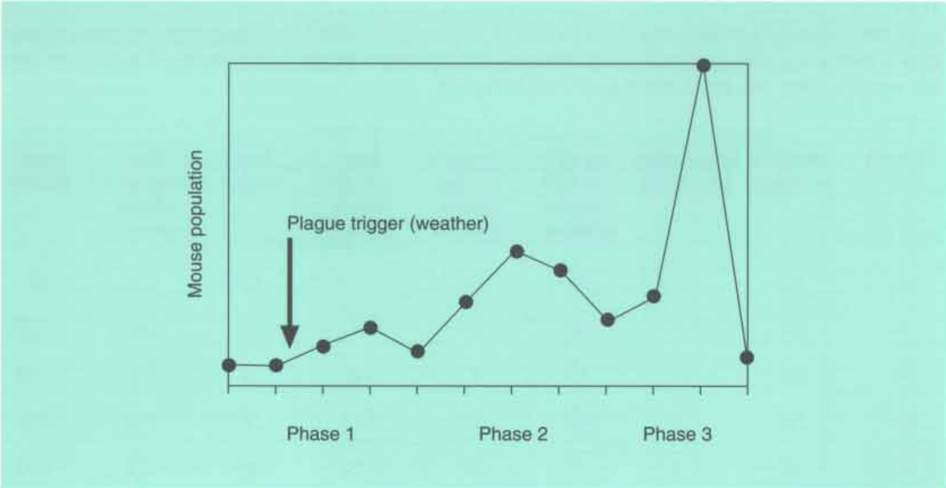

Figure 7: Plague build-up model designed for the Victorian Mallee region showing changes in abundance of house mice (over a two year period) leading up to and during a plague. The heights of peaks may vary between plagues, and drought in Phase 2 may prevent Phase 3 from occurring (after Redhead 1988).

however, propose that drought-breaking rain, rather than drought per se, is the important factor, as it ensures a good growth of grasses in the following spring when the breeding season of mice begins.

'Mice breed in refuge habitats and disperse out into crops and pastures.'

When conditions are poor mice survive in restricted areas of land where there is good cover to protect them from predators. When conditions improve, mice breed in these refuge habitats and disperse out into receptor habitats such as crops and pastures. Here they breed successfully, causing a build-up in numbers that may develop into a plague.

Other factors may contribute to the development of mouse plagues. Griffiths (1993) and Mutze (1993b) suggest that the severity of the 1993 mouse plague in Victoria and South Australia was exacerbated by:

- increase in both the area of crops grown and frequency of cropping;
- greater diversity of crops grown which extended both the time and amount of grain available to mice, for example, barley and canola both shed more seed at harvest than wheat;
- decline in the grazing of stubble with the reduction in the number of sheep run by farmers as a consequence of low wool prices; and
- conservation management practices (such as stubble retention and minimum tillage), which enhanced the survival of mice and thus the rate of development of the plague.

Each of these additional factors include land management practices that are likely to continue and which need to be taken into account when strategies for management of future plagues are designed. Modification or removal of screens from harvesters which results in more grain being spilt, and shallow sowing of grain, are further examples of the development of agricultural practices which increase food supply for mice. These practices could also contribute to the severity and frequency of mouse plagues.

Table 3: Representation of the potential population growth of mice. In this hypothetical example, the starting density is ten adult females per hectare, litter size is constant at six young per female but the proportion of females breeding in each month varies, the sex ratio is 1:1 and the age at first breeding in females is two months. Mortality is not taken into account. These data are presented graphically in Figure 6.

Month	Adult females	Proportion breeding	Juvenile females below ground	Juvenile males below ground	Sub-adults above ground	Adult males	Total (trappable) above ground	*r* per month
Oct	10	0.8	24	24	0	10	20	0
Nov	10	0.8	24	24	48	10	68	1.22
Dec	34	0.7	71	71	48	34	116	0.53
Jan	58	0.5	87	87	142	58	258	0.80
Feb	129	0.2	77	77	174	129	432	0.52
Mar	216	0.2	130	130	154	216	586	0.30
Apr	293	0.4	350	350	260	293	846	0.37
May	423	0.4	508	508	700	423	1546	0.60
June	773	0.0	0	0	1016	773	2562	0.51
							Mean *r*	*0.61*
							Doubling time (months)	*1.14*

3. Economic impacts

Summary

There has been a mouse plague somewhere in the Australian grain belt every four years on average since 1900, and in the last twenty years, the frequency of plagues in eastern Australia has increased to one every year or two. Various estimates of losses to grain growers have been made during mouse plagues. The average of the three most recent estimates is $46 million. If this average loss is typical, then since 1900, the average annual loss to grain growers has been in the order of $13 million, and more than double this figure for the last 20 years. But these are very approximate and conservative estimates.

Apart from damage to crops, grain growers also incur damage to machinery and vehicles, insulation in ceilings and walls of buildings, electrical equipment and fittings, and to household items and personal possessions. There is also an additional cost of baiting. However, these costs are small by comparison with losses in crop production.

Mice (Mus domesticus) *also cause losses to other industries. Graziers, orchardists and vegetable growers sustain damage and mice invade piggeries and poultry sheds causing production losses through stress and physical attacks on livestock.*

Mice also invade rural townships and cause damage in homes, businesses, and community and service facilities such as schools and automatic telephone exchanges. Rural suppliers and food retailers are particularly affected through losses to stock.

The native canefield rat (Rattus sordidus) *and grassland melomys* (Melomys burtoni) *cause economic losses through damage to sugarcane crops in Queensland. Another species of native rodent in Queensland, the pale field-rat* (R. tunneyi), *causes damage in young hoop pine plantations. Black rats* (R. rattus) *cause losses in older macadamia orchards and in citrus, avocado and banana crops. Black rats are also a problem in buildings and storages where they damage equipment by chewing on wood and plastic. Telephone cables, electrical wiring, hoses and similar items are particularly susceptible. Other costs arise from their consumption and contamination of foodstuffs, damage to packaging and structural damage.*

3.1 Mouse plagues

The greatest damage caused by rodents to Australian agriculture is that caused by mice during plagues in eastern Australia. In most years mouse numbers are low and the damage they cause is unnoticeable, but when their numbers increase to plague densities in grain-growing areas, the damage on farms in the affected areas and in adjacent rural townships is measured in millions of dollars (Caughley et al. 1994; Kearns 1994). Figure 8 summarises the types of losses caused by mouse plagues, both on and off-farm.

3.1.1 Impact on grain growers

The greatest impact during mouse plagues is to grain growers (Caughley et al. 1994). Generally, plagues occur in autumn at the end of a protracted breeding season and thus the potential for damage is greatest around the time of sowing winter crops, and grain fill and maturation in summer crops. Mouse numbers usually decline over winter but if survival is high, mice can also cause severe damage to winter crops at flowering and early seed set in spring. High winter survival can also allow rapid re-establishment of plague numbers in the following spring and summer, leading to damage at all stages of crop growth.

In an attempt to assess the economic cost of a plague, a survey was undertaken in winter cropping areas of South Australia and Victoria during the mouse plague in 1993 (Caughley et al. 1994). In that plague, mouse numbers reached plague densities in a single season due to unusual weather. Early rain in the autumn of 1992 created

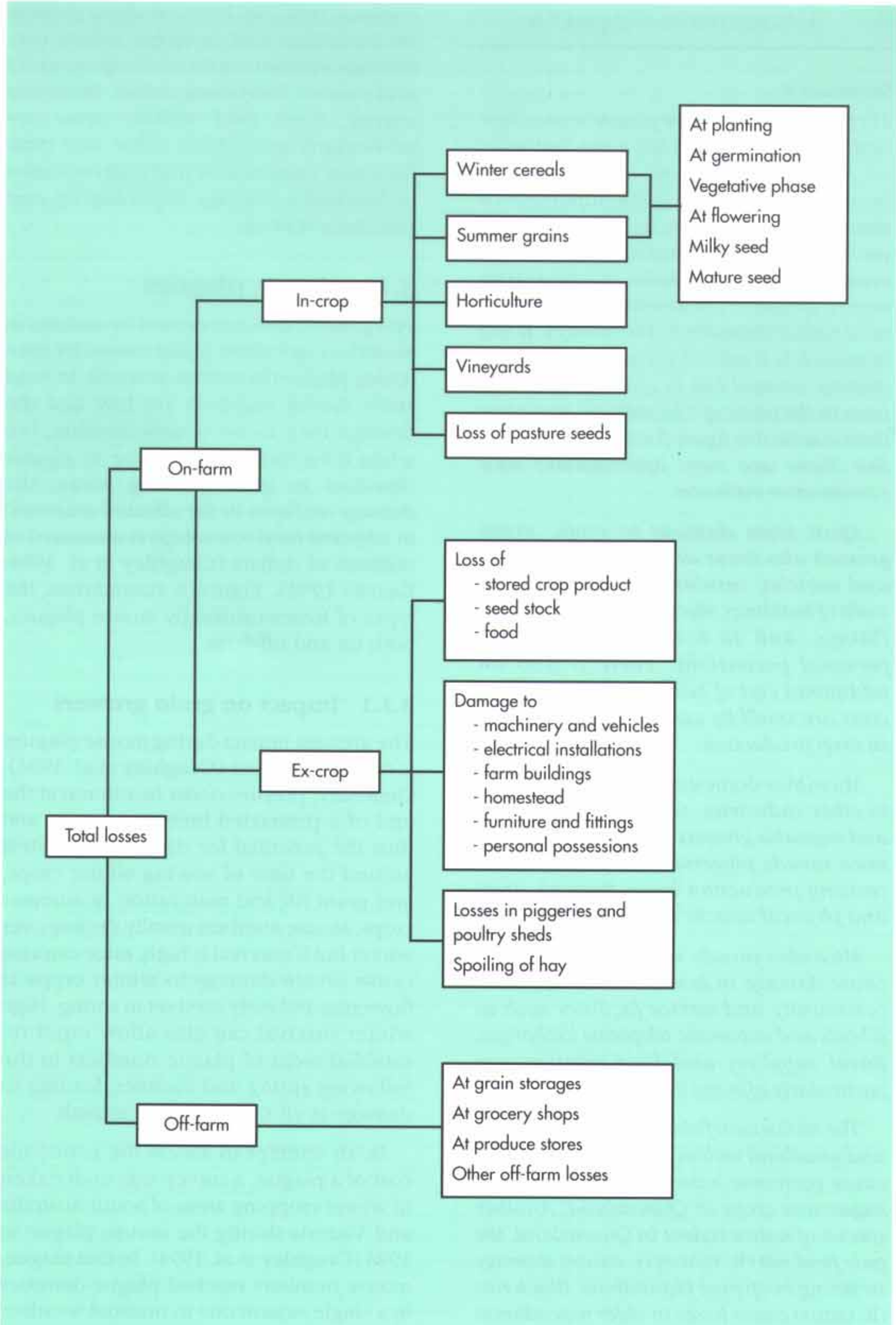

Figure 8: Types of losses inflicted by plagues of house mice in rural Australia (after Redhead and Singleton 1988).

conditions suitable for mice to begin breeding earlier in spring than usual. This was followed by record rains during the summer which caused severe damage and lodging of crops. Much grain was left unharvested, providing mice with an abundant source of good quality food throughout summer. The breeding season extended well into autumn and mouse numbers peaked in June. The arrival of autumn rains was delayed and many farmers sowed dry in anticipation of rain. After rain fell in late May, many crops failed to emerge or were patchy because the seed had been dug up and eaten by mice. In some crops, damage was greater around the edges where mice had invaded the paddock after sowing; in others, mice followed the line of furrows, digging out the seeds from the loosened soil (Griffiths 1993). Many farmers had to resow part or all of their crops, and some farmers had to sow two or three times to achieve a level of germination that would prevent wind erosion of light fragile soils. The mice also ate newly sprouted seedlings, both before and after they emerged. Damage after crop emergence was particularly serious in grain legumes and oil seeds where damage to the growing tips killed or stunted the plants.

'The potential for damage is greatest around the time of sowing for winter crops and grain fill and maturation for summer crops.'

Apart from the damage to crops, farmers incurred damage to plant and equipment. Machinery and vehicles, insulation in ceilings and walls of buildings, electrical equipment and fittings were variously damaged, as were household items and personal possessions. There was also an additional cost of baiting.

In Victoria, 257 farmers responded to a phone-in which was used to gather data on the extent of losses across the plague-affected area[3] (Caughley et al. 1994). On average, 69% of the areas cropped by these 257 farmers was damaged and 40% of the farmers reported all crops were damaged to some extent. The average loss was $56 000 (Table 4) but individual losses varied from nil to $360 000. This variation highlights the patchiness of the plague and its impact. Severely damaged crops could be next to others with little damage.

Table 4: Average losses estimated by 257 grain growers responding to a Victorian phone-in during the 1993 mouse plague (after Caughley et al. 1994).

Losses	**$**
Estimated losses in crop production	56 000
Resowing costs	3 200
Baiting costs	850
Damage to sheds, machinery and household goods	1 500
TOTAL	61 550

Other economic losses experienced by grain growers — namely from damage to machinery, stores and household goods, plus resowing and baiting costs — were small by comparison with the loss in crop production (Table 4).

The response came from 7% of farmers in the region. Their total estimated losses were $15.5 million, but this value is less than the total losses suffered by all farmers in the plague-affected areas of Victoria, because some who received damage are known not to have been included in the survey. As those who were included in the survey were likely to be a biased sample who received more than average damage[3], it would not be realistic to extrapolate from these survey data to all farmers in the region.

3 Three caveats apply to data collected in this way:

1. Respondents are likely to be a biased sample, those suffering more damage phoning in more than others less affected;
2. Respondents' estimates of production losses may not be accurate, particularly when there is compensatory growth in plants or tillers; and
3. Some damage attributed by the respondents to mice may have been caused by other pests or problems.

Source: C. Tann, CSIRO

Source: NSW Agriculture

Source: G.Singleton, CSIRO

Plagues of mice can devastate grain crops including wheat, maize and sorghum.

In South Australia, losses to cereal production were estimated by the State Department of Primary Industries. The area baited with strychnine was used as a guide by departmental agronomists to measure the extent of damage and this was combined with local knowledge of damage levels in different crop types. Machinery costs for resowing and losses from damage to buildings and equipment were not included. Adding an allowance for these costs, the estimate of losses to grain growers in South Australia was in the vicinity of $50 million (Caughley et al. 1994). It was also estimated that a similar amount of money was saved as a result of the strychnine baiting program that was instituted in South Australian grain-growing areas (Mutze 1995).

'Losses to grain growers in South Australia were in the vicinity of $50 million.'

Various estimates of losses to grain growers have been made in other plagues (Table 5). The average of the three most recent estimates is around $46 million. If a plague occurs once every four years (Section 1.2), the average annual loss to grain growers in eastern Australia from mouse plagues totals $13 million. But this is a very approximate and conservative estimate. In the last twenty years, the frequency of plagues has increased to one every year or two, which would more than double this figure. It is obvious from Table 5 that no data are available for losses due to plagues that have occurred in

Table 5: Estimated losses ($ millions) to grain growers during mouse plagues in South Australia, Victoria and southern New South Wales.

Year	SA	VIC	NSW	Total	Source
1979–80	–	45–61	–	45–61	Redhead (1988)
1984	0	19	2	21	Redhead (1988)
1993	50	15	–	65	Caughley et al. (1994)

– Indicates no plague or no estimate available.

Queensland, Western Australia or northern New South Wales during this time. Data for damage from localised plagues are also absent but this damage is not insignificant. For example, in 1994 a plague in the Murrumbidgee Irrigation Area of New South Wales caused an estimated $7 million damage to rice, maize and soybean crops (Croft and Caughley 1995). There are also few estimates of economic losses available for years when mouse numbers were high but not at plague levels. That these are likely to be considerable is evident from the study by Singleton et al. (1991) where the estimated damage to irrigated soybean crops in 1989 in northern New South Wales was in the order of $2 million. At the time, the density of mice was around 200–300 per hectare (Twigg et al. 1991).

3.1.2 Impact on intensive livestock producers

Pig and poultry farmers in plague-affected areas can sustain major losses in livestock production, from increased feed costs (rising by up to 50% during the 1993 Victorian plague), stress (pigs in particular are highly susceptible to stress) and from direct physical attacks by mice upon the animals themselves (Table 6). Mice also block feed lines, gnaw on electrical wiring in air conditioners and waste-disposal units, damage sheds (particularly the insulation in the walls) and even undermine concrete slab flooring. Brown and Singleton (1997) estimated the cost of the 1993 Victorian plague to piggeries was between $12 720 and $16 400 per establishment. The total losses experienced by intensive livestock producers during the 1993 plague were in the order of $580 000 in the worst affected area in north-west Victoria (Caughley et al. 1994).

3.1.3 Impact on horticulturalists

Mice cause damage to a wide range of horticultural crops during plagues. Vegetable growers report losses in broccoli,

Source: CSIRO

Large numbers of mice in animal sheds pose a threat to animal health, feed supplies and shed infrastructure.

Table 6: Losses experienced by pig and poultry producers in Victoria during the 1993 plague (after Caughley et al. 1994).

Pigs		Poultry	
Sows		**Layers**	
Conception rate	Down 20–50%	Weight	Down 30–50%
Litter size	Down 20–30%	Mortality	Up 15%
Litter mortality	Up*		
Baconers		**Eggs**	
Growth rate	Down 20%	Number	Down 20%
Mortality	Up*	Size and quality	Down*
Carcase quality	Down 10%		

* Percentage unknown.

tomatoes, capsicums, chillies, garlic, pumpkins and melons. Grapes, apples and other soft fruit are also damaged and serious losses can occur in almond (up to 10% of production) and pistachio orchards. In the 1984 plague, losses to horticulturalists in Victoria were placed at $175 000 (Redhead 1988). No estimates are available for other areas or plagues but losses are likely to be significant.

3.1.4 Impact on sheep and cattle graziers

No value has been placed on losses experienced by graziers during mouse plagues (Section 10.5). In 1993, farmers reported severe depletion of medic pastures and a loss in stock condition, especially in ewes and lambs. Other losses experienced by graziers were damage to stored hay and wool bales. As with all other farmers in affected regions, other losses would have come from damage to sheds, equipment and household goods, to which need to be added the cost of bait and value of labour to control mice. Further intangible losses would have resulted from the depletion of seed banks in pastures.

3.1.5 Off-farm impact

During plagues, mice often cause damage in rural townships (see also Section 3.4).

The types of off-farm impacts on rural businesses include:

- damage caused to plant and equipment (particularly electrical equipment);
- spoiling and consumption of products;
- lost business opportunities from not stocking, and therefore not selling, products considered at risk (for example, packet foods); and
- cost of redirected time and effort protecting goods and cleaning to maintain health and hygiene standards. Businesses which have little food for mice (for example, machinery sellers or fuel distributors) are not affected to the same extent as those that stock perishable goods. In all businesses, however, electrical and electronic equipment is at risk.

A detailed assessment of the economic cost of a mouse plague to rural townspeople was conducted during the 1993 plague (Caughley et al. 1994). A broad spectrum of retail businesses and community services in South Australia were surveyed by face-to-face questionnaire. All those interviewed indicated that the most significant cost was the labour required to mouse-proof, bait, trap, clean, and search for and dispose of carcasses. In many instances, these costs were incurred every day for the duration of the plague (that is, up to four months)[4].

'Off-farm impacts on rural businesses include damage to plant and equipment and spoiling and consumption of products.'

Apart from labour, the costs incurred were principally from damage to goods and electrical equipment. The extent of the damage was dependent on three factors:

- type of business — retail outlets with large quantities of stock feed or food products, such as rural suppliers, grocers, supermarkets and bakeries, were at considerable risk;
- businesses situated on the edges of town had more problems with mice than similar businesses located centrally; and
- the age and construction of the business premises dictated how easy it was to exclude mice.

Rural suppliers recorded the highest losses (Table 7). Their businesses were almost always located on the edges of towns, their stock included large amounts of produce that mice find palatable (for example, grain and seed supplies, organic fertilisers and animal foods) and often their premises were open sheds which were impossible to mouse-proof. Food retailers and hospitality outlets also experienced high costs. Goods and equipment were damaged and high labour costs were incurred in cleaning premises to the standard required by council health regulations. Schools and hospitals incurred similar costs in maintaining standards of hygiene.

Table 7: Average costs to retailers, community services and residents interviewed in plague-affected regions of South Australia in 1993, and some extrapolated estimates for the region (after Caughley et al. 1994).

Service or business	Number sampled	Average cost $	Number in plague area	Estimated total $
Retailers				
Rural suppliers	9	8 120	45	365 350
Food retailers	33	2 510	100	251 050
Hospitality outlets	13	2 720	82	223 050
Other (for example, finance)	72	850	–	–
Community services				
Schools	9	2 980	24	71 500
Hospitals	7	2 300	36	82 650
Councils, postal and emergency services	14	890	–	–
Households[a]	48	310	–	–

a Household costs do not include labour component.
– Not estimated.

4 The estimates were of costs incurred up to the time of the survey. No flow-on costs beyond the duration of the plague, nor costs incurred prior to the plague (for example, construction costs in making buildings mouse-proof) were included. Some of the costs identified by a business or individual would have come from the sale of goods or services by another, but no method was available to balance the ledger.

Two other off-farm rural enterprises can suffer high losses during mouse plagues — telephone communications and grain handling. Mice damage electronic equipment in telephone exchanges by gnawing and urinating on relays. Automatic exchanges in plague-prone areas are constructed to be mouse-proof and they are regularly checked by technicians who lay rodenticide baits as an extra precaution. Despite this preparedness, mice gained access to one exchange in South Australia during the 1993 plague. It cost $30 000 to replace the damaged equipment, and a further $600 to mouse-proof the building again.

In South Australia and Victoria, most grain is stored in vertical silos which are essentially mouse-proof and hence costs in terms of mouse exclusion and damaged grain are low. However, some grain is still stored in horizontal sheds and covered bunkers. During the 1993 plague, mice caused considerable, though uncosted, losses in these storage facilities. With the onset of the plague in 1993, grain handling authorities instituted specific measures to limit losses. These included increased vigilance (bunker covers were checked weekly for holes or other signs of mouse damage), the removal of grain from districts where the plague was severe, and the increased use of rodenticides around horizontal storage sheds. In Victoria, between April and October, $13 000 was spent on bait. South Australian grain handling authorities spent $27 000 on bait over the same period.

Many other off-farm costs are intangible. For example, redirection of state government staff to managing mouse issues is usually uncosted. Quantified off-farm losses extrapolated by Caughley et al. (1994) gave an estimate of $1 million for the 1993 plague but that figure is considered conservative.

3.2 Rats in macadamia and other plantations

The major culprit in macadamia nut damage is likely to be the black rat (Loebel 1995) although native species have also been implicated. Losses in older macadamia orchards can be as high as 30% in some years, equivalent to around 100 tonnes or $350 000 worth of nuts on some individual farms (R. Turner, National Parks and Wildlife Service, Queensland, pers. comm. 1994). The annual extent of the rodent damage nationally has not been assessed although 5% is considered to be a 'normal' loss.

White et al. (1997) conducted a study of black rat damage to six macadamia crops in an eight square kilometre area of the Sunshine Coast of Queensland. They found that the macadamia crops grown adjacent to undisturbed vegetation, consisting of dense scrubland, experienced mean crop damage levels of 9.9%. In comparison, macadamia crops grown adjacent to highly modified grasslands with no overstorey, that were regularly disturbed by slashing and weed spraying (Section 7.4.2), had mean damage levels of 0.8%. The mean level of rat damage to all six crops recorded in the study was 5.1% and there was evidence that no compensatory production by rat-damaged trees occurred (Section 7.3.2).

The total Australian macadamia crop is valued at $55.6 million, so if annual mean damage levels of 5% are typical for the industry as a whole, the total national damage would be of the order of $3 million per year. The macadamia industry in Australia is rapidly expanding (White et al. 1997), so this figure could increase substantially unless effective control methods are developed and implemented. More studies are required on the abundance of black rats and their economic impact in orchards and other agricultural settings in Australia (Section 10.6).

'Black rats may cause losses of up to 30% in older macadamia orchards.'

Damage from rats is reported in citrus, avocado and banana crops but the extent and severity have not been evaluated.

Native rodents also cause damage by gnawing the bark of trees. In hoop pine plantations in Queensland, the gnawing of pale field-rats causes significant mortality in young trees (Kehl 1987). Yule (cited as pers. comm. in Kehl 1987) estimated the loss in timber revenue from rat damage was $1.7 million for the period 1935 to 1968, which is equivalent to over $10 million net present value. In recent years, changes in silvicultural techniques have reduced the level of damage. New plantings are not sited adjacent to the previous year's and herbicides are used to control the growth of weeds. Grazing was also introduced to reduce the habitability of the plantings for rats. Poisoning is now undertaken only when serious localised outbreaks occur.

3.3 Rats in sugarcane and other crops

The major pest rodents in sugarcane are the two native species, the canefield rat and the grassland melomys. Most of the damage is caused by the canefield rats eating the pith and gnawing on the stems of sugarcane which gives entry to sugar-degrading bacteria, fungi and insects (Section 8.8.2; Wood 1994). Extensive gnawing can also lead to bending or breaking of the canes. The damage causes a loss in yield and in sugar content. Whisson (1996) found that sugarcane was the major component of the stomach content of more than 50% of canefield rats sampled between April and September.

'Gnawing of sugarcane by rats can lead to bending and breaking of canes and permit access of sugar-degrading bacteria, fungi and insects.'

In total, the loss to the Queensland cane crop from rats amounts to $2–9 million each year and a further $0.6 million is spent annually on baiting programs (Wilson and Whisson 1990). While this level of damage represents less than 0.1% of the total value of Australian sugar production ($1.2 billion in the 1994–95 crushing season; Australian Bureau of Statistics 1996), in some areas the damage can be significant with more than 50% of stalks damaged. Large-scale trials into the efficacy of weed control combined with rodenticide baiting have shown that gross margins between treated and untreated areas can differ by a factor of 2.3 (Robertson et al. 1995) (Table 8).


Source: A. Brodie, BSES

Gnawing of sugarcane at the nodes by rodents can lead to bacterial and fungal infection and breaking of the canes.

In the Ord River area of Western Australia, the long-haired rat (*Rattus villosissimus*) can cause crop damage when it is in plague numbers (Wheeler 1987; King 1994) but no estimates are available to quantify the damage. Between plagues, they are rare and have little detectable impact.

3.4 Rodents in stores

Mice and black rats eat stored produce and cause major damage to equipment from their habit of chewing on wood and plastic. Meyer (1994) lists the following types of damage they cause:

Food consumption — On average rodents consume about 10% of their body weight each day. An adult rat would eat in the order of 30 grams per day each which is equivalent to nearly ten kilograms of food per year;

Table 8: Gross margin returns and rodent damage in trials on the efficacy of weed control combined with rodenticides in sugarcane (from Robertson et al. 1995).

Site	Treatment	Tonnes cane cut per hectare	Index of sugar content	Gross margin $	Stalks with rodent damage %
Babinda	Baiting plus weed control	114.0	10.1	1230	2
	Untreated	81.0	8.8	505	14
Proserpine	Baiting plus weed control	62.1	15.6	1510	2
	Untreated	26.7	15.0	705	57

Food contamination and damage to packaging — Rodents damage and contaminate more food than they consume. Through damage to packaging, they cause spillage or spoilage. Contamination through urine, droppings, hair and carcasses makes food unsuitable for human or livestock consumption. An infestation of only ten black rats produces some 146 000 droppings and 54 litres of urine a year; and

Structural damage — Damage can occur to roofing, walls, insulation, electrical wiring, doors, floors, plumbing and machinery. Electrical systems are particularly prone to rodent damage.

Other problems arising from the presence of rats and mice in stores are:

Human and animal welfare and disease transmission — Rodent infestations present a health hazard to people and domestic animals (Section 5.2);

Infestation or reinfestation of adjoining areas — Where buildings with rodent infestations are close to houses or crops, they can act as a source for infestation of these areas. Control of peripheral infestations will be compromised if the source population is not controlled;

Risk of fire — The habit of gnawing electrical cables increases the chance of fire. For intensive livestock farmers, the risk is magnified if their sheds are lined with polyurethane insulation since it gives off potentially lethal cyanide gases when it burns; and

Costs and non-target risks associated with control or prevention — The costs of rodent-proofing a structure can be high. It is usually cheaper to build a rodent-proof structure than to attempt to proof an existing structure. Costs of control need to be weighed against the benefits (Section 8.7). The risks to human health and non-target species of using poisons may be considered as an additional cost (Sections 4.2.1, 4.2.2, 4.3.2 and 5.2).

4. Environmental impacts

Summary

The impact of pest rodents on the environment has not been well documented. During and after mouse plagues, there is an increased risk of soil erosion from reduction of vegetative cover and soil disturbance by mice. Other potential impacts include depletion of native seed banks, competition with native fauna for resources and transmission of disease to native fauna. When predators are abundant at the end of a plague they could switch to preying on native species.

A known environmental impact is that of poisons on non-target species. Rodenticides can be non-specific and lead to unwelcome chemical residues in soil, water and plant and animal products. Large quantities of rodenticides are used during plagues; over one tonne of strychnine was sold to farmers in South Australia during the 1993 mouse plague. Off-label use of many other chemicals for rodent control is a major concern. Non-target poisoning can result from other animals taking the bait or from predators or scavengers eating poisoned animals. Native birds can be killed by poisons during plagues. It is difficult to detect non-target poisoning and therefore the impacts of most rodenticides on non-target populations are poorly quantified.

4.1 Introduction

The impact of pest rodents on the environment has not been well documented (Section 10.7) although they have the potential to:

- compete with other fauna for resources;
- deplete native vegetation seed banks;
- increase the risk of soil erosion through removal of ground cover;
- adversely affect flora and fauna on islands;
- cause an imbalance in the type and abundance of predators; and
- transmit disease to other fauna — rodents are vectors for many pathogens (Section 5.2.1; Gratz 1988, 1994) but there is no evidence that this is a problem.

Another important consideration is the potential environmental impact of poisons. A known environmental impact is that of poisons on non-target species. Several rodenticides are registered for use in and around sheds and buildings, and in bait stations for perimeter baiting of crops, but they are not registered for use in grain crops or orchards. Sugarcane can be legally baited for rodents in Australia. Until recently the poison used was thallium sulphate, but contamination of adjacent waterways led to its withdrawal. It has been replaced by the anticoagulant rodenticide, brodifacoum, but no research has been published regarding the environmental impact of this chemical. In 1997, the National Registration Authority issued minor use and trial permits for the in-crop application of zinc phosphide. As zinc phosphide breaks down to relatively inert non-volatile compounds, residue problems are not expected and appropriate bait placement and low dose rates should reduce the risk of non-target poisoning (Parker and Hannan-Jones 1996).

4.2 Direct impacts

4.2.1 Impact on abundance of predators

One environmental consequence of high rodent numbers, and more especially of mouse plagues, is an increase in the numbers of birds of prey in the vicinity. During mouse plagues, owls (especially barn owls (*Tyto alba*)), Australian kestrels (*Falco cenchroides*), black-shouldered kites (*Elanus notatus*), brown falcons (*Falco berigora*), kookaburras (*Dacelo gigas*) and black kites (*Milvus migrans*) regularly prey on mice. So too do ravens (*Corvus* spp.), magpies (*Gymnorhina tibicen*) and straw-necked ibises (*Threskiornis spinicollis*). Non-avian predators include foxes *(Vulpes*

vulpes), cats (*Felis catus*) and several species of snake.

When a plague ends, the predation pressure on other prey species will be high because of the greater numbers of predators. Not surprisingly, as food resources diminish, many raptors die of starvation (McOrist 1989).

4.2.2 Impact on other fauna

The major impact of pest rodents on other fauna is possibly from competition for food. During plagues, mice could compete not only with granivorous species such as finches, parrots, pigeons and native rodents, but also with insectivorous species. Since plagues of mice tend to be localised, mobile competitors will be able to seek other feeding areas and thus the impact is probably minor. Less mobile species such as reptiles, invertebrates and other species of small mammals may be affected but there are no published records of a decline in their numbers during a plague.

Black rats (*Rattus rattus*) are significant predators of reptiles and birds in New Zealand. In the offshore Mercury Islands, successful eradication of rats led to a twenty-fold increase in lizard numbers. The impact of rat predation has not been quantified on mainland Australia but is possibly substantial in some areas. On Norfolk Island, black rats are the prime predators of the Island Green Parrot (*Cyanoramphus novaezelandiae cookii*) and they have been known to take chicks and sitting females from nests (Stevenson 1997).

4.2.3 Impact on native vegetation

Most rodents feed on the seeds of native vegetation. When rodent numbers are high, they are potentially capable of modifying native plant species composition by removal of seeds. If reintroduction by seed dispersal is possible, no long-term deleterious reduction in diversity will result. In isolated patches of remnant vegetation, however, seed removal may be a threat to its continued existence.

4.3 Indirect impacts

4.3.1 Soil erosion

An indirect environmental effect of mouse plagues is soil erosion in paddocks where winter crops have failed to emerge or are sparse and subject to the tunnelling action of wind and water between plants. Likewise, denuded pastures and areas of native vegetation are susceptible to soil loss. The dust storms in Victoria in autumn 1994 were attributed to the combined effects of the mouse plague and the dry summer (J. Williams, CSIRO Division of Land and Water, Canberra, pers. comm. 1994; see also Section 7.4.2).

It is critical that farmers do not stop using conservation farming principles because they think these practices could encourage mice. If farmers were to revert to conventional tillage, fallowing and stubble retention practices, the adverse consequences for land degradation would be far greater than any harm done by a build-up in mouse numbers.

4.3.2 Impact of poisons

The potential environmental impact of the use of large quantities of poisons to control rodents has always raised concern (Sections 7.4.1 and 10.8; Ryan and Jones 1972; Redhead 1988; Singleton and Redhead 1989; Bird 1995). In the 1984 mouse plague, the rodenticide market was valued at $25 million, compared to $5 million in a non-plague year (Redhead and Singleton 1988). During the 1993 plague, over one tonne of strychnine was used by farmers in South Australia alone.

The potential impact on owls (*Ninox* and *Tyto* spp.) from the use of anticoagulant rodenticides in sugarcane and orchards has also raised concerns (Young and de Lai 1997). There is, however, a need to collect reliable data on any changes in owl numbers associated with rodenticide use (Section 10.7) and to establish if these changes are due to secondary poisoning or, alternatively, reduced food supply for owls when rats are successfully controlled.

Another concern is the types of chemicals used. Ryan and Jones (1972) recorded that during the 1970 mouse plague, farmers used the organochlorines DDT, dieldrin and endrin; the organophosphates parathion, phosdrin and fenthion-ethyl (Lucijet™); a fungicide called thiram; plus strychnine, arsenic, phosphorus, 1080 and the anticoagulants Ratsak™ and Racumin™. The use of organochlorines is now banned and restrictions on the distribution of 1080 would make illegal use highly unlikely. However, off-label use of many other chemicals is still a major cause for concern. The environmental problems associated with these chemicals are the:

- hazard posed by residues in soil or water;
- possible contamination of the harvest (with consequential human health and trade effects); and
- poisoning of non-target animals.

Non-target poisoning can be either from other animals taking the bait (primary poisoning) or from animals eating poisoned animals (secondary poisoning) (Section 7.4.1; Saunders and Cooper 1982; Phillipps 1993; Bird 1995). Detecting non-target poisoning can be difficult, particularly if the chemicals used are organochlorines, organophosphates, heavy metals or anticoagulants which accumulate in body tissues until the amount reaches a lethal level. Animals take several days to die after eventually ingesting a lethal dose and are open to predation during that time.

'Non-target poisoning occurs through animals taking bait or feeding on other animals that have taken bait.'

In contrast, strychnine does not accumulate in the body. If the dose is not fatal, it is rapidly broken down in the liver and excreted. Scavengers such as ravens have been observed gorging on strychnine-killed mice without apparent ill effect. Most non-target deaths are from primary poisoning. During the 1993 mouse plague, birds killed by strychnine in Victoria included red-rumped parrots (*Psephotus haematonotus*), bluebonnets (*Psephotus haematogaster*), galahs (*Cacatua roseicapilla*), mallee ringnecks (*Platycercus zonarius*), white-winged choughs (*Corcorax melanorhamphos*), crested pigeons (*Ocyphaps lophotes*) and feral domestic pigeons (*Columba livia*). In South Australia, where some of the baited areas were monitored for non-target kills, suspected primary poisonings were reported on 69 occasions involving 950 birds of 23 species (Bird 1995). Most of the birds (71%) were feral domestic pigeons (Table 9). A further 22% were native seed eaters (mostly crested pigeons, galahs and parrots). Most of those tested had detectable levels of strychnine. Strychnine was also detected in two tested magpies and one raven but an organophosphate (omethoate) was also present. Only one of the raptors tested positive for strychnine — an immature letter-winged kite (*Elanus scriptus*) whose gut contained a mouse which when analysed contained strychnine.

Lundie-Jenkins and Brown in Eldershaw (1996) monitored non-target species during a trial strychnine baiting study on the Darling Downs. Although there was considerable variation in abundance of non-target species within and between the monitoring sites, the results indicated that 'when bait was distributed according to baiting criteria[5], there was minimal effect on populations of non-target species but when bait was laid incorrectly, non-target birds suffered losses'.

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5 Established baiting criteria includes no baiting of bushland areas or bare ground, and a minimum buffer area of 50 metres around crops.

Table 9: Results of testing for strychnine and the organophosphate, omethoate, in birds suspected poisoned by baits laid for mice during the 1993 plague (after Bird 1995).

Species	Number collected	Number tested for chemicals	Number with strychnine	Number with omethoate
Domestic pigeon *Columba livia*	653	7	6	1
House sparrow *Passer domesticus*	16	1	1	0
Crested pigeon *Ocyphaps lophotes*	137	15	14	0
Galah *Cacatua roseicapilla*	34	9	5	1
Other parrots	29	8	6	0
Magpie *Gymnorhina tibicen*	41	13	2	1
Raven *Corvus spp.*	12	5	1	2
Magpie lark *Grallina cyanoleuca*	2	2	2	0
Black kite *Milvus migrans*	6	2	0	2
Other raptors	6	5	1	0
Southern boobook *Ninox novaeseelandiae*	3	2	0	0

Source: QRLPB

Source: CSIRO

Environmental risks associated with baiting can be minimised through the correct preparation and distribution of bait material.

5. Social impacts and attitudes

Summary

Individual perceptions of rats and mice determine to a large extent how people cope with them. Most people perceive them as unattractive, disease-carrying vermin, and during mouse plagues they find sharing their homes with mice for an extended period highly stressful. Even so, some rural people consider an occasional mouse plague one aspect of rural living.

Good hygiene practices are essential during rodent outbreaks since rats and mice are capable of transmitting many diseases to people. During mouse plagues, cleaning is a repetitive chore because mice constantly mark surfaces with urine. Work routines are severely disrupted on farms and in towns as people spend hours each day baiting, trapping and cleaning up after mice. There is a risk of accidental poisoning during rodent outbreaks, when people use poisons in ways that they would normally avoid, such as on kitchen benches where food is prepared.

The social stress of coping with mouse plagues is exacerbated for many farmers and townspeople by the additional worry of financial loss. Further stress is endured by intensive livestock farmers from the actual physical damage inflicted on their animals by mice and the increased risks of disease and fire. In rural communities these social stresses are often more debilitating than the economic losses.

Rodents are reservoirs for a large number of infectious organisms, many of which, if transmitted to people or domestic animals, may cause outbreaks of diseases with potential high morbidity and some mortality. In Australia, the most significant rodent-borne diseases that can affect people are leptospirosis, salmonellosis and toxoplasmosis. Rattus, *including several native species, is the main rodent genus in Australia that is a reservoir for these diseases, although salmonella and toxoplasmosis are also spread by house mice. Of greater concern to farmers are stock diseases carried by rodents such as swine encephalomyocarditis.*

Management strategies that limit the build-up in rodent numbers are preferred by animal welfare authorities as these reduce the need for widespread use of poisons, limiting the suffering of rodents being controlled and the risk of non-target poisoning. Controlling the build-up in numbers also has the advantage of preventing the parallel build-up in rodent predators that often starve at the end of a plague.

5.1 Community perceptions

Rodents, even native rodents, are considered to be vermin and carriers of disease by most people. This perception is justified since rodents are reservoirs for a large number of infective organisms which, if transmitted to humans and domestic animals, lead to mortality or morbidity (Section 5.2; Gratz 1988, 1994; Stevenson and Hughes 1988).

There is also the perception that rodents are pests because they damage personal goods and property. For example, during plagues mice invade homes and build nests in wall cavities, cupboards and the backs of stoves, refrigerators and washing machines. They drown in rainwater tanks contaminating drinking water. They foul food, clothing and linen with urine and droppings. They gnaw on plastic containers, furniture, books and records. All valued possessions have to be packed away in mouse-proof containers.

For many residents in affected areas, one mouse inside their home is one mouse too many. When faced with an invasion of dozens of mice every night for up to four months, the effects are debilitating. Part of the problem is the stress that largely stems from a cultural perception of the presence of rodents indicating 'uncleanliness' and poor housekeeping. Such a perception is inappropriate during a plague when mice are dispersing in all directions, seeking food and shelter; nonetheless the attitude remains. As a consequence, many people are reluctant to discuss their frustration, which is the converse of what happens during other natural disasters — droughts, fires, floods — which tend to draw rural communities together. This leads to an increasing inability to cope as a plague continues. People take measures that they would normally avoid, such as placing poison baits on kitchen benches and in kitchen cupboards.

5.2 Health and safety issues

In addition to the stress alluded to above, the risks of rodents to human and animal health are threefold:

- *disease and direct physical attacks on shed stock* — disease risks are described in Section 5.2.1, and physical attacks discussed in Section 5.3;
- *poisoning from baits laid for rodents* — there is a risk of accidental poisoning during rodent outbreaks, when people use poisons in ways that they would not normally countenance (Section 7.4.1). No poisoning of people has been attributed to rodent baits during mouse plagues in Australia but accidental poisoning of domestic pets occurs frequently, especially with off-label use of chemicals. During the 1993 mouse plague, one veterinarian reported treating 40 dogs believed to have eaten rodent bait. The owners were often unsure of what baits their animals may have encountered and veterinarians were left with little choice but to transfuse animals which did not respond to initial treatment with vitamin K, the antidote for anticoagulant rodenticides. As a part of any education program prior to mouse plagues, town residents must be alerted to the dangers to pets of accidental poisoning and offered advice on available registered rodenticides, how to prepare baits in bait stations and to lay them in places inaccessible to pets; and
- *fire* — the habit rodents have of gnawing on electrical cables increases the chance of fire in sheds and other buildings. For intensive livestock farmers, the risk is magnified if their sheds are lined with polyurethane insulation since it gives off potentially lethal cyanide gases when it burns.

5.2.1 Rodents as carriers of disease

Rodents are reservoirs of a large number of infective organisms which may, if transmitted to people or domestic animals, cause outbreaks of diseases with potential high morbidity and some mortality (Stevenson and Hughes 1988; Gratz 1994; Saul 1996). The best known disease carried by rats is bubonic plague but many other pathogens are as dangerous. In Australia, most of these pathogens are absent or rare, but a few are of concern, particularly when rodent populations build to high numbers.

'Rodents are reservoirs of a large number of infective diseases which may be transmitted to people or domestic animals.'

Stevenson and Hughes (1988) describe a number of infections (zoonoses) that rodents can carry and may transmit to people. Transmission may be direct or via contamination of food or water with infected rodent urine or faeces. It may also be by arthropod vectors. For example, rodents can be intermediate hosts for arboviruses such as Ross River and Murray Valley encephalitis which are transmitted by mosquitoes. Another disease, murine typhus (*Rickettsia typhi*), is transmitted via rat fleas (Stevenson and Hughes 1988).

Endemic diseases and parasites

The following zoonoses are listed by Stevenson and Hughes (1988) as potential human health problems in Australia:

Bacterial infections — Leptospirosis (causal agent *Leptospira celledoni*) usually spread in water contaminated with urine from infected animals; Lyme disease (causal agent *Borrelia burgdorferi*) spread by ticks; melioidosis (causal agent *Pseudomonas pseudomallei*); salmonellosis (causal agents several serotypes of *Salmonella*, mainly *S. typhimurium*) spread by consumption of food or water contaminated by faeces from infected animals; infections caused by *Streptobacillus moniliformis*, *Spirillum minus*, *Campylobacter* spp. and *Leptospira icterohaemorrhagiae*;

Fungal infections — Ringworm (*Trichophyton* spp.);

Viral infections — Ross River virus;

Rickettsial infections — Murine typhus (normally from rats via fleas), Queensland tick typhus, scrub typhus (mite transmitted);

Parasitic infections — Angiostrongyliasis (rat lungworm), fleas, mites, tapeworms, nematodes (*Physaloptera* spp); and

Protozoan infections — Pneumocystosis and toxoplasmosis (causal agent *Toxoplasma gondii*).

Several worm infections of people and domestic animals have rodent reservoirs (Gratz 1994), but none are of public health significance in Australia.

Stevenson and Hughes (1988) additionally list a number of rodent infections classed as 'potential zoonoses'. These include *Capillaria hepatica* (nematode of rodents and lagomorphs), encephalomyocarditis virus and lymphocytic choriomeningitis virus (LCM). LCM is an increasingly common disease of mice in North America and Europe (Saul 1996).

Some rodent-borne diseases also present a risk for livestock. For example, outbreaks of encephalomyocarditis (EMC) disease occurred in domestic pigs on some properties in New South Wales during the mouse plagues of 1970 and 1984 and caused serious losses (Acland and Littlejohns 1975; Seaman et al. 1986). Serological surveys have found EMC virus present in 22% of water rats (*Hydromys chrysogaster*) and 5–10% of other rodents in Queensland (Stevenson and Hughes 1988).

The best means of limiting the risk from these pathogens is to exclude rodents from human and animal food and to maintain high standards of cleanliness in food preparation and eating areas. It is difficult to maintain cleanliness in animal sheds. During mouse plagues, the stressed condition of the animals and the presence of lesions from mice gnawing the skin increases the potential for a major disease outbreak. Scouring is a frequent problem in pigs during plagues with mice aiding the transfer of bacteria between pens. In the 1984 and 1993 plagues, infection with *Erysipelas* was reported in some piggeries.

Exotic diseases and parasites

Geering et al. (1995) list rodents as potential reservoirs of a number of exotic livestock infections, but most of these are arthropod-borne viruses. The exceptions are rabies, the protozoan *Trypanosoma cruzi* (the cause of Chagas' disease) and the nematode *Trichinella spiralis*. Of these three infections, trichinellosis would be of most concern. Rats could be carriers of *T. spiralis*. This nematode infects a wide range of mammal species including pigs, dogs, cats, horses and people.

Bubonic plague, caused by the bacterium *Yersinia pestis*, is still a major disease of humans in parts of Africa and Asia and could become a problem in Australia. The introduction of pathogenic strains of hantaviruses, however, would be of most concern to human health. Overseas, some of these viruses cause serious human diseases, such as Korean haemorrhagic fever. A new virulent strain of hantavirus (Sin Nombre virus), first identified in the USA this decade, was fatal in more than half of infected cases (Saul 1996). Antibodies to hantaviruses have been detected in feral and native rats in Australia but no pathogenic strains are known to occur here.

5.3 Animal welfare issues

Animal welfare goals are to minimise pain, distress and discomfort to animals, including livestock, wildlife and pests subjected to a control program (Johnson and Prescott 1994). Different control options will achieve these goals to a greater or lesser degree. Measurements of the humaneness of rodenticides (or any poison) are largely subjective, but in animal welfare terms, a poison which acts quickly to kill or leave an animal unconscious is better than one which takes a considerable time to act.

'Management strategies which limit build-up in rodent numbers reduce the need for widespread use of poisons.'

Management strategies that limit the build-up in rodent numbers are preferred (Oogjes 1994). By reducing the need for widespread use of poisons, these strategies limit the suffering of rodents being controlled and the risk of primary and secondary poisoning of non-target animals. Controlling the build-up in numbers also has the advantage of preventing the parallel build-up in rodent predators. These animals often starve at the end of a plague (Section 4.2.1).

Minimising the build-up in rodent numbers also reduces the stress experienced by penned livestock during a plague. The extent of physical attacks by mice on penned animals during the 1993 plague shocked many farmers (Caughley et al. 1994). In piggeries, breeding sows and piglets were particularly affected and badly gnawed animals had to be destroyed to end their suffering. Poultry also suffered, and through stress, birds lost condition and many died.

The Australian and New Zealand Federation of Animal Societies (ANZFAS) considers that the current approach to rodent management, namely crisis management and the use of poisons during plagues, is inappropriate. It considers that a well-planned and coordinated strategy, as advocated in these guidelines, is likely to be more humane.

6. Past management and current policy

Summary

Some rodents are declared pests under legislation in Western Australia, Victoria and the Northern Territory and landholders may be directed to undertake control measures. In other states and territories there is no legal requirement that they be controlled. The only exceptions are (a) under health regulations when authorised health officers may give 'reasonable directions' to the owner or occupier of premises; and (b) if declaration is made under the Rural Lands Protection Act 1989 *in New South Wales. While introduced species can be controlled at a landholder's discretion, native species are protected wildlife and cannot be suppressed without permission from wildlife authorities.*

Management at the farm level usually involves the use of poisons in and around buildings. A number of rodenticide poisons are registered for use. No rodenticide is available for in-crop use except for the anticoagulant brodifacoum in sugarcane. In other situations, access to specific rodenticides requires approval from the National Registration Authority through the issuing of a trial, off-label or minor use permits. When rodent problems were particularly severe, such as during the mouse plagues between 1993 and 1995, state government agencies obtained access to strychnine through emergency regulations enacted within the state.

Strychnine has been the most widely used chemical for controlling mice but its use has been progressively restricted since the 1980s. Other rodenticides are now being evaluated for in-crop use against mice, the most promising being zinc phosphide. Until recently, thallium sulphate was available for controlling rats in sugarcane but the anticoagulant brodifacoum has now been registered to take its place. In hoop pine plantations, pale field-rats are controlled with 1080. Rats in macadamia plantations are controlled with commercially prepared products, Bromakil™, Racumin™ and Talon™, distributed in bait stations.

The administration of the different Acts relating to rodent management falls within different state and territory government departments. Consequently, considerable liaison between departments is necessary to implement management strategies at a government level. Relevant state and territory government policies are described in this chapter.

6.1 Past management

In the past, management of rodent outbreaks on farms was largely directed towards reducing numbers with poisons. A multitude of poisons was used. For example, chemicals used during the 1970 mouse plague included: strychnine; arsenic; phosphorus; sodium fluoroacetate (1080); the organochlorines DDT, dieldrin and endrin; the organophosphates parathion, phosdrin and fenthion-ethyl (Lucijet™); the fungicide thiram; and the anticoagulants Ratsak™ and Racumin™ (Ryan and Jones 1972).

'The use of strychnine has been progressively restricted since the 1980s.'

Because of its effectiveness, strychnine has been the most widely used chemical, but its use has been progressively restricted since the 1980s and ceased altogether when it threatened export market security in 1996. During the 1993–94 mouse plagues, farmers were given temporary access to strychnine for broadacre in-crop distribution in South Australia and Victoria, and again in the 1995 plague in Queensland and northern New South Wales.

Other chemicals have been approved at different times. For example, during the 1993–94 mouse plague, farmers were provided temporary access to the anticoagulant bromadiolone for use around the perimeter of crops in New South Wales

(T. Korn, NSW Agriculture, Dubbo, pers. comm. 1995). Bromadiolone-soaked grain was prepared by Rural Lands Protection Board staff and sold to farmers for distribution.

Until recently, thallium sulphate was available for controlling rats in sugarcane but it was withdrawn from sale because of concern over heavy metal residues in adjacent waterways. The anticoagulant brodifacoum has been registered to take its place. In hoop pine plantations pale field-rats are controlled with 1080.

6.2 Current government policy

Some rodents are declared pests under legislation in Western Australia, Victoria and the Northern Territory and landholders may be directed to undertake control measures. In other states and territories there is no legal requirement that they be controlled (Table 10). Introduced species can be controlled at a landholder's discretion and it is illegal to release them into the wild. Native species are protected wildlife and cannot be suppressed without permission of the wildlife authorities.

In each state and territory, there are health regulations that relate to rodent control. An authorised health officer may give 'reasonable directions' to the owner or occupier of premises to destroy any rats and mice on those premises or to rectify conditions that are conducive to their breeding. In New South Wales, control of introduced species is limited to declaration under the *Rural Lands Protection Act 1989*.

The use of chemical poisons is constrained by regulations in all states and territories. A number of rodenticide poisons are registered and these may be used in and around buildings, animal sheds and storage facilities (Appendix A). The only rodenticide registered for in-crop use is the anticoagulant rodenticide brodifacoum which may be used in sugarcane. An application to the National Registration Authority (NRA) for registration of zinc phosphide for in-crop use is in preparation following its widespread successful use under permit during mouse plagues in Queensland, New South Wales, Victoria, South Australia and Western Australia in 1997. No rodenticide is registered for use in orchards, but the use of anticoagulants in bait stations is allowed under permit issued by the NRA in macadamia plantations in New South Wales. No chemical is registered for use in grain crops, although temporary access through enactment of emergency legislation may be given during mouse plagues.

The administration of the different Acts relating to rodent management falls within different state and territory government agencies. Consequently, considerable liaison between departments is necessary to implement management strategies at a government level. Relevant state and territory government policies are described below.

'State and territory government agencies are responsible for administering the different Acts relating to rodent management.'

6.2.1 Victoria

The following policy statement, taken from the Agriculture Disaster Manual (Department of Agriculture, Victoria 1992), represents standing arrangements for the Victorian Government's response to an actual or potential mouse plague, to be implemented at the discretion of the Minister for Agriculture. The policy statement is under review following Departmental restructure.

"The Department of Agriculture will be the lead agency for implementation of government policy for mouse plague management in Victoria.

Government role in mouse population control/damage reduction will be as follows:

(a) Provision of appropriate information and advice to all sectors of the community;

(b) action to facilitate supply of appropriate chemicals as required both through government agencies (as provided) or commercial outlets;

(c) monitoring of mouse population characteristics and social, health and economic effects of mouse populations to assist development and recommendation of appropriate strategies;

(d) independent evaluation of control strategies in the interests of availability of unbiased information to the community;

(e) continuing assistance with appropriate technical and economic research relating to mouse biology, control strategies, community health, and economic loss; and

(f) liaison with relevant Victorian, interstate and national organisations.

The Department, as lead agency will convene a Standing Committee representing the following agencies: Department of Agriculture, Department of Conservation and the Environment, Health Department Victoria, Community Services Victoria and Department of Local Government.

Functions of the Standing Committee

(a) Provision of policy and technical advice to government through the Minister for Agriculture;

(b) recommendation of appropriate strategy for government response given circumstances in evidence at any given time;

(c) implementation of agreed strategy through relevant agencies;

(d) evaluation of effectiveness of agreed strategies; and

(e) co-option of additional agency representatives as required.

As far as practicable, strategies adopted will be consistent with national approaches to mouse plague control.

In the event that a threat of expansion of mouse populations to plague proportions exists, then:

(a) control of mouse populations on privately owned-leased/occupied land to be the responsibility of, and at the discretion of the owner/lessee/occupier, insofar as Health regulations permit such discretion;

(b) control of mouse populations on land for which responsibility is vested in a public authority to be the responsibility of, and at the discretion of the public authority, insofar as Health regulations permit such discretion;

(c) control of mouse populations in Victoria will not be undertaken by government agencies, other than [those listed above], or with the specific direction of the Minister for Agriculture in consultation with other appropriate Ministers;

(d) Government may supply appropriate chemical(s) for approved uses to rural communities in the form of mixed baits on the following basis:

   — recipients to supply bait materials and containers;

   — levy of charges to represent full recovery of government costs; and

   — supply of chemical(s) will be in accordance with prescribed regulations, and will be at the discretion of the Minister for Conservation and the Environment in consultation with the Minister for Agriculture.

Agency Responsibilities

Department of Agriculture

- Convene Standing Committee.
- Liaison/coordination with other agencies.
- Initiate special funding requests.
- Facilitate Victorian supplies of rodenticides from local or overseas sources.
- Initiate necessary chemical registration procedures.

- Initiate additional training programs for key staff.
- Coordinate preparation, and publish information bulletins inclusive of inputs of all relevant agencies.
- Lead agency in providing extension advice to rural communities.

Department of Conservation and the Environment

- Monitor research data on population characteristics.
- Evaluate mouse population control methods.
- Supply rodenticides to the rural community within policy guidelines.

Health Department Victoria

- Monitor health issues and provide advice as required.

Community Services Victoria

- Monitor social welfare issues and provide advice and assistance as required.

Department of Local Government

- Coordinate advice/information between Standing Committee and local government Municipal Health Surveyors to take lead role in extension advice to town communities."

6.2.2 Queensland

At the time of the mouse plague on the Darling Downs in 1995, the Queensland Government had no formal policy on management of a plague but a very similar strategy to the Victorian Government Standing Committee was adopted. A Task Force was convened to oversee the broadscale strychnine baiting, chaired by the Department of Lands (now the Department of Natural Resources) and included delegates from the Departments of Primary Industries, Health, Environment and Heritage and Treasury and representatives from the Queensland Grain Growers Association and the Wildlife Preservation Society.

The Queensland Department of Natural Resources is, at the time of writing, preparing a policy document, a recent draft of which states:

"The Department of Natural Resources will:

(a) monitor rodent populations on the Central Darling Downs and provide short and long-term predictions of the potential for plague development;

(b) provide grain growers with technical advice on best practice mice control strategies;

(c) undertake research to support the registration of rodenticides suitable for in-crop baiting of mice;

(d) undertake research into effective and integrated long-term management strategies for the control of mice in farming areas;

(e) accept responsibility for coordinating large-scale emergency mice control operations;

(f) collaborate with industry (for example, the Queensland Grain Growers Association), State Departments (Primary Industries, Environment and Health), interstate counterparts and research and development corporations, including CSIRO, as necessary to satisfy Queensland's requirements for mice control consistent with national standards; and

(g) cooperate with industry and other organisations in the development of control options for other rodent species, subject to availablity of funding.

The Department of Natural Resources will not:

(a) declare any rodent species [a pest under the *Rural Lands Protection Act 1985*]."

6.2.3 South Australia

The South Australian Government has no formal policy statement on mouse plagues although it also adopted a very similar format during the 1993 mouse plague to the Victorian Government Standing Committee described in Section 6.2.1.

Under South Australian legislation, pest rodents are included in the *Animal and Plant Control (Agricultural and Other Purposes) Act 1986*. The three introduced species, *Mus domesticus*, *Rattus rattus* and *R. norvegicus* are not proclaimed as pest species as landholders would then be required to control them. They are, however, included in the Class 7 list of species under Section 44 which prohibits the release of proclaimed species into the wild by a wilful or negligent act. Section 44 carries penalties of a fine up to $2000 or up to six months in gaol. The Act was reviewed in 1995 but at the time of writing, the amendments have not been approved by Parliament.

The sale and supply of rodenticides in South Australia is covered by the *Agricultural Chemicals Act 1955*. While there is currently no legislation on use in force, steps are well advanced to remedy this.

6.2.4 New South Wales

The New South Wales Government has no comparable policy statement on mouse plagues to that of Victoria. An operational procedures manual, however, has been drafted for use in a mouse plague. The manual covers legal, staffing and safety requirements, risk assessment, bait distribution, mapping and communication including with media (Croft 1997). No legislation in New South Wales currently requires landholders to control rodents. An Amendment to the *Rural Lands Protection Act 1989* allows communities to 'declare' pests in a district. If such a declaration on mice were supported by the Minister, landholders would then be legally required to control mice.

Use of pesticides for mouse control in New South Wales is regulated under the *Pesticides Act 1978*, which outlines the conditions for use of pesticides. In addition the *Threatened Species Conservation Act 1995* provides a mechanism to ensure that threatened fauna (and flora if applicable) are not harmed by control practices to a significant extent[6]. Before a government agency in New South Wales can approve a mouse control program it must apply the test contained in Section 5A of the *Environmental Planning and Assessment Act 1979*. If this shows that the program is likely to have a significant effect on any listed threatened species, population or ecological community or its habitat (listed in Schedules 1 or 2 of the *Threatened Species Conservation Act 1995*) then a species impact statement must be prepared to allow the Director General of National Parks to decide whether to grant concurrence or issue a licence for the action.

6.3 Other government roles

State government agencies assist with advice and information sheets on aspects of rodent control. Government agencies are also ideally placed to conduct, coordinate and collate monitoring data, and provide feedback and support to landholders. Unfortunately, resources are not always available for this. The only government agency to undertake regular monitoring of mice is the Queensland Department of Natural Resources, although it is widely recognised as desirable. The methodology for monitoring in Queensland was set up by S. Cantrill and J. Wilson

6 New South Wales Agriculture submitted a Fauna Impact Statement (FIS) to the New South Wales National Parks and Wildlife Service for their consideration prior to the issuance of the Temporary Pesticide Order for the use of bromadiolone during the 1993–94 mouse plague in the State (T. Korn, NSW Agriculture, Dubbo, pers. comm. 1995). A Review of Environmental Factors was submitted as an amendment to the FIS for the 1995 strychnine aerial baiting and a similar document prepared for the potential registration of zinc phosphide.

(Queensland University of Technology) in 1982 and has been successful in giving advance warnings of mouse plagues on the Darling Downs. Trapping is undertaken in June, September, October and November on an established transect across the Darling Downs. Each time, data on numbers of mice caught, their age and reproductive condition are entered into a model which estimates the probability of a plague in the following summer months. The system has proved to be a good predictor of plagues and only failed when weather conducive to the build-up of mice over parts of the Downs was not experienced within the established transect. The probabilities are forwarded to the Queensland Grain Growers Association.

'Government agencies may conduct, coordinate and collate monitoring data, and provide feedback and support to landholders.'

Monitoring has been undertaken by government staff in other states at various times but it has been difficult for government agencies to find resources to continue trapping programs through non-plague years. In the Mallee region of Victoria, CSIRO research projects have provided information on rodent numbers over the last 10–15 years which has given warning of plagues in that area. In South Australia, the Department of Primary Industries conducts trapping in response to farmers' reports of high rodent numbers. In New South Wales, monitoring by bait cards (Sections 7.1 and 7.2.2) has recently been introduced (D. Croft, NSW Agriculture, Wagga, pers. comm. 1997). Fifty farmers peg out bait cards every three months and report the level of activity recorded by the cards to local Livestock Protection Officers.

At various times, government agencies have directed considerable funds towards rodent research. In particular the need for a suitable in-crop acute rodenticide has been recognised and research is in progress on the potential value of zinc phosphide (Parker and Hannan-Jones 1996; G. Mutze and R. Sinclair, Primary Industries South Australia, Adelaide, pers. comm. 1997) and brodifacoum for controlling mice.

Table 10: Status of pest rodents in Australia.

	NSW	QLD	WA	TAS	VIC	SA	ACT	NT
Status of the rodent	All introduced rodents unprotected	No rodent species declared a pest	*R. villosissimus* only declared a pest	No rodent species declared a pest	All introduced rats and mice other than domestic types including *R. rattus*, *R. norvegicus*, *M. domesticus* are prohibited pest animals	Class 7 – wild rats and mice proclaimed for entire state	No rodent species declared a pest	*R. rattus*, *R. norvegicus*, *M. domesticus* declared pests
Agencies responsible for management	New South Wales Agriculture; Rural Lands Protection Board; Environment Protection Authority; National Parks and Wildlife Service	Department of Natural Resources (was Department of Lands); Department of Health	Conservation and Land Management; Agriculture Western Australia; Local Councils	Local Government	Department of Natural Resources and Environment; Department of Human Services; Local Government	Animal and Plant Control Commission; Primary Industries South Australia; South Australian Health Commission	ACT Parks and Conservation Service	Parks and Wildlife Commission of the Northern Territory
Landowner or occupier responsibility	Limited to declaration under the *Rural Lands Protection Act 1989.*	Destruction and elimination of harbourage and food sources.	Declared animals to be reported to the above agencies. For all other species, take measures as directed by the Local Councils' Environmental Health Officer.	Reduce problem when directed; protect food in commercial premises.	It is illegal to keep, move or sell prohibited pest animals. There are no legal obligations for control of domestic types except where directed by relevant health authorities.	It is illegal to move, keep, sell or release proclaimed species into the wild.	Nil (rodent plagues are not considered a problem in the Australian Capital Territory).	Illegal to release pest species into the wild. May be directed to undertake control measures.
Relevant legislation	*Pesticides Act 1978; Environmental Planning and Assessment Act 1979; Rural Lands Protection Act 1989; Threatened Species Conservation Act 1995*	Queensland Health Regulations 1996 under the *Health Act 1937;* Poison Regulations 1973; *Rural Lands Protection Act 1985*	*Health Act 1911; Agriculture (and Related Resources) Protection Act 1976*	*Public Health Act 1962; Local Government Act 1993*	*Health Act 1958; Flora and Fauna Guarantee Act 1988; Catchment and Land Protection Act 1994; Agricultural and Veterinary Chemicals (Control of Use) Act 1994*	*Animal and Plant Control (Agricultural and Other Purposes) Act 1986; Agricultural Chemicals Act 1955; Controlled Substances Act 1984*	*Land (Planning and Environment) Act 1991*	*Territory Parks and Wildlife Conservation Act 1994*

7. Techniques to measure and control abundance and impacts

Summary

To manage rodents effectively, techniques are needed to assess changes in their abundance. Rodent numbers can be monitored by trapping. The most common method is to use changes in total trap success or in re-trap success of marked individuals to develop an estimate or index of density. Rodent numbers can also be monitored by placing oil-soaked paper cards in fields and recording the proportion of each card eaten overnight. Counts of burrows, nest sites, crop damage or numbers of rodents on roads or around buildings can also provide density indices. Although these techniques give only rough approximations of rodent densities, they are usually adequate to allow farmers to determine when numbers are increasing and control needs to be implemented. Whatever method farmers select for monitoring rodent numbers, it is important that the data be recorded in a standardised format across local regions so that the results from different farms are comparable.

A means of linking rodent abundance to potential impacts is required. Such information is sparse. Data are also needed on the link between damage and yield loss. Although rodents may damage the vegetative part of plants, allowances must be made for compensatory growth by the plant which reduces the effect of plant damage on final crop yields. The economic losses associated with different levels of rodent damage will depend on the extent of such compensatory regrowth. Measures of damage and yield losses are essential for estimating the efficacy and cost–benefit of control techniques. The best assessment of economic damage is a comparison of crop yields with and without rodent impact.

Rodents in both urban and agricultural environments are still predominantly controlled by rodenticides. There are two main categories of rodenticides: acute or fast-acting poisons which start to act and often kill within 24 hours following a lethal dose (such as zinc phosphide); and chronic, slow-acting poisons such as anticoagulant compounds. The majority of rodenticides are administered as poisoned baits around crops and buildings. Baits are prepared by mixing the active poison with an edible base attractive to rodents and they may be presented as commercial pellets, wax blocks or coated cereal grains.

Habitat manipulation may also be effective in controlling rodent numbers. Areas with good cover and food act as donor habitats from which rodents disperse into crops and pastures. Strategies for reducing rodents in donor habitats include grading down, spraying or slashing grass and weeds along fencelines, roads and channel banks, and around sheds and storages to reduce seed set and remove harbour. Where erosion is no threat, pastures can be grazed lightly and frequently throughout spring and summer to reduce the amount of seed set and cover. Similarly, stubbles can occasionally be grazed or burnt. Reducing cover is likely to increase the rate of rodent mortality from predation and extremes of weather.

Management techniques suitable for controlling mouse damage in cereal crops include not sowing grain until soil is moist enough to allow rapid germination, planting seed at a higher rate to compensate for possible losses to mice, planting deeper so that it is harder for mice to find the seed, and cross harrowing after sowing to obliterate the furrows. Farmers can reduce the amount of grain spilt at harvest by efficient harvesting and also by grazing stubbles.

Rodent-proofing buildings and storages is expensive and difficult unless incorporated at the construction stage. As rodents tend to gnaw, construction materials must be concrete, brick or metal. Doors must fit well and be kept closed.

Trapping is useful for removing rodents in and around buildings and storages. Control by chemical repellents tends to be short-lived and of little practical value. Many studies have also rejected ultrasound as a useful control method. Chemicals used for fertility control are of little practical value because high levels of sterility would need to be maintained whenever environmental conditions were suitable for breeding. If virally-vectored immunocontraceptive techniques currently being researched prove successful, fertility control may become a practical management option, but it is still too early to tell if this technique will work.

It is likely that effective rodent control will require a combination of techniques. Farmers need reliable information on the efficacy, cost-effectiveness and acceptability of different control measures so they can devise appropriate strategies.

7.1 Estimating abundance

Many techniques are available for estimating the density of rodents (Davis 1956; Brooks et al. 1990; Fiedler 1994). The best methods are based on trapping. Other quantitative techniques include use of bait cards, counts of burrows and rate of bait removal. Extent of crop damage is another possible indicator, although signs of damage may easily be overlooked. Qualitative methods (for example, sightings of mice and numbers of predators) are less satisfactory.

Trapping

Three methods can be used to estimate densities of rodents by trapping:

1. *Trap success* — Number caught (or per cent trap success) is the most commonly used density index. Any type of trap can be used. For single-catch traps (for example, break-back traps), a minimum of twenty is set overnight in an area and the index of density is the percentage of traps that catch an animal.

Number of traps set	= 50
Number of mice caught	= 10
Trap success = (10÷50)×100	= 20%

This method is currently used by the Queensland Department of Natural Resources for monitoring mouse numbers at 42 sites (20 traps per site) on the Darling Downs. At low rodent densities, it is a good indicator of relative abundance. However, the relationship between density and per cent trap success is curvilinear because once a trap has caught an animal, it cannot catch another (Figure 9). A correction factor can be applied (Caughley 1977), but the precision of the index declines as the percentage of traps fired rises. During plagues, trap success often exceeds 90% and the index is no longer useful.

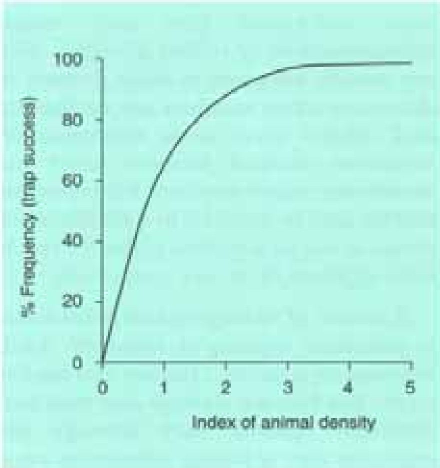

Figure 9: Relationship between frequency (per cent of single-catch traps catching an individual) and density of trapped populations (Caughley 1977).

2. *Mark–recapture* — The mark–recapture method requires live-trapping carried out twice (Petersen index) or three times (Bailey's triple catch) (Caughley 1977). All animals caught on the first occasion are marked and released. On the second (and third) occasion, the number of marked animals caught relative to the total number caught can be used to estimate population size. The method is used regularly in

ecological studies but it requires that some of the animals marked are recaptured. Above densities around 500 per hectare, mice are so numerous and become so dispersive that rate of recapture is exceedingly low and the method is generally unsatisfactory.

3. *Removal trapping* — Measuring density by the removal trapping method requires that traps are set for six to ten nights and the number caught per day is plotted against the cumulative total up to that day (Leslie's method) (Caughley 1977; Brooks et al. 1990). A line is drawn through these points and the intercept on the y-axis gives an index of starting density. The method may be useful for estimating rat density in orchards.

As well as indicating rodent abundance, trapping provides a means of measuring the success of any control operation. An index of density is obtained before and after the control operation. The change in index indicates the level of success in reducing rodent numbers. Then, if the relationship between density index and damage has been determined, the effectiveness of the control operations for reducing rodent damage can be evaluated (Section 7.3).

All these methods have a number of assumptions that are easily violated (for example, no immigration and emigration during the measurement interval and equal trappability of all animals in the population). However, the indices they provide are probably adequate for monitoring rodent populations until research can develop a more accurate method (Section 10.2).

Breeding condition (body fat, lactation and pregnancy rates) are just as important as actual numbers when monitoring population increases as they indicate the potential for population growth (Section 2.3). For this reason trapping, which allows breeding condition to be assessed, has an advantage over other monitoring techniques.

'Trapping has an advantage over other monitoring techniques in that it allows breeding condition to be assessed.'

Other quantitative methods for estimating numbers

1. The *bait card* technique was developed during the 1969 plague by Ryan and Jones (1972). It was widely used during the 1993 mouse plague in Victoria and South Australia when squares of cardboard (10 centimetres by 10 centimetres) soaked in linseed oil were pegged out overnight in crops, stubbles and other mouse environments (Griffiths 1993; Mutze 1995). Baiting in Victoria was recommended if an average of 20% of the cardboard had been chewed. The technique was also used in Queensland during the strychnine baiting program in 1995 (Queensland Department of Lands 1995; Eldershaw 1996).

   The validity of the technique for estimating mouse numbers has not been substantiated and research is needed to correlate the data obtained by bait cards with that from quantitative trapping techniques. One difficulty with the technique is that when alternative food is available mice will not eat the bait cards.

2. Another possible index of local mouse abundance is the number of active burrow entrances in a unit area (for example, per 10 square metres). *Counts of active burrows* may be made in crops, in channel banks around irrigated crops, in grass verges and along fencelines or in stubble. Mouse holes along transects can be lightly covered over one day and those reopened recorded on the next day to give an index of abundance based on active holes. Alternatively, especially just after rain in light soil areas, freshly excavated soil at the entrance to a burrow shows that the hole is 'active'. Runways or trodden paths between burrows are also visible where

colonies are well-established. Mouse holes and runways are most easily seen in sandy red soils (for example, in the Mallee region). In cracking grey soils (for example, Darling Downs), the mice shelter in the cracks and burrows are less evident, although worn pathways can be seen entering the cracks when mouse numbers are high.

3. The *rate of removal of bait* (with or without poison) is another indicator of abundance. A known amount of bait is placed in a bait station, where it cannot be taken by other species, and the amount remaining the following morning is measured to give a quantitative index of abundance (Saunders 1983).

4. *Crop damage* is another possible indicator. For example, mice will dig out newly-planted seeds, chew on the stems of young plants and eat the seeds out of the maturing heads. Damage by mice is distinguishable from damage by insects or birds in that chewed husks, mouse droppings and other debris are visible around the base of the plants. When mouse numbers are high, these signs of damage are obvious but may be easily overlooked at other times. For this reason, crop damage is rarely a satisfactory indicator of mouse density. It is likely to be a better indicator for rats. For example, the proportion of canes damaged is used to measure the density of rats in sugarcane (Buckle 1994b). A similar technique could be used in orchards and hoop pine plantations.

Qualitative methods for estimating numbers

1. Mice do not only nest in burrows. Nests are also found under planks, in length of pipes and other similar environments. *Monthly monitoring of nest sites* for signs of mice is a simple task and has the added advantage of detecting whether mice are breeding. The repeated presence of young in nests in summer and autumn indicates the potential for a build-up to plague densities.

2. *Sightings of mice* on roads and tracks at night and in homes and sheds may be an indicator of high population levels. However, it is important to recognise that mouse numbers fluctuate annually and there will always be more at the end of the breeding season. In addition, mice are often most noticeable in winter when they move into homes and sheds seeking food and shelter from the cold. An influx at these times does not necessarily imply that numbers are approaching plague densities.

3. Another indicator of a build-up is an increase in the *number of predators* (such as raptors, foxes and snakes). For example, several raptors feeding in a particular area can be an indication of high mouse numbers, as can the presence of fox tracks in a crop. However, predators are generally slow to respond to a change in rodent populations. As Saunders and Korn (1984) comment, mice have usually reached plague proportions by the time there is a noticeable increase in predators.

4. In buildings and storages the *number of rodent droppings* or *carcasses* may be a useful indicator of abundance (Buckle 1994a).

   Sales of commercially available rodenticides through retail outlets can also provide an indication of rodent abundance on a local scale.

7.2 Monitoring numbers to predict mouse plagues

7.2.1 Causes of mouse plagues

Hypotheses on the causes and triggers for mouse plagues are discussed in Section 2.3. However, local variations in climate, soil type, crops and farm management systems make it impossible to predict where mice will reach plague proportions in a given region. It is necessary that landholders conduct regular monitoring of mouse numbers on their properties to obtain advance warning of build-ups so that control techniques can be implemented before numbers reach plague densities.

7.2.2 Landholder monitoring programs

Monitoring and record keeping is becoming an integral part of best farm practice. Incorporating records of abundance into an existing crop monitoring program is the preferred approach for maintaining awareness of rodents and the problems they pose. In the 1990s, networks of self-help crop monitoring groups have been established by grain growers to monitor crops at various stages of development. These innovative landholder programs are coordinated by regional state government agricultural officers. One such monitoring program is TOPCROP, funded by the Grains Research and Development Corporation (GRDC). Similar programs are run within private consultancy or farmer groups. Under each program, information on crop condition is recorded by farmers on score sheets in a standardised format. If mouse monitoring were included on these score sheets, it would provide an excellent method for maintaining farmer awareness of rodent numbers and detecting changes in their abundance (Section 10.2). Standardised recording allows comparisons between properties, districts and regions.

'Ideally, mouse monitoring systems should be incorporated into general crop monitoring programs.'

In areas where there are no crop monitoring groups, other local groups such as Landcare groups could coordinate monitoring activities. Groups formed specifically to monitor mice are less likely to be able to sustain grower interest in monitoring when mice are at low densities. Where possible, it will always be preferable to incorporate a mouse monitoring system into a general crop monitoring program that encompasses the whole spectrum of pests and crop condition. Rodent monitoring should become part of routine farm management.

Farmer monitoring for mice

If farmer monitoring for mice is encouraged in a local group program, there are a number of options that may be used to measure the abundance of mice in paddocks. These options may vary according to the stage of crop development.

Up to crop flowering, farmers may:

- count the number of active mouse holes seen on a metre wide strip each side of a 100 pace transect in from the edge of a crop[7];
- count the number of runways or tracks on a metre wide strip over 100 paces through the centre of a crop or along the edge of a crop;
- place a weighed amount of grain in a series of bait stations (for example, an icecream container with holes cut in the sides to give mice access to bait covered with bags or sheets of iron) in or around crops. Weigh remaining grain on following day;
- take five squares of paper, each 10 square centimetres, ruled up into 100 small squares and soaked in linseed or canola oil. Peg these paper squares (called bait cards, Section 7.1) around or in a crop overnight. Count the number of ruled squares that are chewed away by mice[8]; or
- set 20 break-back traps in a line through each crop or along the edge of crops at five-pace intervals and record the number of mice caught overnight.

After flowering, methods include:

- all of the above; plus
- counts of the number of damaged[9], bent or removed seed heads.

Monitoring signs of mouse activity in roadside vegetation and adjacent paddocks, and around buildings, may be as important as monitoring mouse activity in crops. Information should also be gathered in these areas.

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7 Only suitable for areas with soils where holes are obvious.

8 Research is needed to validate the accuracy of this technique for estimating numbers.

9 Need to distinguish between mouse damage and insect, bird or frost damage to seed heads.

Whatever method farmers select for monitoring mouse abundance and damage, it is important that the results are recorded in a standardised format by all farmers in the monitoring group to allow local patterns and trends to be recognised.

7.3 Estimating impacts

7.3.1 Estimating damage

Conducting damage assessment is essential for understanding the nature and extent of a rodent problem. As Buckle (1994b) states, damage assessments can be used to:

- estimate economic costs, so justifiable expenditure on control can be evaluated;
- determine damage distribution so control effort can be concentrated in areas where it is most needed;
- estimate efficacy of control methods, so different management strategies can be compared; and
- provide information for planning, such as allocation of funds for research and development programs.

Where feasible, damage should be measured by direct methods, for example the percentage of chewed tillers in random plots. Where direct measurements are not feasible, it may be possible to use indirect methods. For example, rat damage to oil palms has been calculated from an estimate of rodent density based on mark–recapture methods (Section 7.1), multiplied by the quantity of oil palm eaten per rat per day (based on laboratory feeding trials) (Buckle 1994b). At best, such methods provide only a rough approximation of the actual damage (Section 10.3).

Direct measurements require skill. For most grain crops at the pre-harvest stage, damage levels less than 5% are difficult to detect and damage levels less than 10% can be difficult to quantify by untrained observers. One of the main problems is that the damage tends to be patchy and its assessment requires complex sampling techniques. Statistical analysis is essential if valid conclusions are to be drawn from the data collected. Random sampling is usually adequate in uniform habitats. Where the environment in which damage is being measured is variable, sampling may need to be stratified so there is adequate representation of different areas. The number and size of samples required will depend on the type, level and pattern of damage. These techniques have been applied successfully by Singleton et al. (1991) and Mutze (1993a) in soybean and wheat respectively.

'For most grain crops at the pre-harvest stage, damage levels less than 5% are difficult to detect.'

Damage to stored produce may be quantified by measuring the number of items eaten, chewed or infested. Indirect methods, such as described above using estimates of rodent numbers (using trap success or mark–recapture, Section 7.1) and multiplying this figure by an estimate of the quantity of food eaten per day, are unsatisfactory since much rodent damage is due to contamination or destruction, rather than consumption, of stores.

7.3.2 Relationship between damage and yield loss

The correlation between damage assessment after flowering and yield loss has been examined by Mutze in wheat (Mutze 1993a), but most assessments of yield loss are subjective. For example, the extent of damage in the 1993 plague presented in Section 3.1 was based on landholder estimates of production losses (Footnote 3 Section 3.1.1). These may be inaccurate since some crops can recover if damage occurs at particular times during the vegetative stage (Wood 1994). According to Buckle (1994b) young rice plants can fully compensate for destruction of up to 60% of growing tillers. Tobin et al. (1993) suggest macadamia trees may compensate for rat damage by retaining nuts that might otherwise have dropped prematurely. The extent to which the plant can compensate depends on the level of rodent damage and its timing.

Alternatively, a small level of rodent damage to a crop may cause yield losses far in excess of that caused directly by the rodents — for example, if the damage leads to bacterial or fungal infections. Due to the complex relationship that may exist between the level of damage and actual yield loss, care needs to be taken in the interpretation of damage sampling. For example, Williams (1974) categorised coconut palms according to the level of damage they sustained, and then monitored nut yields and found no apparent difference in yield between palms that sustained low and high levels of damage. This was because damaged palms increased flower production which compensated for nuts lost due to rats. There is an obvious need for experimental trials, with and without rodent damage, to ascertain yield losses. This may be achieved either by exclosures or by the application of reliable control measures (Section 7.4; Wood 1994). Exclosures are expensive and are a tool suitable only for research. Comparing areas with and without rodent control can be done between similar crops or between years with and without rodent problems. In some cases, however, variation of other factors which affect yield must be taken into account (for example, weather, other pests and cultivation techniques).

Other factors that may need to be taken into account when assessing yield loss are a downgrading in the quality of the produce due to rodent damage (Wood 1994) and the effect of delays in harvest, both of which add to the economic effect of direct yield loss.

Measures of damage are essential for estimating the effectiveness of control measures (Section 7.4.5), and whether their cost is economically justified by returns in increased yields. Figure 10 shows a comparison in rodent damage levels to fruit on brodifacoum-treated and untreated experimental control plots. Clearly the treatment reduced rodent numbers and damage to fruit.

'Measures of damage are essential for estimating the cost-effectiveness of control measures.'

7.4 Control techniques

Integrated pest management is the key to effective rodent control. Control is most likely to be effective if a number of management techniques are combined although the increased costs of using more than one technique needs to be weighed against the benefits. A range of options are available including poisoning, habitat manipulation and trapping .

7.4.1 Poisoning

Rodenticide chemicals are still the mainstay of all practical rodent control programs in both urban and agricultural environments although the benefits of non-chemical methods are increasingly being recognised. Appendix A gives a description of rodenticides that are, have been, or have the potential to be, used for the control of agricultural pest rodents in Australia. Examples of their use in integrated pest management for rodents are given in Section 8.8. Section 8.8.1 discusses the use of poisons to prevent and control damage caused by mouse plagues in cereal-growing regions. Section 8.8.2 describes the use of poisons to reduce damage caused by rodents in sugarcane. Information on the agricultural applications of rodenticides is given in Appendix A (Table A2). Reference should be made to relevant state authorities for specific applications permitted at the time of use.

The majority of rodenticides are administered as poisoned baits. There are two main categories of rodenticides: acute or fast-acting poisons which start to act and often kill within 24 hours following a lethal dose; and chronic, slow-acting poisons such as anticoagulant compounds (Appendix A; Buckle 1994a). Genetic resistance to 'first

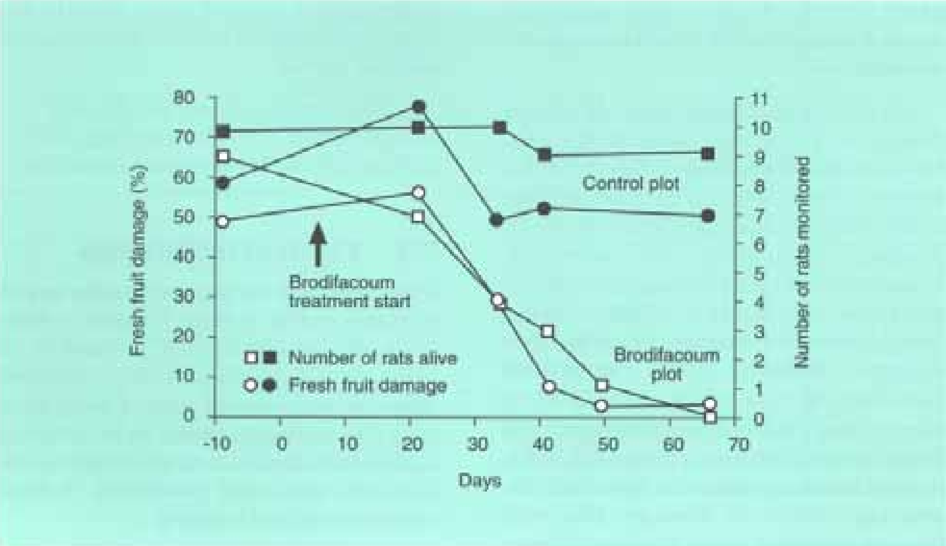

Figure 10: Survival of radio-tracked rats and levels of fresh fruit damage on brodifacoum-treated and untreated experimental control plots (after Chia et al. 1990 in Buckle 1994a).

generation' anticoagulants, such as warfarin and pindone, has been recorded in many rodent populations (Saunders 1978) and in some situations use of these chemicals may be unsatisfactory. Resistance to 'second generation' anticoagulants, such as brodifacoum and bromadiolone, has been recorded in rat populations in some parts of the world (Buckle 1994a), but has not yet been demonstrated in Australia and they are still satisfactory rodenticides.

In addition to standard rodenticide baits, other poisoning options include the use of fumigants, liquid baits, contact or grooming toxicants, tracking powders, rodenticide gels and impregnated wicks.

Baits

Baits are prepared by mixing the active poison with an edible base attractive to rodents. Baits may be presented as commercial pellets, wax blocks or coated cereal grains. In the last case, high grade grain should be used; it is a false economy to use poor quality grain because of low acceptance.

Compounds must be sufficiently toxic to act at concentrations that are not unpalatable to target species. The speed of action is also important. Rodents are unlikely to consume a lethal dose of a poison if the onset of toxicosis is too rapid (Buckle 1994a). Problems can also occur if the concentration of poison in bait is too low. If the dose an animal receives makes it sick, it may learn to avoid the bait in the future. Therefore it is important that baits contain an appropriate concentration of rodenticide.

Laboratory studies have shown that mice can feed from up to 20–30 different sites each night, eating only a little at each location. An effective baiting strategy for mice is therefore likely to be one where small quantities of bait are placed at a large number of sites (Macdonald and Fenn 1994). This technique will also ensure that subordinate animals in a population have access to the baits.

Appendix B describes the use of poisons for managing rodent problems in and around buildings and storages. When using anticoagulant poisons around sheds and storages, it is advisable to conduct pulse baiting since rodents will continue to feed on baits over the several days it takes for the poison to act. If pulse baiting is not conducted, overconsumption of bait adds to the expense and increases the risk of secondary poisoning of predators. Rodents preferably should have access to bait for two or three nights only. To ensure that each animal receives a lethal dose, a large quantity of bait should be provided in a number of bait stations on these baiting occasions. The remaining bait is then removed and the procedure repeated at regular intervals until there is no further evidence of rodent activity.

Other formulations

Dust and gel formulations are available as contact poisons that can be applied in burrows, harbourages and around buildings and storages (Buckle 1994a). The poison is ingested from fur and feet during grooming. An advantage is that, unlike baiting, intake is not affected by the availability of alternative foods. Contact gels are usually applied to toxic wicks in tunnels. These preparations usually carry a much higher concentration of rodenticide than baits, so non-target safety is an issue, particularly if particles can become airborne.

Other formulations are presented in water. Black rats (*Rattus rattus*) need access to water to survive and may be poisoned by addition of a rodenticide to a drinking station. In this situation, great care is needed to keep non-target species away from poisoned water.

Poisonous gases (fumigants), such as phosphine, can be used where an infestation is in a small area which can be sealed (for example, appropriately constructed feed stores or bulk grain storage facilities). Fumigants can also be used in rat burrows. Fumigation is hazardous and should only be conducted by skilled operators.

Registration

The only rodenticides that may be used are those registered by the National Registration Authority (NRA). Appendix A (Table A2) lists the rodenticides that are registered for use around buildings. Some of these rodenticides have also been approved for use in some states for perimeter baiting and one, brodifacoum, has been registered for use in sugarcane. For other crops, in-crop baiting is an option only if a landholder has been given temporary access to a rodenticide under state legislation. At the time of writing an application for registration of zinc phosphide for in-crop baiting is in preparation. Registration of a range of poisons for broadacre use would be valuable so that the most appropriate rodenticides could be used at a particular time. A variety of rodenticide options would also reduce the risk of resistance, bait avoidance and use of other chemicals by farmers in the absence of an available alternative. Research is continuing into the safety of alternative rodenticides for in-crop baiting.

Residues and non-target risks

Regulatory authorities need to ensure that rodenticides are not persistent in terrestrial and aquatic systems, or in agricultural products, and that there is no likelihood of other adverse effects on the environment. The use of illegal poisons, or off-label use of legal poisons, poses unacceptable risks.

Because Australia needs to maintain a 'clean and green' image for its agricultural produce, it is important that more research is conducted on residues, particularly where poisoning is conducted in-crop or near waterways. There is a widely accepted standard approach for evaluating the risk rodenticides and their residues pose to non-target species (Brown et al. 1988; Brown 1994). All rodenticide approvals given by the NRA consider environmental impacts including an evaluation of non-target susceptibility.

Many rodenticide registrations that were current when the Commonwealth *Agri-*

culture and Veterinary Chemicals Code Act 1994 was introduced in Australia were accepted without testing. Hence there has been little research on non-target impacts and residues for some rodent poisons currently used in Australia. For future rodenticide registrations, full testing will be required.

It has proven virtually impossible to develop a rodent-specific poison, and therefore non-target species may be poisoned if they are exposed to baits (Section 4.3.2; Buckle 1994a). Granivorous birds are particularly susceptible. Also species that prey on rodents may be poisoned indirectly. Rodenticides that are rapidly broken down in the bodies of rodents after ingestion reduce the risk of indirect poisoning of predators.

'Use of illegal poisons and off-label use of legal poisons pose unacceptable risks.'

People and dogs may accidentally ingest rodenticides because of the commensal behaviour of introduced rodent species. The availability of an antidote for treating accidentally poisoned animals or people is desirable. Few acute rodenticides have a specific antidote and even if one exists, the rapid action of most acute rodenticides means there is little time for its administration. This lack of an antidote, combined with the high toxicity of most acute rodenticides, enhances the risk to people and other non-target species and has led to limitations on their use (Buckle 1994a). Anticoagulants, with their slow mode of action and available antidote (Vitamin K), are much safer. Another safety strategy is to incorporate compounds into baits which will decrease the risk of accidental poisoning of people. For example, rodents appear to be unable to taste, or at least are not repelled by, some compounds that humans find unpleasant (for example, Bitrex™ — denatonium benzoate).

Regulatory authorities also require that the use of rodenticides will cause no risk of abortifacient (causing abortions), teratogenic (causing abnormal foetuses), oncogenic (causing tumours) or carcinogenic (causing cancer) effects for people or non-target species. Anticoagulants generally produce no carcinogenic or teratogenic effects, although there is evidence warfarin may adversely affect human foetal development (Buckle 1994a).

Animal welfare

Animal welfare agencies consider that it is desirable to make a balanced evaluation of the benefits of using a rodenticide against the cost in terms of suffering inflicted on the target and non-target animals and in comparison with alternative control options (Sections 5.3 and 8.4.4). In Australia the NRA attempts to consider animal welfare issues when assessing applications for approval to use rodenticides.

Efficacy

People managing pest rodents need information on the cost-efficacy of using different poison types and application techniques so they can plan appropriate control strategies (Sections 7.4.5, 8.4 and 8.7). Direct baiting with no pre-baiting in and around agricultural crops is the normal practice. There is, however, little information on the cost-efficacy of this approach.

7.4.2 Habitat modification

Rodent numbers may be manipulated by changes in agricultural practices or land use. For example, habitats may be modified to reduce or prevent build-ups. Rodents need habitat with good cover to protect them from predators and bad weather. Mice are more abundant in undisturbed areas such as roadside verges and fencelines (Twigg and Kay 1995; Chambers et al. 1996). These areas of refuge habitat act as a 'donor habitat' from which mice disperse across the landscape into crops and pastures (Mutze 1991).

Other donor habitats include areas where weeds or rubbish are allowed to accumulate; buildings including animal houses; and grain, hay and food storages

Source: R. Eldridge, DNRE

Controlling weeds and grasses along fencelines by spraying or slashing reduces mice harbour and has a number of incidental benefits.

Source: R. Eldridge, DNRE

Correct sowing rate, depth and timing can reduce the impact of mice.

(Singleton 1989). To prevent the build-up in mouse numbers and therefore reduce the impact of rodents on crops, it is essential to manage these donor habitats.

Reducing mice in donor habitats

Reducing mice in donor habitats involves removing weeds and debris around crops, buildings and storages and controlling growth along fencelines, channel banks and roads by grading, ploughing, burning, grazing or applying herbicides (Saunders and Korn 1984). It is important to ensure that there are no undisturbed areas where rodents can shelter. Attention to grain, hay and food storage areas is also important. Hessian and paper packaging should not be used. Bags of seed and other food are best stored off the ground, or better still, in rodent-proof containers (Meyer 1994). Areas around storages, piggeries and poultry sheds should always be kept tidy and free of spilt grain or other food sources for mice. Occasional trapping or baiting with anticoagulant rodenticides may be warranted around feed sheds. Temporary grain or hay storages should be located away from growing crops to minimise the potential for colonisation from these sites.

Reducing rats in donor habitats

The same principles as those given above for mice are applicable to rats. In sugar-growing areas, slashing and spraying grass on headlands and maintaining weed-free crops are proven strategies for controlling rodent numbers (Wilson and Whisson 1987; Robertson et al. 1995). Cleaning up debris (including old or unmarketable produce) in orchards and around storages is broadly advocated as is controlling growth along fencelines and roads, particularly as predators such as raptors and foxes often hunt in these areas (see Box on Control of Rats in Macadamia Orchards).

Reducing mice through crop and stubble management

Undisturbed stubble can harbour mice. It appears that the progressive adoption of stubble retention and minimum tillage practices, along with the sharp increase in summer cropping in northern cereal-growing areas, has increased the amount of habitat and food available to mice, and plague frequency appears to be increasing as a consequence. Therefore crop and stubble management is important for reducing mouse numbers if this is compatible with conservation goals.

In cereal-growing areas, minimising grain spill at harvest by careful setting of combs and sieves is desirable. Introducing sheep to clean up spilled grain in stubble soon after harvest can be effective in reducing food for mice (Saunders and Korn 1984). Burning stubbles to remove cover is also frequently adopted, but exposes the surface to potential erosion and invasion by weeds. Hence careful consideration of all aspects is required before deciding to burn. Another management option that is occasionally used is working up stubbles or ripping pastures to break up the mouse burrows and to bury surface seed, but it is seldom cost-effective unless it is tied in with planned future land use for the particular area. Neither ripping nor burning are proven methods for reducing mouse numbers and neither are recommended practices for soil management. Research is needed into the effectiveness of these practices.

Management techniques recommended for managing mice at the time of sowing (Saunders and Korn 1984; Griffiths 1993; Mutze 1993b) include:

- not sowing grain until soil is moist enough to allow immediate germination so that mice have less time to find the seed before it germinates and grows beyond the susceptible stage;
- planting seed, particularly legumes, at a higher rate to compensate for possible losses to mice; and
- planting deeper (except for semi-dwarf wheat varieties) so that it is harder for mice to find seed.

CONTROL OF RATS IN MACADAMIA ORCHARDS

The primary method recommended for controlling rats in macadamia orchards is good hygiene (Table 11). Skirtings, prunings, old kernels, fruit and other refuse should not be dumped in or around the orchard but burnt or removed. Regular slashing of weed growth in the crop and control of vegetation in adjacent gullies or surrounds is also advised. For macadamia orchards, Barnes et al. (1989) recommend that barner grass, used as a windbreak for young trees, be cut down in September every second year and allowed to ratoon. When the trees are six to seven years old, these internal windbreaks should be removed.

There are a number of predators of rats, including carpet snakes (*Morelia spilota*), owls (*Tyto* and *Ninox* spp.), cats (*Felis catus*) and foxes (*Vulpes vulpes*). Carpet snakes in particular should not be killed as they are renowned for feeding on rats (Loebel 1995). Owls may be encouraged by constructing nesting boxes in and around orchards (Barnes et al. 1989; Smith 1994). Landholders need to ensure rodenticide use will not put these birds at risk (Sections 4.3.2 and 8.8.2).

Current management of macadamia crop damage caused by black rats mainly relies on the use of rodenticides in and around macadamia crops and, according to White et al. (1997), there is no evidence that this is a cost-effective way to reduce damage. These authors suggest macadamia damage could be greatly reduced by habitat manipulation of areas adjacent to crops with dense scrubland which harbours rats. White, J., Horskins K. and Wilson, J. (unpublished) found that when such habitat was reduced in three sites each with 125 metres of orchard frontage, damage in the adjacent area of orchard (each area being 25 trees by 7 rows) was reduced by 65% relative to two untreated sites. Their manipulation involved clearing scrub from the strip of land adjacent to the orchard in spring, to a distance of 20 metres away from the edge of the crop, and spraying the cleared land with herbicide to prevent regeneration through summer. The average cost of habitat manipulation was $292 for each site, and the savings in enhanced production was $980, resulting in a profit of $688 for each treated site.

Table 11: Seasonal calendar for rat control in macadamia crops (after Loebel 1995).

Activity	Time
Burn off gully areas.	July–August
Clean up fence and windbreak areas.	September–October
Remove lower limbs from mature trees. These prunings should be mulched and not left lying in the inter-row areas.	September–October
Carry out ground works around dams and drains to fill in holes and depressions.	September–October
Commence baiting program in windbreaks and vegetation on the edge of crops and in tree rows where rat activity may be noticed.	December
Remove bait stations from underneath trees prior to harvest.	March
Ensure that verges are slashed regularly over the wet season.	February–May

Other strategies for reducing the damage at sowing could include cross harrowing after sowing to obliterate the furrows since mice are reported to 'work' along furrows digging up the seeds. Prickle chains and diagonal rolling harrows can be used to obtain a similar effect. It is critical to ensure that seed drills are kept horizontal both fore and aft, and sideways, to avoid variable sowing depth. It is also desirable to plant crops only where surrounding areas can be cleared of potential harbour (Saunders and Korn 1984).

'Crop and stubble management is important for reducing mouse numbers.'

During the growing season, general management options include strategic baiting of the perimeters of sown paddocks and mouse refuge areas to prevent development of colonies or invasion of paddocks from adjacent areas (Section 7.4.1). Grazing paddocks adjacent to crops to reduce habitat for mice is also advisable at this time, provided the risk of erosion is taken into account. This practice will have the added advantage of reducing seed set.

Grain left behind in paddocks after harvest, through poor harvest technique or timing, is the single most important source of food for mice over the summer and autumn period, and will encourage a build-up in mouse numbers. Several management practices can influence the amount of food left for mice in stubble fields. Modern farm practices aim for a fast harvest to reduce seed shedding and the risk of rain damage. Harvesters should be fitted with a screen, and preferably a double screen, to capture broken and pinched grain and weed seeds. Where crops have been lodged by high winds or storms, it is important to use air fronts or lifters to lift the lodged stems when harvesting or grain residues left in paddocks can be particularly high. The problem of unharvested or spilt grain can be acute where the stubble is not grazed by livestock after harvest. When wool prices were high, sheep were often put into stubble fields to clean up shed and spilt grain after harvest. With lower wool prices this practice has been largely discontinued. Heavy and prolonged grazing is still, however, the most effective and cost-efficient method to reduce grain residues.

Enterprise substitution

If mouse numbers start to build up, farmers may consider planting crops that are less susceptible to mouse damage. In general, legumes are more susceptible to rodent damage than cereals (Caughley and Croft 1994). Oil seeds vary in susceptibility; for example, canola may be little damaged, whereas sunflowers can be heavily damaged. Even with cereal grains mice show preferences, with triticale being favoured over soft wheats, and soft wheats being favoured over harder varieties and barley. The location of crops relative to donor habitats is also important and may have as much influence on damage levels as the type of crop.

For intensive livestock producers, destocking is one option during mouse plagues, but the costs of destocking and restocking are high. Farmers usually choose to persevere with baiting and the constant care of stock. The aim of strategic control of mice should be to prevent the population build-up and not let the problem develop.

Encouraging raptors

An option that has been investigated both in Australia and overseas is the placement of raptor perches in or at the margins of crops to increase the level of predation on rodents (Howard et al. 1985; Kay et al. 1994b). While birds of prey cannot eat sufficient mice to prevent a plague (Sinclair et al. 1990), they may take enough over the summer to delay plague formation by several weeks. This is illustrated by a hypothetical example in Figure 11 in which the rate of growth for a population of mice with predation is compared with the rate when there is no predation.

The value of perches in increasing the number of raptors hunting over a crop and in slowing a build-up in mice was established in New South Wales by Kay et al. (1994b) using perches 2.5 metres high and 100 metres apart. In North America, however, Howard et al. (1985) found no significant reduction in the numbers of voles (*Microtus californicus*) or pocket gophers (*Thomomys bottae*) in lucerne fields even though raptors were using the perches as roosts and for hunting almost immediately after their erection. More research may be needed to validate this technique for controlling rodent numbers in Australia.

Erosion control

The problem of soil erosion in areas with sandy soils could be addressed by planting windbreaks. Windbreaks need to be properly constructed to prevent wind tunnelling which may exacerbate erosion of light soils. Windbreaks are a long-term solution but advantageous in that the trees will also provide perches and nest sites for raptors. Landholders need to weigh these potential benefits against the economic benefits of growing crops on this land.

Exclusion

Rodent-proofing structures

Exclusion from structures such as storages, houses and grain silos needs to take account of both the physical ability and biology of the target species (Smith 1994). The black rat is an excellent jumper and climber, and can scale vertical walls if they have a rough surface. Climbing guards need to be sufficiently high to prevent access by jumping and be sufficiently wide to prevent access by climbing around them (Meyer 1994). Both rats and mice can burrow deeper than 30 centimetres, so rodent-proof walls need to be sunk at least 45 centimetres. Rodents can squeeze through any aperture their heads will go through (Smith 1994); therefore rodent-proof structures must not have apertures larger than the head diameter at weaning age, which is as small as six millimetres (the diameter of a pencil) for house mice (*Mus domesticus*). Doors must fit well and be kept closed. Drains and sewers must have drain traps fitted. All vents must be screened. Proofing materials must be gnaw-resistant, for example, concrete, brick or metal. Rodent-proofing existing structures can be expensive, technically difficult and often impractical. It is usually more effective, and far cheaper, to incorporate these requirements at the design and construction stage of building, rather than attempting to rodent-proof existing structures.

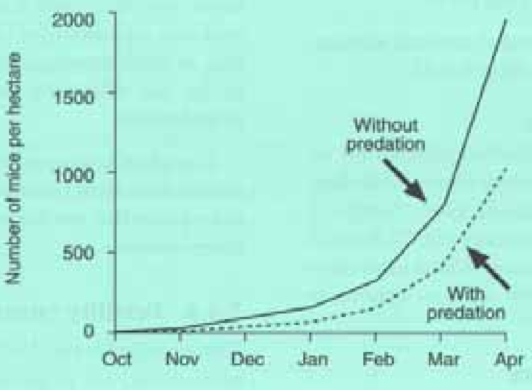

Figure 11: Mouse population growth curves showing hypothetical effect of predation. Chart assumes a starting density of 20 mice per hectare and reproductive rate of six young per month. Predation rates of four mice per month and no mice per month are plotted.

Barriers

Barrier fencing may only be economically viable for very valuable crops because of the cost of materials and high maintenance requirements. The ability of rodents to climb most surfaces, penetrate small gaps and find weakness in the barrier system has been exploited by incorporating traps into the corners of plastic fences in Malaysia (Singleton and Petch 1994). The combination of a fence and multi-catch system has been further modified at the International Rice Research Institute in the Philippines. Engineers developed a cheaper fence containing a trap every 15 metres. Studies indicate the barrier/trap system can substantially reduce crop losses (Lam et al. 1990 cited in Singleton and Petch 1994).

Sheet metal to a height of 0.9 metres can prevent access but rodents may climb over at joins or exposed corners (Smith 1994). Generally the cost is so high that effective metal barriers may only be justifiable where no alternatives are available (Smith 1994).

Electric fences may be an option in small areas to protect valuable resources although their efficacy varies between species (McKillop and Sibley 1988). Shumake et al. (1979) evaluated the use of non-lethal electrical barriers for protecting rice crops from rats, and concluded the approach had potential value for protecting high-value crops and plant breeding plots.

Barriers may be useful around storage areas in a plague (Section 8.8.1).

Ultrasonic devices

Many studies have rejected ultrasound as a practical means of rodent control (Meehan 1984; Howard and Marsh 1985; Bomford and O'Brien 1990; Shumake 1997). Even if rodents initially withdraw from a loud new ultrasonic noise, they start to ignore it within a few days.

Chemical repellents

Chemical repellents have been proposed as a means of controlling rodents partly because of their acute sense of smell (Section 2.2.5; Stoddart 1988). Although many wildlife repellents affect rodents, in practice, the repellent effect tends to be short-lived. As noted by Smith (1994), 'behavioural modification is only effective if the animal can choose a more attractive alternative. If food or harbourage is short, or population density is high, methods that do not exclude absolutely may be overcome because the animal perceives that the alternatives are worse'. The success of repellent use is dependent upon critical evaluation of the biological and environmental context in which they are applied.

7.4.3 Trapping

Trapping is probably only useful for removing rodents in and around buildings and storages, such as mice that invade homes (Kaukeinen 1994). Trapping is the preferable option in homes and other buildings because the use of poisons may pose a risk to human and animal health. Trapping can also be effective around trial plots or small areas of crops like vegetables.

Break-back traps, also called snap-traps, (available from hardware shops and supermarkets) are adequate for most purposes. Single-catch live traps are more expensive but may be necessary to control black rats since they are often difficult to catch with snap-traps. Pit-traps (bucket-traps) are often used during mouse plagues and can successfully catch many rodents but, at such densities, trapping is unlikely to be an effective means of reducing populations.

Trapping is a good tool for monitoring rodent numbers (Section 7.1). However, it may pose the problem of catching non-target species.

7.4.4 Fertility control

Using fertility control techniques to manage mouse and rat populations is a difficult proposition, given their promiscuous behaviour, opportunistic breeding and short lifespans (Bomford 1990). Jackson (1972) suggests that nearly 100% sterility would be required for effective control of rodents in the genera *Mus* and *Rattus*. Such high levels of sterility would need to be maintained whenever environmental conditions were suitable for breeding and achieving this for rodents would be prohibitively expensive. However, McCallum and Singleton (1989) and Singleton and McCallum (1990) suggest that when conditions are suitable for mouse plagues to form, fertility control could reduce litter size or litter frequency sufficiently to prevent rapid exponential population growth and so avert plagues.

Chemical fertility control

Many chemicals are known to cause infertility in rodents, although many of these are not species-specific, and some are toxic (Marsh 1988; Bomford 1990). As yet none are considered to be of practical use for rodent control.

Because fertility control chemicals need to be delivered repeatedly, any technique that kills mice (rather than sterilises an equal number) could be expected to reduce population growth rates to an even greater degree than fertility control, because dead mice do not breed (Bomford and O'Brien 1997). It is therefore more effective to use rodenticides than chemical sterilants to reduce rodent populations (Bomford 1990; Garrott 1991). The only exception would be if sterilised rodents reduce access to resources needed by fertile rodents for breeding (for example, access to food or nest sites through territorial or dominance behaviour). It is probable that at times of plague formation, such environmental resources are abundant and behavioural interference would not limit breeding by unsterilised mice. Therefore, unless fertility control techniques are cheaper than lethal techniques, or have some other significant advantage, they are unlikely to be a preferred option.

Biological fertility control

Immunocontraception — Research is being conducted to develop a technique to use a viral vector to deliver immunocontraceptives to rodents (Tyndale-Biscoe 1994). If this technique is successful, it may be possible to permanently sterilise a high proportion of a rodent population at a sufficiently low cost to make fertility control a practical management option. This approach is currently being investigated at the Vertebrate Biocontrol Cooperative Research Centre in Canberra and at this stage the likelihood of its successful development and implementation is difficult to estimate. To date, a mouse-specific virus[10] that is present in nearly all Australian mouse populations has been identified as a suitable vector for the fertility-blocking protein. Laboratory trials have shown that the virus will carry foreign material and that the modified virus will replicate in mice. The next step in the research is to identify an appropriate fertility blocking protein which only affects house mice.

Capillaria hepatica — The potential for a parasitic nematode, *Capillaria hepatica*, to control mouse populations has been investigated (Singleton and McCallum 1990). Because mice infected with *C. hepatica* have less frequent litters, it was hypothesised that this could slow population growth rates and so prevent plagues (McCallum and Singleton 1989). Field tests, however, failed to demonstrate any decline in breeding by mouse populations that were experimentally infected with *C. hepatica* (Singleton et al. 1995; Singleton and Chambers 1996) and the research has been discontinued.

7.4.5 Estimating the effectiveness of control measures

The effectiveness of baiting during mouse plagues has been evaluated in a number of studies (see Box on Effectiveness of Poisoning to Control Mice). It appears that

10 Murine cytomegalovirus (MCMV).

once mice have reached plague densities, baiting is generally too late to prevent crop damage, although it may reduce it in some cases. During build-ups of mice, however, baiting may be an option for reducing numbers. Although no rodenticides are currently registered for broadacre use, trials on zinc phosphide have been completed and an application for registration for in-crop control is in preparation. The cost-effectiveness of zinc phosphide and appropriate strategies for its use in limiting build-ups will need to be evaluated.

EFFECTIVENESS OF POISONING TO CONTROL MICE

Perimeter baiting

With perimeter baiting, the aim is to bait shelter areas where the mice feed and breed. Such areas include irrigation channels, check banks, fencelines, roadsides and headlands. The rationale of the technique is that it will reduce the number of mice and the rate of crop invasion, thus decreasing crop damage. Perimeter baiting is of value if it is undertaken prior to the onset of breeding and before offspring disperse into crops.

Perimeter baiting was used in New South Wales during the 1984 mouse plague (Saunders and Korn 1984). At that time Saunders and Korn cautioned landholders that it 'will have little effect on a mouse population already established in a crop. However, it will play a role in limiting movement into the crop, especially if used in conjunction with clearing around that crop'.

Mutze (1995) found perimeter baiting with strychnine ineffective for controlling mice in grain crops, but Kay et al. (1994a) evaluated the effect of baiting refuge habitats around irrigated soybeans with bromadiolone. They found that bromadiolone significantly reduced the number of mice inhabiting the refuge habitat and also reduced the rate at which mice colonised the adjacent crops. However, no significant reductions in damage were detected in the crop as mouse numbers failed to reach densities where crop damage was detectable. Their findings support the rationale of perimeter baiting but do not confirm that it is effective for limiting crop damage.

In-crop baiting

In-crop baiting is subject to greater restrictions than perimeter baiting because of the need to prove freedom from crop residues. Because perimeter baiting has little impact on mice living within a crop, permission is given for in-crop baiting at various times. If protection is needed for only a short time, for example, during crop establishment, baiting may be beneficial. Strychnine-coated grain was spread in-crop following sowing during the 1993 plague in South Australia and Victoria. Bait was mixed by the State government agencies and distributed by air or from spreaders on the ground at a rate of one kilogram per hectare (equivalent to 2.7 grams strychnine per hectare, or 2–3 grains per square metre). Bait was dyed green and it was recommended that it be spread in the late afternoon to reduce its consumption by birds. Aerial application of strychnine treated bait was also approved for use in Queensland and New South Wales in 1995. In 1997, permission was given for the broadacre use of zinc phosphide treated bait in Victoria, South Australia, Queensland and Western Australia. Control work in Geraldton, Western Australia, demonstrated the success of controlling mouse damage in maturing crops with well advanced seed-set. Following aerial application of one kilogram of grain treated with zinc phosphide per hectare, mouse populations were reduced by more than 90% (G. Martin and D. Hill, Agriculture Western Australia, pers. comm. 1997).

Value of baiting during mouse plagues

In-crop baiting during mouse plagues is not always successful. It may produce high kill rates but the sheer numbers of mice during a plague may mean that baited areas are soon reinvaded (Ryan and Jones 1972; Saunders 1986). The extent to which reinvasion occurs following baiting will depend on several factors, such as how well baiting is carried out, whether buffer areas are included, the supply of alternative food in non-baited areas and the size of the bait area.

Baiting during a plague can waste resources if it coincides with the natural decline in the mouse population. For example, during experimental trials in the 1984 plague, baiting significantly reduced the number of mice, but after three to four weeks, numbers were similarly low in both baited and unbaited areas (Standing Committee on Agriculture 1985).

Other studies have attempted to estimate the cost–benefits of baiting in standing summer crops. During a plague in the Murrumbidgee Irrigation Area in 1979–80, Saunders (1983) found baiting with strychnine in a sunflower crop achieved a 90% reduction in mouse numbers. On the assumption that the mice poisoned would have eaten three grams per mouse per day, Saunders and Robards (1983) calculated that baiting prevented a loss in yield of 20.4% over the next seven weeks before harvest. Cost of control (excluding labour) was $15.50 per hectare; the value of the crop was $1250 per hectare. Baiting may thus have prevented a loss of $250 per hectare, giving a benefit–cost ratio of 16:1. It should be noted, however, that these calculations make no allowance for any recruitment through reinvasion or breeding, or natural decline in mouse numbers over the seven weeks prior to harvest.

Singleton et al. (1991) undertook a cost–benefit analysis of baiting with bromadiolone in summer soybean crops using a questionnaire. From farmers' responses, crop losses to mice were estimated to be $2 million. Around 10% of respondents had baited their crops with bromadiolone; at baiting costs of $55 per hectare[11] and a crop value $515 per hectare, Singleton et al. (1991) estimated that the break-even point would have been when crop damage was around 11%. The extent of crop damage varied considerably between farms and between areas. On average, the damage exceeded 11% so for many farmers the benefit of baiting would have exceeded the cost. The cost–benefit would be even more favourable if labour costs were excluded. Then the break-even point would be at 6% crop damage. Reports of damage in summer crops are often higher than this (Ryan and Jones 1972), suggesting that baiting around the time of flowering and seed set in these crops would be worthwhile if it removed enough mice to significantly reduce damage.

The value of strychnine baiting in grain crops has been assessed by Mutze (1993a, 1995). Mutze (1993a) found baiting in a wheat crop at the time of flowering reduced mouse numbers by 46%. Although by the time of harvest two months later, densities were similar to pre-baiting levels, he found baiting had reduced the level of damage to the grain heads by 81%. Mouse numbers were only around 50 per hectare at the time of the study so the actual tonnage lost was small (approximating a 2% reduction in yield) and wheat prices were lower than the previous ten year average. Mutze (1993a) concluded that the cost of baiting was close to the gain in yield, however, higher wheat prices or a minimum density of at least 100 mice per hectare would have improved the cost-effectiveness. During

11 Comprising cost of bait and grain ($5.00); cost of bait stations ($25.00) (which could be re-used) and cost of labour ($25.00) (Singleton et al. 1991).

the 1993 mouse plague in South Australia, Mutze (1995) assessed a broadacre strychnine baiting program at seeding and late-tillering/flowering of winter grain crops. Mouse numbers were probably greater than 2000 mice per hectare and the program returned benefits of $35–40 million for a cost of $2–2.5 million (including bait production and distribution, and wildlife and residue monitoring).

All of these studies have looked at cost–benefit of baiting in standing crops. Given that mouse numbers typically peak in autumn around the time of sowing for winter crops, what benefit would accrue by baiting before sowing? In 1994, Brown et al. (1997b) evaluated the efficacy and cost-effectiveness of strychnine baiting just prior to sowing in the Wimmera and Mallee regions of Victoria to reduce cereal and legume crop damage. They found no significant reductions in mouse numbers at treated sites. The extent of damage was difficult to gauge because the measured plant establishment rates exceeded the figures on sowing rates provided by growers. Damage levels were low and the plants began to compensate at an early stage of growth. Although this Victorian study found baiting at sowing did not reduce crop damage, further studies are needed to see if baiting may be worthwhile under different conditions.

The effectiveness of all the habitat manipulation techniques recommended in Section 7.4.2 for controlling mice have not been evaluated. Some of these techniques have been investigated by the CSIRO Division of Wildlife and Ecology and the Department of Natural Resources and Environment in Victoria (Brown et al. 1995; Brown et al. 1997a). The research, funded by the Bureau of Resource Sciences and Grains Research and Development Corporation, evaluated 'best farm management practices' for mouse control in the Wimmera and Mallee. Results of the effectiveness of management techniques evaluated by the project are summarised in Table 12. A comprehensive list of the recommended practices for reducing the impact of mouse plagues is given in Table 13.

7.4.6 Integrated pest management

Successful rodent control is likely to require a combination of approaches to deal effectively with the overall conditions that foster rodent outbreaks. For example, poisoning to control rats in sugarcane is more effective when it is combined with weed control (Robertson et al. 1995; A. Brodie, Bureau of Sugar Experiment Stations, Queensland, pers. comm. 1996). In developing a management strategy for rodents, the broad spectrum of possible control techniques should be considered and compared for efficacy, cost-effectiveness and acceptability. Combinations that best meet long-term sustainable management aims can then be selected for use (Section 8.4.3).

Data are needed on the efficacy and economic benefits of all rodent control techniques and strategies (Section 10.9). For a truly comprehensive assessment, large-scale replicated experiments which cover a range of seasonal conditions and rodent densities are required to evaluate the effect of farm management practices on mouse populations. The 'best farm management practice' project conducted by Brown et al. (1997a), evaluated the effectiveness, costs and feasibility of implementing practices for mouse control in the Victorian Wimmera and Mallee. The recommended actions arising from the project are listed in Table 13.

A break-even analysis undertaken by Brown et al. (1997a) showed that farmers in the Mallee would need to prevent losses of between 0.13 and 0.19 tonnes per hectare in cereal crops (8–12% of average yields) to cover the costs of mouse control. In the

Table 12: Effectiveness of management techniques for mouse control in the Wimmera and Mallee regions of Victoria (after Brown et al. 1997a).

Action	Region	Effective
1. Fencelines – control of weeds and grasses	Wimmera	Yes
	Mallee	?No
2. Stubble management – reduce food supply for mice	Wimmera	Yes
	Mallee	Yes
3. Sowing – light cultivation immediately after sowing	Wimmera – pulses	?Yes
	Wimmera – cereals	No
4. Baiting:		
Strychnine – winter 1994	Wimmera	Yes
	Mallee	Yes
Bromadiolone – spring 1994	Wimmera	*
Brodifacoum – spring 1996	Mallee	Yes

* The effect of bromadiolone in spring 1994 in the Wimmera was inconclusive due to insufficient mice.

Wimmera, the figures were between 0.19 and 0.23 tonnes per hectare for cereals (10–13% of average yields) and between 0.09 and 0.13 tonnes per hectare for pulses (8–11% of average yields). The total cost of implementing mouse control options over a three year period for the Mallee was $17 per hectare for both cereals and pulses and for the Wimmera was $29 per hectare and $26 per hectare respectively for cereals and pulses.

Brown et al. (1997a) also conducted a survey of farm management practices which showed that some of the recommended practices for mouse control were already part of the normal farm management. Slashing or spraying along fencelines, for example, has a number of benefits apart from mouse control. Other practices could easily be incorporated with appropriate resources while some would only be implemented during mouse plagues. It is important that the adoption of conservation farming in all its aspects is not compromised by mouse management practices. Best practice farming will fit mouse management in with conservation farming.

Table 13: Recommended actions to reduce the impact of mouse plagues. These actions are applicable to the Mallee and Wimmera regions of Victoria, but the underlying principles are valid for eastern Australia (after Brown et al. 1997a).

Actions: Winter/spring

Routine actions:

- control weeds and grasses along fencelines, channel banks and crop margins before seed set, by spraying or slashing;
- remove and reduce cover around sheds, buildings, silos, fodder rolls and hay stacks;
- mouse-proof houses, grain and stock feed storages, and intensive livestock buildings;
- check fodder rolls for mouse activity, particularly if rolls consist of oats, peas or vetch which contained mature or maturing grain when cut. Feed these first; and
- **monitor** for signs of mouse activity.

Preventative actions if high mouse numbers are forecast for autumn:

- bait buildings and key habitats (fencelines, channel banks etc) in late September and October;
- **monitor** signs of mouse activity (active mouse burrows) and use 'bait cards'* in different habitats; bait where activity is high; and
- spray-top or graze pasture hard to minimise seedset of grasses and weeds.

Actions: Summer (harvest time)

Routine actions:

- set machinery to harvest as cleanly as practicable to minimise grain loss;
- **monitor** how much grain is lost;
- harvest at the best time to minimise grain loss (that is, ensure canola is windrowed at the appropriate time and crops are not over ripe at harvest particularly pulses and barley); and
- clean up any concentrated spillage of grain, particularly around field bins, augers and silos.

Preventative actions if high mouse numbers are forecast for autumn:

- **monitor** signs of mouse activity, particularly in vulnerable paddocks such as stubbles of barley, canola and lentil crops and any other crop stubbles which sustain heavy grain loss through wind or hail damage;
- harvest crop with the most mouse damage first, all else being equal; and
- heavily graze vulnerable paddocks (stubbles with high harvest grain losses) immediately following harvest, but leave sufficient ground cover to minimise potential for erosion.

Actions: Autumn (sowing time)

Routine actions:

- sow to even depth;
- sow as early as possible to get plants established quickly;
- keep paddocks free of grain spillages; and
- **monitor** signs of mouse activity (burrows) and use bait cards*.

Preventative actions if mouse numbers are moderate:

- sow as deep as agronomically possible, appropriate for each crop;
- consider sowing at a higher rate;
- do not plant dry;
- cross harrow, roll or prickle chain after sowing ensuring grain is well covered;
- do not direct drill into heavy stubble; and
- consider changing the crops in the rotation. For example, chickpeas after barley is a high risk combination, beans may be a better option.

Crisis management if mouse numbers are high:

- **monitor** then consult with relevant government agency to see whether baiting is warranted.

* Bait cards (canola squares) provide a more effective index of mouse density when little alternative high quality food is available to mice. Hence the cards are more effective in autumn than spring and summer (Section 7.1).

8. Strategic management at the local and regional level

Summary

The four components of the strategic approach to managing pests are: defining the problem; developing a management plan; implementing the plan; and monitoring and evaluating the progress and outcomes. For rodents, strategic management involves integrating control operations into overall land management planning to achieve a particular rodent density or rodent impact outcome, taking into account specific local knowledge and conditions.

Depending on the nature of the problem, landholders have two options. The first option is sustained management which involves an initial widespread and intensive control campaign to reduce populations to low levels, followed by maintenance control to prevent population recovery. This strategy is appropriate for managing damage caused by rats in orchards or rats and mice in storages and buildings. The second option, more appropriate for controlling mice in crops, is targeted management where the control effort aims to minimise damage at a particular time. Successful implementation of this strategy hinges on monitoring mouse numbers so that build-ups are detected early, then implementing management strategies that prevent or delay a plague so that damage is avoided or reduced.

With mouse plagues, the problem is that detection often comes too late to alleviate damage significantly. Crisis management may waste resources and have little lasting benefit since mice can reinvade the treated sites from surrounding untreated areas. There are occasions where crisis management may be effective, such as broadscale aerial in-crop baiting during mouse plagues, although there are few data available to evaluate the efficacy of such approaches.

Strategic monitoring of the build-ups in mouse numbers will allow landholders to take action by modifying a number of farm management practices which affect the amount of food and harbour available to mice, and also to implement early poisoning where this is desirable. Whenever possible, monitoring and implementation of control strategies should be conducted at a district level so that action can be coordinated across neighbouring properties. Management plans should be devised for areas of land that are small enough to be manageable by local farmer groups but also large enough to minimise the effects of reinvasion following control.

Management plans need to include provisions for monitoring the effectiveness of the control operations and the overall strategy. Both aspects are an essential component of a management program. Monitoring of program efficiency and outcomes provides information which allows both the control strategy and the resource protection goals to be continually improved. It is important to distinguish between efficiency and effectiveness. For example, management can be efficient if it kills many rodents for a small cost, but ineffective if it fails to reduce damage or increase crop yields. In some cases, control may not be environmentally or economically justified if the cost of control exceeds the benefits.

Economic frameworks can assist land managers assess the relative value of different rodent control strategies. Such frameworks require: definition of the economic problem; data on the relative costs and benefits of different management strategies; an understanding of why actions of individual land managers may not lead to effective levels of rodent control; and assessment of the means by which governments might intervene to overcome identified problems. Land managers can use such economic frameworks to select the most appropriate rodent management strategy for their circumstances.

8.1 Introduction

The challenge for landholders and others concerned with rodent management is to develop a strategic management plan for lessening the damage caused by rodents, using information described in the preceding chapters, combined with local knowledge and the processes described in this chapter.

Three primary facts need to be considered when planning control of rodents:

- rodent breeding success depends on food availability;
- rodents disperse when food runs out; and
- quantity and quality of food varies between areas and over time.

Because rodents disperse readily, areas that have been baited can be recolonised rapidly from adjacent unbaited areas. They also quickly invade an area when food becomes available (for example, when a crop comes to head). When their habitat is disrupted (for example, by harvesting), they may move to an adjacent crop. Consequently the benefit of controlling rodents by baiting or destruction of harbour may be short-lived. Nonetheless the benefit may be adequate if the time that the crop is susceptible is also short (for example, at sowing). It may also be satisfactory if it restricts damage to a tolerable level.

If crop damage extends for more than a short time (for example, in sugarcane and grain crops between flowering and harvest) or is likely to be unacceptably high, then control must be maintained to be effective since the population will recover quickly during the breeding season. Alternatively, the control method must change the carrying capacity of the environment, that is, it must reduce food or shelter sites or increase the level of predation (Section 7.4.2).

8.2 Strategic approach

The previous chapters have described current knowledge concerning pest rodents in order to develop general principles and strategies for best practice management of rodents. This includes the use of reliable knowledge on the biology and impact of rodents and lessons learnt from previous attempts to alleviate rodent damage. This particularly applies in the case of mouse plagues where crisis management (Section 8.4.2) is invariably employed.

The components of the strategic approach described by Braysher (1993) and set out in Figure 1 are:

- defining the problem;
- developing a management plan;
- implementing the plan; and
- monitoring and evaluation.

8.3 Defining the problem

Chapters 3 and 4 set out the initial steps in defining the problem of any rodent management program. In the case of mouse plagues, the problem can be sporadic; for rats in orchards and sugarcane, it tends to be seasonal. Techniques for measuring rodent numbers and impacts are described in Chapter 7. In most enterprises the impact of rodents on production is known although not always costed or quantified (Chapter 3). There is a paucity of techniques and knowledge that allow growers to relate rodent numbers to levels of damage or potential damage if no action is instigated. This is an area in urgent need of research (Section 10.4).

Generally, the problems associated with sporadic rodent damage are that controls are initiated too late to alleviate damage significantly. For mice, there is a lack of management practices being implemented that alert farmers to the potential for a mouse plague. This could be alleviated by including rodent monitoring within a formal process already used by some farmers to record crop condition (such as TOPCROP or similar programs, Section 7.2.2). This would maintain and reinforce grower awareness of the potential for rodent infestation on each occasion the crop is inspected.

These agencies and agribusinesses facilitating local crop monitoring programs would be able to advise landholders on appropriate rodent monitoring techniques and integrate the results of the monitoring across local areas (Chapter 9). By combining the results of the monitoring with recent weather events, it may be possible to predict the future development of rodent numbers within localities and regions. When this information is passed back to landholders, they will have the opportunity to modify a number of farm management practices that will affect the amount of food and harbour available to rodents (Section 8.6).

'Without reporting systems, coordination of early detection and management is difficult.'

Where there is no reporting system in place between landholders, coordination of early detection and introduction of management strategies to restrict the likelihood of damage is more difficult. Industry publications and local media outlets are possibly the only means of achieving awareness of potential rat damage amongst orchardists and sugarcane growers. Avenues for increasing awareness of potential rodent problems need improving (see Chapters 9 and 10).

8.4 Management plan

8.4.1 Objectives

The objective of pest control is to reduce or prevent the damage caused by the pest in the most cost-effective and safest way possible, keeping in mind long-term sustainability goals. However, when formulating a management plan it is necessary to be more specific and define the objective in terms of an outcome that can be measured. That is, the objective states what will be achieved and by when.

For protecting agricultural production from rodent damage, a reasonable objective is to limit the extent of damage to an acceptable level, predetermined by the value of the enterprise and the environmental benefits, and the cost of control (Section 8.7). Usually rodent control programs attempt to achieve this objective by stabilising numbers at low levels or by reducing or delaying upsurges in numbers. The principal tool available to growers in reaching this objective is to manage their properties so as to limit food supplies and harbour available to rodents, thereby limiting their reproduction and reducing survival.

Objectives for management plans on a regional level might include reduced non-target incidents or monthly rodenticide sales, or increased participation in local group meetings or activities.

8.4.2 Management options

Once an objective has been set, the next step in developing a management plan is to select management options. In selecting options it is important to match them to the desired objective and to be realistic in terms of available resources and technical feasibility. Constructing a 'decision matrix' can be a useful aid for evaluating which options are most appropriate along with a 'pay-off matrix' for determining their benefits (Appendix C, Step 7; Norton 1988).

A range of options are available for managing vertebrate pests:

Local eradication

Local eradication is the permanent removal of the entire pest population from a defined area within a set time (Bomford and O'Brien 1995). This is rarely likely to be technically feasible or economically desirable for rodents, except in the following two instances:

- on small offshore islands[12] where rodents

12 Rodents have been successfully eradicated on islands up to 2000 heactares in New Zealand (W. Green, Department of Conservation, New Zealand, pers. comm. 1996).

have been threatening the survival of rare or endangered species; and

- in buildings which have been externally rodent-proofed but where there is still an internal resident population.

Eradication should not be attempted unless it is an attainable goal. Bomford and O'Brien (1995) list six assessment criteria which can be used to determine whether an attempt to eradicate a rodent infestation is worthwhile for any given situation.

Strategic management

Strategic management is that undertaken where local eradication is not an achievable option and where it is clear that pest damage will require continuing management. It involves integrating control operations into overall land management planning to achieve a specific reduction in damage. There are three major types of strategic management: sustained, targeted or one-off.

Strategic sustained management — Involves an initial widespread and intensive control campaign to reduce populations to low levels, followed by maintenance control to prevent population recovery. Rodent damage can be restricted to tolerable levels if their density is held below a certain threshold. This is a practical option for managing some cases of rat damage. For example, it would apply to keeping areas around sugarcane fields clear of vegetation that provides food and refuge for rats (Section 7.4.2). Before this approach is embarked on, resources must be allocated to ensure control is maintained for the foreseeable future. Managers need to determine the level of effort at which the benefits of control at least equates with the costs of control.

Strategic targeted management — Where the control effort is targeted to manage rodent damage at a particular time, either when the crop is most susceptible to damage or when the rodent population is most susceptible to control. This is the principal strategy for managing damage caused by mice during plagues. The key to the strategy for controlling mice is to monitor density so that forewarning is received of potential upsurges, and then to implement a strategic, targeted response to avoid or reduce damage at such times.

Strategic one-off management — Involves a single action to achieve the long-term or permanent reduction of rodent damage to an acceptable level. An example might be the release of an effective biological control agent if one was available for rodents.

Crisis management

Crisis management is when action is taken when the pest species is already having unacceptable economic or environmental impact. All too often managers undertake rodent control only when populations are large enough to be causing obvious damage. Crisis management is generally unsuccessful in limiting further damage since rodent numbers rapidly increase to pre-control levels due to immigration and breeding. Considerable resources may be wasted for little lasting benefit. There may, however, be occasions where crisis management is effective. One example might be broadacre in-crop rodenticide baiting during mouse plagues (Mutze 1995).

Commercial management

Commercial harvesting can be a management option for some pest species, but no rodents have commercial value in Australia.

No management

In some situations no rodent control may be the most environmentally or economically justifiable option. For example, land managers may perceive that control measures will cost more than the resultant gains in production; in such cases, no management is the appropriate strategy. This will particularly be the case in pastoral areas where control would not be cost-effective.

Flexible management

A flexible approach is required when managing complex natural systems. One such approach is known as adaptive management or 'learning by doing' (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 because of natural variability and changes in community expectations and perceptions, management practices and land use. Hence, management options should aim to improve understanding of the system as well as meeting environmental, social and economic goals. Danckwerts et al. (1992) recommend that managers can learn from their own past successes and mistakes (and those of their neighbours) and make management decisions based on this experience.

8.4.3 Choosing a management option

Having determined the most appropriate management approach from the alternatives listed in Section 8.4.2, the next step in developing a management plan is to integrate the chosen management techniques into a management strategy. The strategy needs to take account of the:

- potential for applying strategic control to have maximum effect on rodent populations at a particular time of the year — for example, through baiting of refuge habitats in spring or early summer;
- availability of resources to implement options — for example, where funds are limited but human resources are satisfactory, ground baiting may be preferable to aerial baiting; and
- nature of the habitat and size and location of the management unit — for example, technique selection may be constrained by access to management area or rates of bait application.

Farm layout and location with respect to surrounding habitat (for example, location of roadside reserves and land use on adjacent properties) may be important in assessing the above factors as well as the potential for mice to recolonise areas (Section 7.4.2). Variables such as local geography, land use, resources, soil types, fencelines and refuge areas will all influence the decision on what is a reasonable management unit. Small hand-drawn property maps may be useful for recording these factors.

'Multiple approaches and a combination of different techniques may be needed to achieve optimal management.'

A management strategy sets out the techniques and when and how they will be used. This includes methods for monitoring rodent populations to provide forewarning of outbreaks and for reducing rodent density and damage. Control techniques need to be compared for efficacy, cost-effectiveness, safety and acceptability of alternatives. Multiple approaches and a combination of different techniques may be needed to achieve optimal effectiveness, prevent development of bait shyness and taste aversion and take account of neophobia.

8.4.4 Factors affecting acceptance of control strategies

When selecting appropriate control techniques, it is not sufficient to consider only the issue of whether they work and how much they cost. Environmental, social and legal issues also need to be considered. Risks to non-target species are particularly important for rodenticides (Sections 4.3.2, 5.2 and 7.4.1). Animal welfare issues should also be considered in all pest animal management plans. Animal welfare agencies consider that it is desirable to make a balanced evaluation of the benefits of using a rodenticide against the cost in terms of suffering inflicted on the target animals relative to alternative control options (Section 5.3; Oogjes 1994).

Norton (1988) describes a series of questions that can be asked to discover the hindrances to the acceptance of a management strategy. His questions, and the answers for the strategy proposed here for managing mouse populations, are listed in Table 14.

Table 14: Decision analysis table for consideration of factors affecting the acceptability of control measures for managing mouse populations (questions after Norton 1988).

Questions	Answers
Is the proposed control measure:	
– technically possible?	yes, provided there are no legal constraints on use of poisons (Sections 6.1 and 7.4.1; Appendix A).
– practically feasible ?	yes, but time and resources may be limiting if areas to be managed are large.
– biologically effective*?	yes.
– economically favourable?	uncertain, as studies are needed on cost–benefit analysis; expect it will depend on crop value, farm business equity and cash flow (see Section 7.4.1 on poison efficacy).
– environmentally acceptable?	yes, provided non-target mortality and residues from use of poisons can be minimised and monitored (Sections 4.3.2 and 7.4.1); conservation farming practices may need to be maintained in sandy soils to prevent soil erosion (Section 7.4.2).
– politically advantageous?	yes, provided all legal and environmental issues are adequately taken into account.
– socially acceptable?	yes, but possible concern about use of poisons and animal welfare (Sections 5.2 and 7.4.1); difficulty of managing a problem before it becomes apparent.

* That is, the proposed control measure will reduce population size sufficiently to reduce damage levels.

These questions and answers identify five problems:

- the current lack of a registered chemical for baiting;
- environmental impacts on non-target species;
- conservation farming practices in sandy soils;
- limited time and resources for large landholders; and
- the difficulty of managing a problem that is not apparent.

8.4.5 Performance indicators

Where rodent damage is affecting crop production, effective rodent control should give improvements in profitability compared with areas with no or less rodent control. Increased crop productivity for example, should be sustained (or continue to improve) where long-term rodent management is implemented. However, allowances need to be made for other factors influencing production before and after rodent control. For example, variation in seasonal conditions which can cause natural declines of rodent populations in the absence of any imposed controls. Because mouse plagues are sporadic, performance indicators may need to take into account factors such as the extent of damage in crops during previous plagues when no control was implemented or the levels of damage recorded in surrounding areas where no control was implemented.

The final important component of a management plan is setting one or more measurable performance indicators. For example, a performance indicator might be that average levels of crop loss in a region will be less than 5% in a year when a plague is forecast. Performance indicators will demonstrate whether or not the management objective is being achieved. If success is not achieved, it may be necessary to change the management strategy, or at least accept that it has ceased to be worthwhile to continue spending money on the failed strategy. Where rodent management does not lead to increased profitability (criterion for failure), the effectiveness of control techniques should be reassessed.

8.4.6 Scale of plans

Plans to manage rodents must be for defined areas of land and can be at any scale — national, state, regional, district or farm. Management planning requires determining the right size for a management unit. Selection of an appropriate sized management unit will often be a trade-off between several factors, such as:

- risk of reinvasion if the management unit is small;
- economies of scale for management of larger units (for example, aerial application of poison); and
- advantages of small community groups working together to solve a problem in a local area (Chapter 9).

Rodents can disperse over considerable distances (Krebs et al. 1995) so whole areas may need to be tackled at one time for effective rodent control (Section 8.8.1 M3.4; Wood 1994); otherwise reinvasion may occur. Often the area where rodents inflict damage (such as a crop) may not be the same as the area where numbers build up. Also rodents may move from one area to another as food supplies or other resources change (for example, in a mosaic of crops) (Section 8.1). These movements of rodents between habitat patches need to be taken into account when control strategies are planned and it is clear that neighbouring landholders need to work together as a group to manage rodent problems (Section 9.4). Management units should not, however, be so large that groups fail to function as cohesive units.

8.5 Implementation

Implementation of rodent management strategies requires cooperative action between landholders, government agencies and other stakeholders. This is described in detail in Chapter 9.

8.6 Monitoring and evaluation

Both the damage caused by rodents and the effectiveness of control techniques to reduce this damage need to be monitored and evaluated against performance indicators (Section 8.4.5). Although many landholders and government agencies recognise that evaluation of performance is necessary, in practice implementing control is usually given a far higher priority than monitoring and evaluation. On a busy farm, or in the urgency of getting poisons out when a mouse plague is threatening and mice are damaging crops, no time or resources can be found for an activity that does not have an immediate benefit. This is a false economy. Without monitoring and evaluation a lot of money may be wasted on ineffective campaigns. If this waste is not identified, the same errors will continue to be made. Therefore, the monitoring and evaluation component is an essential part of best practice to ensure that rodent management becomes more efficient, effective and safe. Monitoring of program efficiency and outcomes provides information which enables the continuing refinement of both the control strategy and the desired outcomes.

'Monitoring and evaluation is essential to ensure that rodent management becomes more efficient, effective and safe.'

It is important that the management plan distinguishes between efficiency (operational objectives) and effectiveness (performance objectives) as management can be efficient but ineffectual. For example, 75% of mice may be killed efficiently for little cost by a poisoning strategy, but this strategy could fail to meet the resource protection goal of reducing crop damage if mouse numbers rapidly build up to pre-control levels due to breeding and immigration. Both operational monitoring and performance monitoring are therefore essential.

8.6.1 Operational monitoring

Operational monitoring aims to assess the efficiency of a control operation — to determine what was done, where and at what cost. Most states and territories have developed, or are developing, computer-based Pest Management Information Systems (Fordham 1991) which could be used to collate this information and provide landholders with an analysis of the success of a particular strategy.

8.6.2 Performance monitoring

Performance monitoring aims to assess the effectiveness of the management plan in meeting its objectives. The primary objective is the reduction of rodent damage to an acceptable level. Therefore, the effectiveness of the rodent control program is measured by the level of crop protection.

Performance indicators should therefore:

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

8.7 Economic frameworks

Economic frameworks can assist land managers assess the relative value of alternative control strategies and select the most appropriate rodent management strategy for their circumstances. Land managers who wish to determine the optimal economic strategy for managing rodent problems need to consider a number of issues or steps which are outlined in more detail in Appendix C. Briefly the steps are as follows. First of all, the question 'What are the desired outcomes?' needs to be asked. In most instances this will be increased crop yield and for such an outcome it should be relatively straightforward to make dollar value estimates.

The next step is to list all control options and how much it would cost to implement them. These control options can be different techniques or different levels or frequencies of application of techniques. It is important that the options for control are expressed as activities that the land manager can select to do or not to do.

The last step is to estimate the relationship between rodent density and damage for each resource damaged by the pests. In the case of damage where it is present in most years (such as rats in sugarcane) it is a simple calculation of identifying what level of production will be achieved by reducing rodent density in the crop by say 50%. The calculation will not be so simple when damage varies markedly between years, as for example during mouse plagues. By necessity, mouse plague control will need to be pre-emptive or strategic. The land manager will therefore have to take into account the probabilities of correctly predicting that significant damage will occur. It will also be necessary to take into account the outcome of control activities in relation to surrounding areas. In some years the most economic option with the prospect of a widespread mouse plague might be to plant no crops at all. In most cases accurate information to support the making of these decisions will be absent and the land manager will have to rely on a series of 'best guesses'.

8.8 Case studies

8.8.1 Mice in cereal crops

Mice live in a diversity of rural environments — crops, pastures, road verges, fencelines, dam and channel edges, sheds and hay stacks. During dry times mice survive in pockets of favourable habitat, then in years when food is plentiful and breeding is successful, they disperse out from these pockets into other habitats, including crops, where if conditions remain favourable, they will colonise and continue to breed through the summer months (Section 2.3; Newsome 1969; Singleton 1989; Mutze 1991). In some agricultural areas, they may reach plague densities within a single breeding season (for example, in the Mallee regions of Victoria, Singleton 1989; and of South Australia, Mutze 1993b); in other areas, the data suggest that two favourable seasons are required (Redhead 1988).

Best practice management of mice in cereal crops

M1. Problem definition

Mice periodically build up to plague densities and cause millions of dollars worth of damage in grain-growing areas of eastern Australia (Section 3.1.1).

M2. Management plan

M2.1 Objective

The objective is to predict when mouse plagues are likely to occur and to act to reduce or delay the build-up of mice to plague densities, or if this fails, to reduce their numbers sufficiently in and around crops to cost-effectively reduce crop damage.

M2.2 Management options

The management option selected for preventing plagues is strategic, sustained monitoring to detect build-ups and strategic, targeted control in response to build-ups.

M2.3 Management strategy

When managing mice, two levels of strategies need to be employed:

1. regular monitoring to recognise mouse build-ups and put management strategies in place that restrict numbers and impact; and
2. specific actions when plagues occur despite these preventative strategies.

M2.3.1 Monitoring mouse numbers and preventing build-up

Reducing the impact of mice means limiting the build-up of populations. The greatest hurdle to be overcome for successful plague prevention is recognition that a build-up in mouse numbers is happening. At present, a farmer's first indication of a mouse plague is usually damage to a crop and this is often too late to take effective preventative action. Yet sufficient advance warning of a plague can be obtained from monitoring mouse numbers, particularly if this information has been entered into a crop monitoring program.

Government level action

Government level action begins with plague prediction from monitoring mouse numbers. Currently, monitoring is undertaken in the Victorian Mallee region by CSIRO. Agriculture Victoria is monitoring sites in the Wimmera and Mallee under funding from the Grains Research and Development Corporation. New South Wales Agriculture has recently begun collating information provided by farmers. The Queensland Department of Natural Resources undertakes regular monitoring on an established transect across the Darling Downs. The system has proven to be a good predictor of plagues and shows the value of monitoring at this level.

What has been less satisfactory is an appropriate response to the prediction. Government monitoring is only successful in association with farm level action.

Farm level action

Modern farming practices increasingly involve routine monitoring and recording of farm activities. Strategies to regularly monitor mice also need to be part of the general management practice of a farmer. Mouse monitoring could be incorporated into farm monitoring programs such as TOPCROP (Sections 7.2.2 and 8.3). Similar programs run by consultants, or farmer groups managed by agribusiness or industry use standardised recording sheets which allow farm to farm, farm to district and farm to regional comparisons. Measures of mouse abundance that farmers could use at the paddock level are the number of traps (break-back or pit-traps) that catch mice, the number of active burrows over a given area or the amount of gnawing on bait cards soaked in linseed or canola oil (Section 7.1). As yet the correlation between these indices, mouse abundance and subsequent mouse damage, is unknown, but research is in progress to establish these relationships.

Indices of mouse abundance allow a farmer to estimate the size of the problem and to target the application of specific management options when mouse numbers are still relatively low and little or no damage is being inflicted.

Farm management options to restrict build-up

A number of farm hygiene and habitat manipulation strategies are advocated to restrict the build-up in numbers (Section 7.4.2). Regular habitat manipulation is recommended to reduce the risk of an outbreak, even though some farmers may not consider it cost-effective to do so. Agricultural practices farmers will adopt are: limiting the amount of grain spilt; grazing stubbles after harvest to remove spilt grain; and spraying or slashing of grass and weeds along fencelines, roads and similar areas to reduce seed set. Grazing pastures lightly and frequently throughout spring and summer will also reduce the amount of seed set and cover. Reducing cover is likely to increase the rate of mortality from predation and extremes of weather. Removing harbour around sheds and storages is recommended for the same reason. All these strategies are proactive and are employed as regular management tools.

M2.3.2 Managing a build-up

When conditions are favourable, build-ups can still occur despite regular habitat manipulation. When monitoring detects a build-up in numbers, farmers undertake trapping and baiting around buildings, clean up areas that can harbour rodents, construct barriers around storage facilities, and rodent-proof homes (Section 7.4.2; Appendix B).

Farmers also intensify actions to reduce harbourage, targeting control to areas where build-ups are detected. At this stage, baiting may well be a feasible option (Figure 12).

Baiting

When mouse numbers are building up in refuge and donor habitats, but have still not invaded vulnerable crops, grower groups seek advice from local government agencies responsible for vertebrate pest control or agricultural and veterinary chemicals before implementing perimeter baiting around their crops or in adjacent areas (Sections 7.4.1 and 7.4.5). Consideration is given as to whether baiting will be environmentally safe and whether it is likely to cost-effectively reduce the damage mice will cause if they invade the crop (Sections 4.3.2, 7.4.1 and

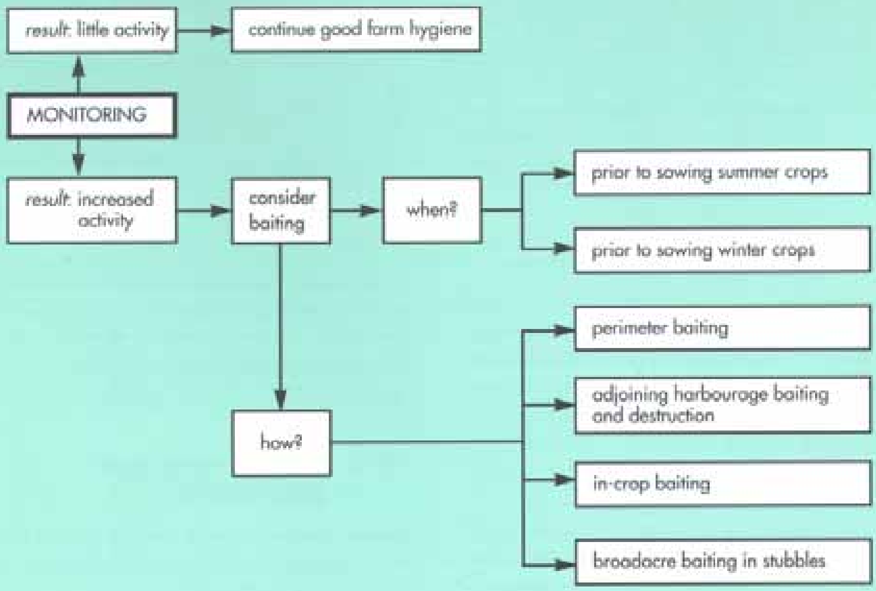

Figure 12: Baiting alternatives for managing a build-up in mouse numbers.

7.4.5). This will depend on the stage of crop growth, the value of the crop, and the evaluation by registration authorities of rodenticides and their safety. Site specific factors may need consideration, such as state legislation on the use of registered rodenticides.

M2.3.3 Specific actions during a mouse plague

Control techniques implemented in response to a build-up in mouse numbers will not achieve sufficient control under all circumstances to prevent a plague. When mouse numbers continue to increase despite the use of the preventative methods, then strategic, targeted control in and/or around crops is usually considered to be the most effective management option. This can include both habitat manipulation (Section 7.4.2) and poisoning in and around crops with the use of registered rodenticides (Section 7.4.1). It is, however, necessary to look at whether it is feasible and economically desirable to manage damage when mouse numbers are high, or whether it is preferable to accept crop losses and wait for the plague to decline naturally.

For mouse plagues, since the decline of a plague cannot be foreseen and reinvasion of treated areas is likely, it is best to aim for the short-term protection of a crop at its most susceptible stage (sowing and just after, flowering and early head maturation).

M2.4 Management units

Mice can move over considerable distances, and while it is now known that plagues build up locally rather than move in from other regions, it is still important to control them over reasonably large areas rather than on single properties.

The benefits of control can be lost through reinvasion if treated areas are too small. Pest management is best organised by communities and small-scale plans (developed within the rules set by governments) need to be the primary focus with state, territory and national plans being the sum of district or regional plans (Section 8.4.6).

M3. Implementation

To implement the management plan, interested farmers from a local region meet together with a government extension officer and other stakeholders to discuss and agree on actions for monitoring and managing mouse numbers. For example, they might agree to put out ten bait cards (Section 7.1) four times a year as part of a crop monitoring program (Sections 7.2.2, 8.3 and 9.4.1). At TOPCROP or equivalent group meetings, a report on mouse numbers in the local area is a standing agenda item. If mouse numbers increase above normal levels, farmers agree to declare a 'mouse alert' (which remains in force in the area until mouse numbers decline to normal levels) and appoint a 'Mouse Alert Coordinator'.

Farmers make a commitment to meet and discuss their proposed actions as soon as possible after a mouse alert is declared. At the meeting they seek advice from government extension officers on how to monitor mouse numbers and crop damage (Section M4), and the best techniques and approaches to use to prevent the build-up from developing into a plague (Section 7.4). Farmers make a commitment to:

- conduct regular (at least monthly and preferably fortnightly) monitoring of mouse numbers and crop damage using standardised techniques and record keeping where this is feasible (Sections 7.1, 7.2, 7.3 and M4);
- implement habitat management for mouse control on their properties (Section 7.4.2); and
- keep the Mouse Alert Coordinator informed of progress on their properties.

The Mouse Alert Coordinator keeps close contact with the state government extension officer and if mouse numbers continue to build up and it is thought necessary, seeks information on the availability of rodenticides for perimeter baiting (Sections 7.4.1 and 7.4.5).

If mouse numbers continue increasing, and a plague is developing and crop invasion occurs, the Mouse Alert Coordinator seeks approval for supply and application of in-crop rodenticides.

M4. Monitoring and evaluation

Farmers meet to seek expert advice from state extension officers on techniques for monitoring and recording:

- mouse numbers (for example, using an agreed number of bait cards and lines of break-back traps in crops, along crop edges and around buildings or along fencelines on a fortnightly basis during a 'mouse alert', or four times a year at other times);
- crop damage levels (low levels of crop damage are not usually easily detected by farmers and techniques for assessing and recording crop damage levels may need to be demonstrated); and
- changes in mouse numbers and crop damage before and after poisoning (if conducted), for both treated and untreated crops where this is feasible, as well as collections of any non-target species found dead which are sent to the relevant state department for testing.

Whenever possible, farmers in a local region agree to use standardised techniques for monitoring and recording data on mouse numbers, crop damage, control techniques used (types, dates and places) and non-target kills, and provide written copies of all these data to the Mouse Alert Coordinator who collates them and gives them to the state department extension officer. The state department officer combines these data with additional data from other mouse-affected areas and arranges for an evaluation of damage levels, the effectiveness of control techniques and effects of poisoning on non-target species. The state department officer then arranges and facilitates a meeting with farmers and other stakeholders to discuss the effectiveness of the response to the mouse alert, whether the objective and performance indicators were met, and how a response to a future mouse build-up could be improved.

M5. Performance indicators

The performance indicators need to be adequate to assess whether or not the management objective is being met. The following are essential performance indicators at the farm and regional level:

- detection of build-up in mouse numbers early enough to allow farmers to implement control measures before mice start to damage crops;
- average damage levels across the farm or region do not exceed a pre-determined level in a year when mouse numbers build up and control is implemented (for example, no more than 5% reduction in yield compared to average yield for years with similar seasonal conditions); and
- cost of control of mice is less than a pre-determined level (for example, cost of mouse control is less than 5% of the total value of susceptible crops harvested from the farm or region) and less than the estimated savings in reduced damage.

Indirect performance indicators could include reduction in normal seasonal sales of organophosphate insecticides and no increase in regional reports of non-target birds handed in to fauna rescue workers.

8.8.2 Rat damage to sugarcane in north Queensland

Two species of native rodents, the canefield rat (*Rattus sordidus*) and the grassland melomys (*Melomys burtoni*), damage sugarcane in north Queensland with approximately 50% of the cane-growing area affected (Wilson and Whisson 1990).

Sugarcane growers in north Queensland have traditionally relied on rodenticides to control rats. Before 1990, the rodenticide used was thallium sulphate but because of concern over heavy metal residues in adjacent waterways, it was withdrawn from sale. The anticoagulant brodifacoum (Klerat) has been given registration to take its place, the recommended application rate being the placement of two blocks at five metre intervals in every seventh crop row (equivalent to two kilograms of bait per hectare). Aerial application is not permitted and ground baiting is conducted in January and February before the sugarcane canopy closes.

Research on its efficacy has shown that application of Klerat is of little benefit unless it is used in conjunction with weed management in and around crops (Robertson et al. 1995). Other research suggests that it may be having undesirable environmental effects; such as a reported decline in the abundance of owls in the area as a result of secondary poisoning (A. Brodie, Bureau of Sugar Experiment Stations, Queensland, pers. comm. 1996). Starvation could also contribute to owl deaths, as the number of rats available as food for the owls is reduced following a baiting program. It is therefore important that the management plan incorporates the use of the rodenticide only when and where it is necessary.

The following case study, provided by the Bureau of Sugar Experiment Stations, shows that best practice management of rodents in sugarcane requires habitat management to reduce harbourage and in-crop weeds combined with occasional strategic targeted control comprising timely rodenticide use. Regular monitoring of rodents, weeds and sugarcane damage allows assessment of the effectiveness of the strategies for reducing weeds and rodents to achieve the overall objective of reduced sugarcane damage.

Best practice management of rodents in sugarcane

(Provided by A. Brodie, Bureau of Sugar Experiment Stations, Queensland)

R1. Problem definition

Two native species of rats, the canefield rat and the grassland melomys, damage sugarcane by feeding and gnawing on the stems of sugarcane, allowing entry to bacterial and fungal infections, which lead to a decline in sugar content. Extensive gnawing can cause bending or breaking of the canes (Section 3.3) leading to further direct losses. Up to 50% of the cane stalks can be damaged in some blocks. The total cost of damage in the affected region varies between $2–9 million each year.

R2. Management Plan

R2.1 Objectives

The objectives are to:

- implement management strategies that will reduce damage caused by rodents in sugarcane to a level of less than 5%;
- reduce rodenticide use; and
- increase district awareness of rodent numbers and weed levels.

R2.2 Management options

The two options available to achieve the objectives are strategic, sustained control using habitat management to reduce harbourage and in-crop weeds, and occasional strategic, targeted control using rodenticides early in the breeding season if conditions indicate that habitat management will not reduce rodent numbers sufficiently.

R2.3 Management strategy

R.2.3.1 Habitat management

The two broad habitat management strategies for reducing numbers of rodents in sugarcane are reducing harbourage in non-crop areas and excluding weeds in crops.

Reducing harbourage

Weed control around crops is implemented throughout the year. There are several methods for controlling weeds:

- keeping grassy headlands mowed;
- clearing weeds from drains and similar areas;
- mowing or intensively grazing grassland areas; and
- revegetating unused grassland areas with closed-canopy forest.

Revegetating grassland areas with forest is very effective for weed control, especially where access for mowing is difficult. In trial areas where forest trees have been planted by landholders and local conservation groups in cooperation with government agency staff, up to 75% fewer rodents were captured one year after planting (Robertson et al. 1995). Within two years, the trees had developed a closed canopy and the resultant shading made the area totally unsuitable for rats. Up to 35 different native tree species are suitable.

Revegetation with commercial timber species can be undertaken in areas where vehicle access is possible, although more information is needed about the best species to provide both shade and saleable timber. Trees with pole like structures and few side branches such as blue quandong (*Elaeocarpus grandis*) and kauri pine (*Agathis microstachya*) minimise interference with farm machinery. Slashing is usually needed under these trees in the early stages of growth, but within 6–7 years shading is sufficient to make the habitat unsuitable for rats.

Use of herbicides in harbourage areas around crops is usually too expensive to be cost-effective and is best limited to areas that are difficult to manage by mowing, such as narrow grassy strips at the forest margin.

In-crop weed control

Crops are kept free of weeds, especially summer grasses, at all times as these provide a high-protein food source for the rodents which encourages breeding. Without the weeds, breeding is suppressed and rodent numbers remain low. Weeds can be reduced by using herbicides or by trash blanketing following green-cane harvesting. Where herbicides have been used to exclude weeds, up to 60% reduction in crop losses have been achieved (Robertson et al. 1995). In trash blanketed areas, Whisson (1996) found the percentage ground cover of weeds was less than 25%.

R2.3.2 Use of rodenticides

When rodent numbers are low, baiting is unnecessary; good weed control and reduction of harbourage are sufficient to keep crop damage to a minimum. However when conditions are likely to be highly favourable for breeding and numbers are high, rodenticides can be used in combination with weed control to limit damage (Robertson et al. 1995).

Although sugarcane damage from rodents occurs between May and October, the rodenticide is applied in January while the cane can still be entered with machinery. The advantages of baiting at this time are both environmental and economic since control is achieved early

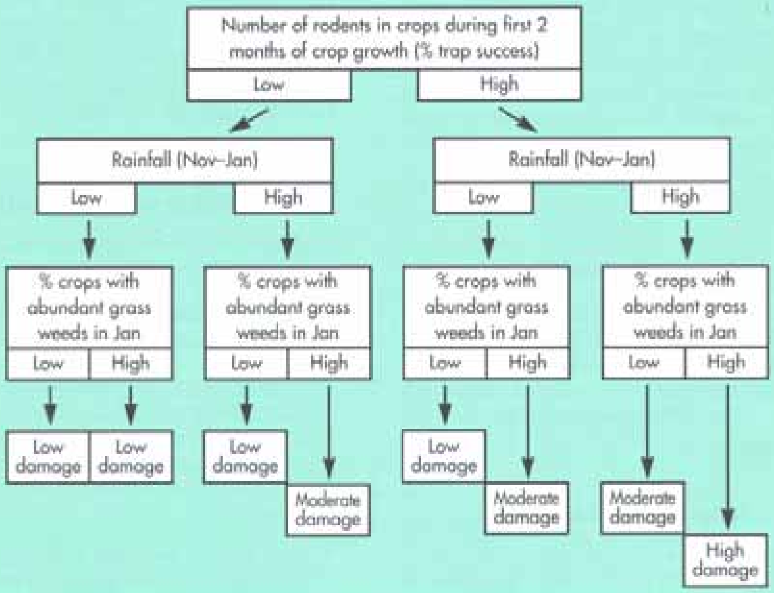

Figure 13: Flow diagram for predicting level of rodent damage to sugarcane (after Robertson et al. 1995).

in the breeding season before numbers build up and less bait is needed for effective control.

To limit rodenticide use to those areas and times when it will be worthwhile, it is necessary to monitor conditions that favour a build-up in rodent numbers.

R2.3.3 Monitoring

Rodent numbers and weed levels in sugarcane are monitored in the Mackay and Herbert districts by staff from the Cane Protection and Productivity Board (CPPB). Weeds are monitored monthly throughout the year; rodent numbers are monitored monthly between July and December using traplines, each with 20 break-back traps, along crop margins and in-crop at a number of sites. Traplines on crop margins are placed to sample all landuses adjoining the crop, including other crops, pasture and headlands. Condition of the rats captured (body weight and proportion of adults breeding) is also recorded.

These results are interpreted according to the prediction model presented in Figure 13. In December, CPPB and Bureau of Sugar Experiment Stations (BSES) staff meet with growers from each sub-district and provide advice on weed control and whether strategic baiting is recommended for the current season. In seasons when rodent numbers are low, weed control is still recommended but the use of rodenticide is not.

R2.4 Management units

Because of the risk of reinvasion by rodents from poorly managed areas, the best management unit for monitoring and coordinated action is a sub-district, which is an area of approximately 10 000 hectares.

R3. Implementation

Individual landholders undertake weed control on their farms. Revegetation of grassland harbourage areas is undertaken by landholders in conjunction with local Landcare groups and with support from government agencies.

Rodent, weed and sugarcane damage monitoring is conducted on farms by employees of the local CPPBs.

The CPPBs and BSES provide advice to farmers regarding effective in-crop and harbourage weed control and appropriate times for baiting. BSES runs field days and study tours and circulates extension literature to encourage increased adoption of this best practice approach.

R4. Monitoring and evaluation

Monitoring effectiveness of the management strategy is undertaken by the staff of the local CPPBs. Weed monitoring assesses the effectiveness of farmers' control strategies in reducing weeds in crops. Rodent monitoring indicates how successful the weed control strategies are in reducing rodent numbers.

The CPPB staff also conduct damage monitoring prior to harvest by counting the number of damaged stalks along several transects. This monitoring gives an overall assessment of the management strategy for achieving the goal of limiting rodent damage in sugarcane to less han 5%.

R5. Performance indicators

Performance indicators to evaluate the success of the management strategy are:

- reduced rodent numbers (trap success) in crops and crop margins;
- reduced sugarcane damage levels (less than 5%) at harvest and increased sugar content of cane;
- reduced sales of rodenticides in region; and
- increased attendance by growers at meetings and participation in cooperative management actions.

9. Implementing a management program

Summary

This chapter addresses the involvement of landholders, community, government and other stakeholders. It discusses group dynamics and the social aspects of rodent management. Group action to develop and implement rodent management is essential as it gives a sense of ownership of the problem and its solution to all people responsible for, or interested in, rodent control. Cooperation between landholders is needed to achieve successful control because rodents move between buildings, crops and properties and rapid reinvasion occurs if only small areas are treated.

In addition, the successful implementation of a rodent management strategy relies on two key factors. The first is the commitment of property managers to take responsibility for solving rodent problems on their land. The second is the provision of technical and financial resources adequate for the size of the problem.

The role of government agencies is to advise land managers on appropriate land management for rodent control. Government also has an important role in coordinating landholder monitoring of mouse populations and facilitating actions during mouse plagues.

9.1 Identifying stakeholders

Management of rodents needs to be seen within the wider context of landholders' goals for long-term sustainability and profitability of their lands. Although the primary stakeholder is the landholder, all stakeholders need to be identified and involved, particularly at the planning stage, to implement a management plan effectively. Effective on-farm management requires cooperation and assistance from other individuals and agencies who have the potential to influence individual property management practices. As in most land management issues, problems will only be solved if those responsible for implementing the solution 'own' the problem and the solution. Scientists may be able to assist in recognising management problems, but it is the local land managers who must remedy the situation.

The involvement of multiple stakeholders spreads ownership and thus commitment to successful outcomes. As well as landholders and government, animal welfare groups, conservationists, rural industry and grower groups, and companies producing rodenticides and baits, have an interest in rodent management. They have different perspectives and through cooperative action, a common understanding of the problem and the complexity of related issues in each local area is achieved. One means of involving interest groups is to include them on a state or regional steering committee along with representatives of landowners, grower groups and government agencies that have influence on local and regional planning to help ensure appropriate frameworks are used. Local communities must also be involved in all stages to ensure adoption of rodent management plans.

9.2 Government involvement

Government agencies are a legitimate stakeholder in rodent management as legislators, regulators of chemical sale and use and as representatives of the wider community.

At the national level, the Commonwealth Government is involved in the management of policy issues arising from rodent outbreaks. For example, the national interest could be endangered by an exotic disease outbreak during a rodent plague or from rodenticide residues in crops which would jeopardise export trade income. Strict regulations are imposed at the national level to manage these risks, such as registration of rodenticides through the National Registration Authority.

The Commonwealth Government also has a role in environmental management and funding of pest management research. It represents the national interest on State–Commonwealth intergovernmental committees. The Vertebrate Pests Committee (VPC) is one such committee and acts as a formal coordination body in setting national priorities for pest animal management.

The role of state governments is broader, and varies from area to area and at different times according to the nature of pest rodent problems. Generally, state government agencies have a continuing role in encouraging landowners to adopt good management practices, achieved by providing appropriate incentives, education, training, research and development.

'Government has an important role in facilitating group action.'

Another key role state governments can have is to coordinate monitoring of mouse numbers to predict plagues. This requires sustained commitment on the part of government for the longer term, particularly during non-plague years. State government agencies need to maintain close communication with landholder organisations at all times, not only when monitoring indicates that a mouse plague is likely. The results of the monitoring need to be passed on regularly to industry organisations, commercial bait manufacturers and distributors, farmer groups and other relevant government agencies so decisions about action are undertaken jointly by all stakeholders.

It is not the role of government to manage pest rodents (Section 6.2). The impetus for rodent control needs to come from the landholders and community. However, governments have an important role in facilitating group action. Previous experience with outbreaks in South Australia, Victoria, New South Wales and Queensland indicates that a government initiated and supported committee is very effective. The Mouse Task Force for the 1995 plague in Queensland had representatives from State government departments concerned with agriculture, pest management and human health as well as rural industry, conservation and animal welfare groups. A similar Mouse Plague Task Force is used in South Australia when stakeholder input is required in decision making. In Victoria, government policy requires the establishment of a Task Force to manage mouse plagues. The Victorian policy statement provides for similar interest groups to be represented and could be used as a model. This Mouse Plague Committee or Task Force needs to be formed whenever monitoring indicates a mouse plague is highly likely but before it develops to a stage where crops are seriously damaged.

9.3 The role of extension services

Implementation of a strategic approach towards management of rodents involves several control technologies and processes (Chapter 7). Extension officers receive on-the-job training on these methods and their role is to provide landholders with advice on appropriate control options and to encourage a group approach towards management. The role of extension officers will vary depending on the management option chosen. Different extension techniques need to be adopted to suit the situation, the management goals and scale — national, state, regional, district or farm.

During mouse plagues, local extension officers are also involved in facilitating district control programs, providing advice on safe use of rodenticides and, in some cases, operator training in rodenticide use. Local conferences, workshops and meetings are also held where mouse biology, ecology and control options are discussed with other stakeholders. Extension officers from other states may visit a plague area to observe the alternative strategies used. Additionally, technology may be borrowed or shared. In Queensland, for example, the Department of Lands (now the Department of Natural Resources) contracted the South

Australian Animal and Plant Control Commission (APCC) to exhibit the bait mixing equipment devised by the APCC. The monitoring systems implemented by each state were also discussed.

Extension officers also act to encourage a group approach towards the management of the problem. Given the pivotal role of group action for effective management of rodents, extension officers need facilitation skills, yet most extension staff do not receive formal training in advisory techniques, conflict resolution, negotiation and problem definition. Sound technical knowledge is essential, but has to be complemented by skills which permit front-line extension officers to determine both landholder and wider community views quickly and negotiate around that knowledge. Courses that offer training in these skills are a priority for those officers involved in coordination and facilitation of stakeholder groups (Section 10.10).

9.4 Group formation

An increasing emphasis has been placed on involving a broader range of stakeholders in environmental management (Campbell 1992; Carr 1994). Participation at the community level with groups is one of the key strategies to achieve sustainability (Alexander 1993). Group structures can also be useful in different levels depending on the particular circumstances. Cooperative action is recognised as essential in pest rodent management for many reasons.

At the community scale group schemes allow better management of rodents that cross property boundaries by providing for broadscale, synchronised actions to minimise reinfestation. Groups with a shared understanding of the problem can monitor performance and results, and integrate the knowledge gained into their regular property management (Woods et al. 1993). Joint action by landholders over several properties can also lead to economies of scale by reducing costs to the individual.

At broader scales, group structures are also helpful in that they:

- encourage strong ownership of the problem by the group as it develops cohesiveness;
- promote greater interest and awareness of the problem and its solutions within the group and local community;
- result in peer group pressure, thus further contributing to group ownership; and
- can lead to more strategic long-term management.

'Group management of pests reduces individual costs and minimises reinfestation.'

In strategic management, opportunities to involve stakeholder groups occur during all of the four components — defining the problem, developing the management plan, implementing management practices and monitoring and evaluation (Section 8.2). People learn better when they are involved in all of the stages from problem definition through to evaluation (Kolb 1984). If government and landholders both need to learn about specific situations, cooperation is required at all times.

9.4.1 Landholder groups

Rodents may cross property boundaries and each landholder's action, or lack of action, may affect his or her neighbours. Therefore, management of rodents requires a cooperative group approach to effectively:

- gather data about rodent numbers;
- make sound, free and informed decisions about what actions to take;
- implement those decisions with commitment; and
- coordinate actions, including integrating rodent habitat reduction into property management.

The structure of such groups may vary between states and regions but in general, groups which meet regularly to discuss general farm management strategies are ideal. One example is TOPCROP groups which meet four times a year (Sections 7.2.2, 8.3 and 8.8.1 M4). Farming organisations such as Queensland Grain Growers Association (QGGA), South Australian Agricultural Bureaus and consultant groups may also provide an appropriate forum.

9.4.2 Broader community groups

The use of broader stakeholder groups is essential during mouse plagues. Town communities as well as rural properties can be seriously affected. In addition, the control options proposed are often of concern to conservation and animal welfare groups. Further, health and trade risks posed must be addressed by government.

All stakeholders should therefore be involved. The proposed Mouse Plague Committee or Task Force (Section 9.2) is one way of representing the views of a wide section of the community and addressing the issues which have the potential to cause conflict. Other regional groups may be needed as well, depending on the scale of the problem. The severity and extent of mouse outbreaks determines the level at which action needs to be taken. At the state level, a Plague Committee provides a mechanism for state-wide decision making involving many stakeholders. At the local level, it is preferable to use existing group structures where possible but one-off groups may need to be formed specifically to coordinate local action during times of outbreaks. For example, industry groups proved effective in coordinating local action during the 1995 Queensland mouse outbreak. Local QGGA members called and organised the group meetings; government officers assisted with facilitation and coordination at the meetings.

Government support for such pest management groups is likely to increase the probability of achieving successful outcomes. The role of government officers and others should be carefully negotiated and clearly understood by all parties. The government agency should encourage and facilitate group meetings but not impose this, otherwise local landholders will not have ownership of the problem or of the proposed solution. This partnership-based participative approach, rather than top-down consultation, is essential for effective pest management (Kelly 1995).

9.5 Facilitation of effective groups

The ultimate aim of implementing rodent management is to change behaviour and facilitate adoption of sustainable and profitable land management practices. It is recognised that new approaches in extension are needed to encourage adoption, especially within the complexities of overall land management introduced in the 1990s (Vanclay and Lawrence 1994; Blacket et al. 1995). For example, the development of Landcare over the last decade has done much to improve knowledge of the social dimensions of land management and the role of group dynamics in ensuring successful program outcomes (Campbell 1992; Alexander 1993; Carr 1994). Replacing traditional technology transfer models with new approaches that ensure all stakeholders improve their decision-making skills will enable groups to operate more efficiently and effectively.

Successful formation and facilitation of groups in times of crisis such as mouse outbreaks are particularly important. The tasks are often difficult, requiring skills in conflict resolution, negotiation, mediation, leadership, team building, planning and evaluation. Conflict resolution skills are especially important and facilitation skills of extension officers need to be well developed. Although such skills are inherent in some people and can be learnt by most people, performance is often less than optimal. An understanding of group dynamics and strategies is needed to work effectively with multiple stakeholders in groups (Chamala and Mortiss 1990; Pretty 1994). Ultimately, flexibility is paramount.

10. Deficiencies limiting effective management

Summary

A number of deficiencies have been identified during the preparation of these guidelines. Firstly, better techniques for estimating rodent numbers are required for landholders to monitor rodent build-ups and implement appropriate control actions to prevent or limit damage. Landholders also require simple and reliable techniques to assess rodent damage so that they can estimate the economic losses caused by mouse plagues and rat infestation of crops.

Reliable measures of economic losses will allow evaluation of the efficacy of different control techniques and of appropriate expenditure on control, research and development programs. They will also allow control effort to be targeted to areas where it is most needed. Rodent damage to the environment also needs to be measured.

The effects of current and potential rodenticides need to be evaluated. It is essential that regulatory authorities are satisfied that rodenticides are safe for non-target species, including people, domestic animals, granivorous birds, birds of prey and other native species, before approval is given for their use. Regulatory authorities need also to ensure that rodenticides are not persistent in terrestrial and aquatic systems, nor in agricultural products, and that there is no likelihood of other unacceptable effects on the environment. Because Australia needs to maintain a 'clean and green' image for its agricultural produce, it is important that more research is conducted on residues, particularly where poisoning is conducted in crops or near waterways.

The costs and benefits of different rodent management strategies need to be compared. In particular, managers need reliable information on the costs and benefits of (a) perimeter and in-crop baiting for mice and rats and (b) reducing mice and rats in donor habitats through controlling food availability and harbour destruction. An evaluation of the costs and benefits of different control techniques, alone and in combination, will allow a comparison of their cost-effectiveness and a determination of whether their cost is economically justified by returns in increased yield.

10.1 Introduction

A number of deficiencies in our understanding of the impact of pest rodents and the effectiveness of different control options have been identified in the course of preparing these guidelines. To implement a satisfactory management strategy, these deficiencies require addressing with some urgency.

10.2 Techniques for monitoring rodent numbers

Deficiency

Simple and reliable techniques for estimating rodent numbers are required so that landholders can monitor rodent build-ups (Section 7.1).

Developments required

Rodent monitoring techniques need to be evaluated to assess:

- if they give estimates of changes in rodent numbers that are sufficiently timely, reliable and in a form suitable to enable landholders to take appropriate management actions to limit or prevent rodent damage;
- their cost in terms of landholder time and resources; and
- if landholders are willing to use them and if not, how they can be modified to make them practical and useful.

A standardised process needs to be developed to include recording rodent numbers or activity into landholder crop monitoring programs (Section 7.2.2). A formal process also needs to be developed to collate and evaluate data from these monitoring programs to form an early warning system to advise landholders of build-ups in rodent populations in local areas.

Consequences

Reliable assessment of rodent numbers in local areas, particularly refuge habitats, will raise awareness of potential problems and ensure that appropriate control actions are implemented soon enough to prevent or reduce damage.

10.3 Techniques for assessing damage and economic losses

Deficiency

Simple and reliable techniques are required by landholders to assess rodent damage and economic losses (Section 7.3).

Developments required

Simple techniques need to be developed and evaluated for landholders to measure rodent damage and estimate economic losses.

Landholders need to be able to determine the relationships between rodent damage levels (the direct effect rodents have on commodities) and economic losses (the value of losses caused to producers). A complex relationship may exist between the level of damage caused by rodents and actual economic losses. For example, crops damaged by rodents may have compensatory growth, or alternatively, a small level of rodent damage to a crop might lead to fungus infection, and to yield losses far in excess of the initial levels of damage. Landholders need information on these relationships for different crop types and different types and levels of damage (Section 7.3).

Consequences

Landholders and researchers will have techniques that can be used to give reliable estimates of economic losses due to rodents which can be used for developing and planning improved management strategies.

10.4 Decision support systems to aid management

Deficiency

Decision support systems would be useful to landholders when determining appropriate management techniques (Section 8.3).

Development required

A decision support system that combines monitoring results (Section 10.2) and damage estimates (Section 10.3) would assist landholders in determining when to take action and what action to take.

Consequences

Landholders can implement appropriate strategies at appropriate times, reducing potential damage and crop losses, and possibly preventing plague populations.

10.5 Evaluating economic losses caused by mouse plagues

Deficiency

More knowledge of the economic losses caused by mouse plagues to agricultural production is required. There are few quantified estimates of losses caused during mouse plagues to agriculture, and no value has been placed on the extent and severity of losses experienced by sheep and cattle graziers (Section 3.1.4).

Development required

Economic impact of mouse plagues needs to be determined to evaluate:

- losses to different grain crops;
- depletion of pastures and a resultant loss in stock condition, especially in ewes and lambs; and

- losses to vegetable, fruit and nut crops.

Consequences

Reliable measures of economic losses caused by mouse plagues will allow:

- evaluation of justifiable expenditure on control and on research and development programs;
- control effort to be concentrated in areas where it is most needed; and
- estimation of efficacy of control methods, so different management strategies can be compared.

10.6 Evaluating economic losses caused by rats

Deficiency

More studies are required on the extent and severity of losses caused by rats in orchards (Section 3.2).

Development required

Economic impact of rats requires evaluation, particularly in macadamia, citrus, banana and avocado orchards.

Consequences

Reliable measures of economic losses caused by rats will allow:

- evaluation of justifiable expenditure on control, and on research and development programs;
- control effort to be concentrated in areas where it is most needed; and
- estimation of efficacy of control methods, so different management strategies can be compared.

10.7 Evaluating environmental damage caused by rodents

Deficiency

The extent and severity of damage caused by pest rodents to the environment has not been well documented (Section 4.1).

Developments required

The extent and severity of the following potential impacts need to be evaluated:

- competition with other fauna for resources;
- impact on native vegetation, including depletion of seed banks;
- increased risk of soil erosion through removal of ground cover;
- transmission of disease to other fauna;
- impact on abundance of predators; and
- predation on native fauna, including invertebrates, particularly on islands.

Consequences

Environmental managers will have the knowledge necessary to make sound decisions about whether rodent control is needed, where it should be targeted, and how much to spend on control, and on funding for research and development.

10.8 Impacts of rodenticides

Deficiency

Little is known about the potential environmental impact of poisons used to control rodents. The large quantities of poisons used to control rodents and their potential environmental impact has always raised concern. Many poison registrations were current when the Commonwealth *Agriculture and Veterinary Chemicals Code Act 1994* was gazetted and were accepted without testing. Because Australia needs to maintain a 'clean and green' image for its agricultural produce, it is important that more research is conducted on residues, particularly where poisoning is conducted in-crop or near waterways (Section 4.3.2).

Development required

Current and potential rodenticides need to be evaluated for humaneness and environmental impacts such as:

- poisoning of non-target animals, including people, domestic animals, granivorous birds, birds of prey and other native species;

- abundance of predators after poisoning prey species;
- hazards posed by residues in the soil and water run-off; and
- possible contamination of the harvest.

Consequences

Evaluation of the impact of rodenticides will enable farmers, regulatory authorities, community groups and other stakeholders to properly distinguish between chemical agents on welfare, environmental and human health grounds.

Regulatory authorities will be satisfied that rodenticides are safe for non-target species, including people, before approval is given for use. In addition, they will be able to ensure that rodenticides do not persist in terrestrial and aquatic systems, nor in agricultural products, and that there is no likelihood of other unacceptable effects on the environment.

10.9 Costs and benefits of rodent control techniques and strategies

Deficiency

Cost–benefit analyses of different rodent control techniques and management strategies need to be undertaken (Section 7.4.6).

Development required

To plan appropriate management strategies, pest rodent managers need information on the cost–benefits of different control techniques, alone and in combination. Because rodents come and go, and crops can have compensatory growth following rodent damage, designed experiments are needed to get data on the efficacy and economic benefits of different rodent control strategies. Large-scale, replicated experiments which cover a range of seasonal conditions and rodent densities are essential, because management strategies that work in one place, time or crop may not be equally effective elsewhere. In particular, managers need reliable information on the costs and benefits of the following techniques, alone and in combination:

- perimeter and in-crop baiting for mice and rats;
- reducing mice and rats in donor habitats through control of food availability and harbour destruction; and
- encouraging raptors in and around crops.

Consequences

An evaluation of the costs and benefits of different control techniques and strategies will allow landholders to compare their cost-effectiveness and determine whether their cost is economically justified by returns in increased yields.

10.10 Training of extension officers

Deficiency

Given the pivotal role of extension services in providing advice to landholders and encouraging group action, extension officers need facilitation skills. Most extension staff do not receive formal training in advisory techniques, conflict resolution, negotiation and problem definition (Section 9.3).

Development required

Courses are required that offer training in facilitation and negotiation skills. Sound technical knowledge is essential, but has to be complemented by skills which permit front-line extension officers to determine both landholder and wider community views quickly, and facilitate information exchange between different groups.

Consequences

Training and facilitation will enhance the role of extension staff in achieving group action by all stakeholders for effective regional rodent management.

10.11 Conclusions

Addressing these deficiencies is essential for achieving effective management of rodents and the damage they cause to agriculture and the environment. Some of the necessary research is currently under way but the nature of these problems is complex and will require considerable effort on the part of the research community. Successful rodent control is likely to need an integrated approach using multiple techniques to deal effectively with the conditions that foster outbreaks. Close communication between researchers and landholders will be invaluable for obtaining data on the benefits of different management options. For this reason, the involvement of researchers in the design and implementation of management strategies is strongly recommend.

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SUMMARY

In Australia, a number of rodent species are agricultural pests. Two species, the house mouse (*Mus domesticus*) and black rat (*Rattus rattus*), were introduced around the time of European settlement. House mice occur throughout Australia and, when conditions are favourable, they build up in agricultural regions. Their numbers can increase to a level where they form plagues and cause significant crop damage. Black rats (sometimes called plague rats, ship rats or roof rats) occur throughout temperate and tropical Australia in environments modified by people.

Several native species can also be pests. Two species whose natural habitat is tall coastal grassland in tropical and subtropical areas have become serious pests of sugarcane. These are the canefield rat (*R. sordidus*) and the grassland melomys (*Melomys burtoni*). Another species, the pale field-rat (*R. tunneyi*), causes damage to young trees in hoop pine plantations. In the Ord River area of north Western Australia, the long-haired rat (*R. villosissimus*) can cause crop damage when it is at plague densities.

Biology

Rodents typically grow rapidly, reach sexual maturity early, and are highly fecund. They are also good dispersers and quickly colonise new areas when conditions are good. Mortality rates are usually high and life spans short.

Breeding is generally triggered by rainfall. In tropical and subtropical areas, rats typically breed in late summer and autumn following the onset of the wet season. Mice mostly breed in spring and early summer but they also breed at other times of the year when conditions are favourable. The young grow rapidly and reach sexual maturity within two months, well within the span of a breeding season. Female mice can produce a litter per month which means that the doubling time for a population can be as short as three to four weeks.

All the major pest rodent species in Australia feed primarily on seeds, the pith of stems and other plant material. A house mouse eats 3–4 grams of grain per day and the larger rats eat 20–30 grams of food per day.

Economic impact

The greatest economic impact of rodent pests in Australia is that caused to grain crops during mouse plagues in eastern Australia. At such times, mice also damage farm machinery, electrical equipment, household goods and personal possessions. However, the cost of other damage is small by comparison with losses in crop production.

There has been a mouse plague somewhere in the Australian grain belt every four years on average since 1900, and in the last twenty years, the frequency of plagues has increased to one every year or two. Various estimates of losses to grain growers have been made during mouse plagues. The average of the three most recent estimates is $46 million. If this average loss is typical, then since 1900, the average annual loss to grain growers has been in the order of $13 million, and more than double this figure for the last 20 years. But these are very approximate and conservative estimates.

During plagues, mice also cause losses to other agricultural enterprises. They invade piggeries and poultry sheds, consuming and spoiling feed and causing production losses through physical attacks on livestock. Orchardists and vegetable growers also sustain damage from mice which eat their crops and foul produce with faeces, urine and carcasses, both in the field and in storage. Graziers too are affected through loss of pasture, seed reserves, stored hay and feed grain.

Mice invade rural townships during plagues, with rural suppliers and food retailers being particularly affected through loss of stock. The highest cost for all businesses is the time spent controlling mice and maintaining standards of hygiene. The social cost is also very high for rural town and farm people.

Other rodent species can also have a significant economic impact. Black rats cause losses in orchards with the damage in some years as high as 30% in older macadamia orchards, although 5% (equivalent to $2 million annually) is considered to be a 'normal' loss. Avocado, banana and citrus crops can also sustain damage but the extent and severity have not been evaluated.

Two species of native rodent damage sugarcane by eating and gnawing on the stalks allowing access to sugar-degrading bacteria, fungi and insects. The loss to the Queensland sugarcane crop from these rats is between $2 and $9 million each year with a further $0.6 million being spent annually on baiting programs. The rats also cause damage to equipment such as plastic irrigation lines.

Environmental impact

The impact of pest rodents on the environment has not been well documented. Mouse plagues increase the risk of wind erosion of soils by reducing the amount of ground cover in pastures and crops. Other potential impacts include competition with native fauna for resources and depletion of native seed banks. The switch in diet of predators after mouse plagues may place pressure on native prey species, especially as predator density tends to increase during plagues.

One known, but poorly quantified, environmental impact is that of rodenticides on non-target species. Rodenticides are generally non-specific poisons and, if not used appropriately, can kill other species, including people, livestock and native animals. Although large quantities of rodenticides are used annually, there are few reports of non-target losses. To minimise the risk of such losses, pest rodents are targeted through the use of special baiting techniques and careful selection of bait substrate. Detecting the extent of non-target poisoning is difficult and this is why losses are rarely quantified. Of greater environmental concern is the uncontrolled off-label use of chemicals when cost-effective registered products are not available, as has occurred during mouse plagues.

Inappropriate use of either registered or off-label rodenticides may also lead to unwelcome chemical residues in soil and in plant and animal products.

Social impact and attitudes

Cleanliness and hygiene are essential during rodent outbreaks since rats and mice are capable of transmitting many pathogens to humans and livestock. Rodents are reservoirs for a large number of infectious organisms. In Australia, the most significant rat-borne diseases that can affect people are leptospirosis, salmonellosis and toxoplasmosis. The last two are also spread by house mice. Potentially more dangerous for farmers are diseases such as swine encephalomyocarditis that can be carried to livestock. This increased risk of disease is an additional concern for intensive livestock producers during plagues.

Individual perceptions of rats and mice determine to a large extent how people cope with plagues. Most people perceive them as unattractive and during mouse plagues they find sharing their homes with mice for an extended period of time highly stressful. For many farmers and townspeople, the stress is exacerbated by the additional worry of financial loss. There is also the worry of accidental poisoning from the widespread use of poisons. People will use poisons in ways that they would not normally countenance, such as on kitchen benches, in their attempt to achieve control. In rural communities these social stresses are often more debilitating than the actual damage incurred.

Past management and current policy

Some rodents are declared pests under legislation in Western Australia, Victoria and the Northern Territory and landholders may be required to undertake control measures. In other states and territories there is no legal requirement for rodents to be controlled. While introduced species can be controlled at a landholder's discretion, native species are protected wildlife and cannot be controlled without permission from wildlife authorities. The use of chemical poisons is constrained by regulations in all states and territories. A number of rodenticides are registered for use in and around buildings, animal sheds and storage facilities, but none are registered for in-crop use except for the anticoagulant brodifacoum in sugarcane. Special permits need to be obtained from state governments before specific rodenticides can be applied in or around crops and orchards.

Poisoning has always been, and still is, the usual management practice for dealing with plagues at the farm level. Strychnine used to be the most widely used chemical for controlling mice but its use has been progressively restricted since the 1980s and it is currently unavailable. Other rodenticides are now being evaluated for in-crop use against mice. Until recently, thallium sulphate was available for controlling rats in sugarcane but was withdrawn from sale because of concern over heavy metal residues in adjacent waterways. Brodifacoum has been registered to take its place. In hoop pine plantations, pale field-rats are controlled with sodium fluoroacetate (1080). Rats in macadamia plantations are controlled with commercially prepared anticoagulant rodenticides distributed in bait stations.

Techniques to measure and control rodent impact and abundance

Techniques for assessing rodent densities include: trapping success; the proportion of oil-soaked cards eaten in fields overnight; counts of active burrows or nest sites; extent of crop damage; and numbers of rodents seen on roads or around buildings. Although these techniques give only rough approximations of densities, they are usually adequate to allow farmers to determine when numbers are increasing and control needs to be implemented. Whatever method farmers select for monitoring rodent numbers, it is important that results be recorded in a standardised format across local regions so that patterns and trends can be recognised.

Rodent densities need to be correlated with damage. Data on the relationship between numbers and damage are sparse, but measures of damage are essential for estimating the efficacy of control measures and whether or not their cost is economically justified by returns in increased yields. Assessment of damage is often subjective. Good experimental design and techniques are essential if valid conclusions are to be drawn from the data.

Rodenticides are still the mainstay of all practical rodent control in both urban and agricultural environments. The majority of rodenticides are administered as poisoned baits. In and around buildings and storages, bait should be laid in bait stations for two reasons: to reduce the risk to non-target species; and to monitor consumption of bait. Similarly, bait stations are a preferable means of bait delivery in orchards and for perimeter baiting around crops, although in the latter situation this is not feasible where large areas are to be protected.

Other methods of control are directed towards reducing the amount of cover and food available to rodents, particularly in donor habitats from which the animals disperse into crops and pastures. Reducing cover is likely to increase the rate of mortality from predation and extremes of weather. Strategies for reducing rodents in such donor habitats include grazing stubbles after harvest to reduce shelter and remove spilt grain; and spraying or slashing of grass and weeds along fencelines, roads and channel banks, and around sheds and storages to reduce the seed set and remove harbour. Similarly, pastures can be grazed lightly and frequently throughout spring and summer to reduce the amount of seed set and cover. Other management techniques recommended for controlling mice in cereal crops include: not sowing grain until soil is moist enough to allow immediate germination; slashing or burning stubble where there is no risk of erosion; planting seed at a higher rate to compensate for possible losses to mice; and planting deeper and cross harrowing after sowing so that it is harder for mice to find the seed.

Controlling rodents around buildings and storages by rodent-proofing can be expensive and technically difficult unless it is incorporated at the design and construction phase. To be rodent-proof, structures must have no apertures wider than the width of the head of the pest at weaning age, which is as small as six millimetres for house mice. As rodents tend to gnaw, structures must be built of concrete, brick or metal. Doors must fit well and be kept closed. Other control techniques for storages include trapping and, in small areas that can be sealed, the use of poisonous gases (fumigants), such as phosphine.

Biological control techniques for mice are still at an early stage of development. Research is currently under way into techniques for delivering immuno-contraceptives to rodents using genetically modified viruses. Although the outcome of the research is still uncertain, if successful, it may one day be possible to permanently sterilise a high proportion of a rodent population at a sufficiently low cost to make fertility control a practical management option.

Strategic management at the local and regional level

The strategic approach to managing pests has four components: defining the problem; developing a management plan; implementing the plan; and monitoring and evaluating progress and outcomes. Strategic management involves integrating rodent control operations into overall land management planning that incorporates specific local knowledge. For rodents, two factors are critical: coordinated monitoring by landholders to ensure early detection of a build-up in rodent numbers; and implementation of management strategies by landholders to reduce numbers in order to minimise the likelihood of damage. A problem with rodent control, particularly for mice, is that it often comes too late to alleviate damage significantly. Awareness of a build-up in rodent numbers within localities and regions will give landholders the opportunity to modify a number of farm management practices which affect the amount of food and harbour available to rodents, and also to implement early poisoning where this is desirable.

Strategic management requires reliable information on the efficacy, cost-effectiveness and acceptability of different control measures so that alternatives and combinations can be evaluated. It is likely that successful rodent control will require an integrated approach using multiple techniques to deal effectively with the conditions that lead to a build-up in numbers.

Operational monitoring (efficiency of the strategy) and performance monitoring (effectiveness of the strategy) are both essential aspects of implementing a management program. It is important to distinguish between efficiency and effectiveness — management can be efficient if it kills many rodents for a small cost, but ineffective if it fails to reduce damage. Effective rodent control should give increased crop productivity compared to areas with no or less rodent control.

Economic frameworks can assist land managers assess the relative value of alternative control strategies. Such frameworks require: definition of the economic problem; data on the relative costs and benefits of different rodent management strategies; an understanding of why actions of individual land managers may not lead to effective levels of rodent control; and assessment of the means by which governments might intervene to overcome identified problems. Land managers can use such economic frameworks to select the most appropriate rodent management strategy for their circumstances.

Implementing a management program

Landholders need to cooperate as a group to achieve successful rodent management over large areas. Group action to develop and implement rodent management is essential for two reasons. Firstly, it gives a sense of ownership of the problem to all people responsible for, or interested in, rodent control, whether they be private or government. Secondly, the management program needs to cover large areas to be effective because some rodents move between crops and properties and may rapidly reinvade small treated areas.

Modern farming practice involves monitoring and record keeping and therefore rodent management can be incorporated into routine farm management. The key to the strategy for managing rodents is for landholders to maintain an awareness of their numbers at all times. For mice, the preferred approach for achieving this is to incorporate a system of assessing mouse activity or abundance into an existing crop monitoring program such as TOPCROP. Awareness may also be encouraged and monitored by landholders within local Landcare groups, consultancy groups or other farmer groups managed by agribusiness as well as rural industry groups such as branches of grain growers organisations. Early detection of mouse build-ups will increase the options for landholders to reduce harbour and to modify land management techniques to restrict the build-up in mouse numbers.

Apart from the benefits of keeping landholders aware of mouse numbers, the inclusion of mouse monitoring in a general pest monitoring program is that information on population changes can be more readily passed on to government agencies through regional officers. Then, if temporary availability of rodenticides is necessary, the government can ensure landholders have access to safe and effective rodenticides before mice reach plague numbers and landholders resort to off-label use of chemicals. Spreading an early warning among the landholders in a community will also be an important function of the regional officers of the state governments.

Deficiencies limiting effective management

During the preparation of these guidelines, a number of information deficiencies were identified. In particular there is a need for reliable techniques that enable landholders to estimate rodent numbers and evaluate the economic losses associated with rodent damage. Decision support systems, that describe options for when rodent numbers and activity reach threshold levels and the probable outcomes of implementing those options, would assist landholders in making management decisions. Research is needed into the efficacy and cost–benefits of control methods. The lack of available data on environmental impact of rodents and rodenticides also needs to be addressed.

APPENDIX A

Rodenticides used for rodent control in Australia

The following is a brief description of rodenticides that are, have been or have the potential to be used to control agricultural pest rodents in Australia. Each entry begins with the common name, followed by the chemical name (where different) and the Chemical Abstracts Service (CAS) registry number in square brackets. As different names are used around the world, the latter identifier is useful for searching for information in literature and on computer databases. Treatments described are for guidance only and reference should be made to the Material Safety Data Sheet (MSDS) or Poisons Information Centre for appropriate treatment procedures.

Available rodenticides

Acute poisons

Acute rodenticides are generally cheap and highly toxic. These poisons start acting and often kill within 24 hours of the ingestion or absorption of a lethal dose. Usually, the larger the dose, the more rapid the effect.

Many rodent species, especially rats, avoid new foods, and may only take very small quantities of a poison bait in initial feeding bouts (Barnett 1988; Macdonald and Fenn 1994). This neophobic behaviour can reduce the efficacy of acute rodenticides, particularly as the rodent may eat enough to get unpleasant symptoms without dying. On future contact, it is likely to avoid the bait. For this reason, pre-baiting is often conducted over several days with unpoisoned bait to increase the likelihood that a lethal dose is consumed when the poisoned bait is introduced.

Because acute poisons can kill rapidly, they are popular if there is a heavy rodent infestation in a valuable crop or stored commodity. To gain the advantage of rapid action, however, pre-baiting must be foregone. Consequently survivors may be bait shy and it is desirable to change the bait type and use an anticoagulant rodenticide for follow-up poisoning (Buckle 1994a). Using anticoagulants from the outset may give better results but may be more expensive, so operators will need to make a judgement as to whether cost or high kill rates are a priority.

Pre-baiting in and around agricultural crops is rarely economically feasible and direct baiting is the normal practice. There is limited information on the efficacy of direct baiting. An alternative to pre-baiting is to add poison to a food in the area that is naturally eaten by rodents.

None of the acute poisons listed are registered for use as a rodenticide at the present time other than strychnine, and because of the grains industry's concern about implications for export markets, state authorities will not approve strychnine use. Following safe and effective use of zinc phosphide during mouse plague control programs in Queensland, Victoria, South Australia and Western Australia during 1997 under permit from the National Registration Authority, applications for its registration as an in-crop rodenticide are in preparation.

Alphachloralose

Alphachloralose, (or α-chloralose) (R)-1,2-O-(2,2,2-trichloroethylidene)-α-D-glucofuranose, [1587993-3], is a fast acting narcotic. It acts by slowing down essential metabolic processes including heart rate, respiration and brain activity, inducing hypothermia and eventual death. Its effectiveness is very dependent on ambient temperatures with best results being recorded at temperatures less than 15°C. As a narcotic, alphachloralose initially sedates the animal. Because of this it is believed to be one of the most humane rodenticides, despite being largely ineffective on rats, and mice having the ability to develop tolerance (Meehan 1984, 1985). Naloxone is antidotal and is administered by injection under medical supervision.

Cholecalciferol

Cholecalciferol, 9,10-secocholesta-5,7,10 (19)-trien-3-β-o1, [67-97-0], is one of the D group of vitamins (vitamin D_3). It acts by increasing (a) the adsorption and retention of calcium and phosphorus, and (b) the mobilisation of calcium from bone. This leads to high levels of circulating calcium and phosphorus causing circulatory system collapse and subsequent death. Cholecalciferol poisoning can be treated by: decreasing the absorption of cholecalciferol from the intestinal tract; prevention of skin conversion of vitamin D; decreasing intestinal absorption of calcium and phosphorus with a low calcium diet and phosphate binders; correcting the resulting fluid and electrolyte imbalances; reducing hypercalcaemia; and controlling life threatening complications such as seizures and cardiac arrhythmias (Carothers and Chew 1991).

Sodium fluoroacetate (1080)

Sodium fluoroacetate, 2-fluoroacetic acid, sodium salt, [62-74-8], or 1080, is highly toxic to rodents, especially rats, which are more sensitive to it than mice. It is also used in feral animal control campaigns against rabbits, wild dogs, foxes and feral pigs in Australia. Fluoroacetate acts by blocking an important biochemical energy generating mechanism, the citric acid cycle, leading to convulsions and either respiratory or cardiac failure (Buckle 1994a). The use of 1080 is carefully regulated because of its high toxicity and lack of antidote, as well as the risk of accidental poisoning of non-target animals. Treatment consists of inducing vomiting, and gastric adsorption with activated charcoal or sorbitol whilst the patient is still conscious. Early treatment, commenced as soon as possible after ingestion, offers the best prognosis for recovery (B. Parker, author, personal observation). Symptoms must be controlled and essential life processes maintained until the poison is excreted.

Strychnine

Strychnine, strychnidin-10-one, [57,24,9], is a fast-acting rodenticide. It acts by attacking the central nervous system leading rapidly to paralysis and death, generally due to respiratory failure. Sub-lethal doses are quickly metabolised by the liver, leading to temporary increased tolerance of the poison. There is no antidote to this poison and treatment consists of inducing vomiting; gastric adsorption with activated charcoal or sorbitol whilst the patient is still conscious; and maintaining essential life processes.

Thallium sulphate

Thallium sulphate, [7446-18-6], is a relatively slow-acting acute poison. It acts by attacking the central nervous system leading to convulsions, paralysis and death. Treatment is by administration of a chelating agent such as dimercaprol.

Zinc phosphide

Zinc phosphide, [1314-84-7], is a moderately fast acting poison with death commonly occurring within an hour of ingestion. It acts by releasing highly toxic phosphine gas in the acidic conditions of the stomach. The gas is readily adsorbed from the gastro-intestinal tract leading to central nervous system depression and subsequent death, usually from heart failure. The poison is used extensively in Europe, Asia and the United States for the control of rodents and has been under trial in Australia. Phosphine generated from aluminium phosphide is already used in Australia for grain fumigation, and there are established maximum residue limits (MRLs) for a variety of crop types. Phosphine poisoning is treated symptomatically.

Anticoagulants

Anticoagulant poisons were introduced in the early 1950s. These poisons block the recycling of the active form of vitamin K that is essential for blood clotting. Following ingestion of an effective dose, sufficient clotting factors remain in the blood to maintain clotting for 4–10 days (Buckle 1994a). The delay prevents rodents associating the symptoms with the bait and therefore no bait shyness develops. Administration of large doses of vitamin K acts as an antidote for all the anticoagulant poisons.

Resistance to the early anticoagulants, such as warfarin, soon appeared (Saunders 1978). A second generation of anti-coagulants, such as brodifacoum and bromadiolone, were developed with a different mode of action and are a better option if they are available. Resistance to these anticoagulants has developed in some parts of the world (Buckle 1994a), but as yet has not been recorded in Australia.

Brodifacoum

Brodifacoum, 3-[3-(4'-bromobiphenyl-4-yl)-1,2,3,4-tetrahydro-1-naphthyl]-4-hydroxy-coumarin, [56073-10-0], is a second generation anticoagulant rodenticide. It acts in the same way as warfarin, by interrupting the vitamin K cycle leading to a fatal haemorrhage. Again, it is a chronic poison with a period of several days between intake and death, but in contrast to earlier first generation anticoagulants, the target animal has only to consume a single dose. Rodents, however, continue to feed for several days before their appetite fails, which increases the cost of control. The oral toxicity for brodifacoum is higher than that for bromadiolone and the lethal dose is correspondingly lower (Table A1). Poisoning can be treated by administration of vitamin K or, in severe cases, by blood transfusion. However, the treatment can be hampered by the long biological half-life of this rodenticide.

Bromadiolone

Bromadiolone, 3-[3-(4'-bromobiphenyl-4-yl)-3-hydroxy-1-phenylpropyl]-4-hydroxy-coumarin, [28772-56-7], is also a second generation anticoagulant acting in the same way as brodifacoum. Poisoning can be treated similarly by administration of vitamin K or by blood transfusion although as with brodifacoum, the treatment can be hampered by the long biological half-life of the compound.

Coumatetralyl

Coumatetralyl, 4-hydroxy-3-(1,2,3,4-tetra-hydro-1-napthyl) coumarin, [5836-29-3], is a first generation anticoagulant. It similarly acts by interrupting the vitamin K cycle and clotting factor synthesis. It is more effective with sequential baiting over several days rather than ingestion of a single large dose. Poisoning can be treated by administration of vitamin K or, in severe cases, by blood transfusion.

Flocoumafen

Flocoumafen, 4-hydroxy-3-[1,2,3,4-tetra-hydro-3-[4-(4-trifluoromethylbenzyl-oxy)phenyl]-1-napthyl] coumarin [90035-08-8], is a second generation anticoagulant, acting in a similar way to those described above. It is less active in non-target birds but is toxic to dogs. Poisoning can be treated by administration of vitamin K or, in severe cases, by blood transfusion. Flocoumafen is effective against rodents resistant to other anticoagulants.

Warfarin

Warfarin, 3-(α-acetonylbenzyl)-4-hydroxy-coumarin, [81-81-2], is one of the original first generation anticoagulants. It acts as described above by interrupting the vitamin K cycle, leading to a loss of blood clotting ability and eventually a fatal haemorrhage. Warfarin is more effective with sequential baiting over several days than with ingestion of a single large dose. It is a chronic poison with a period of several days between intake and death. Poisoning can be treated by administration of vitamin K or, in severe cases, by blood transfusion.

Toxicity to rodents

Table A1 gives toxicity data of these rodenticides for the European house mouse (*Mus musculus*) and the brown rat (*Rattus norvegicus*). Values could differ for sub-species of *Mus*, including *M. domesticus*, and also for Australian native species. Furthermore, because resistance can develop where local animals have been continually exposed to a particular rodenticide, toxicity may vary between populations of the same species.

Table A1: Toxicities of rodenticides to two rodent species. Values are presented as acute oral LD_{50} in milligrams per kilogram. A range of values reflects citations from a number of sources (Hone and Mulligan 1982; Meehan 1984; Jing-Hui and Marsh 1988; Buckle 1994a).

Rodenticide	*Mus musculus*	*Rattus norvegicus*
Alphachloralose	190–300	200–400
Bromadiolone	0.99–1.8	0.65–1.8
Brodifacoum	0.4	0.22–0.27
Cholecalciferol	42.5	43.6
Coumatetralyl	5.4–10.8*	16.5
Flocoumafen	0.79–2.4	0.25–0.56
Sodium fluoroacetate	6.3–16.5	0.2–5
Strychnine	3	5–6
Thallium sulphate	16–27	16–25
Warfarin	374	186
Zinc phosphide	32.3–53.3	27

*Racumin technical and scientific information, Bayer AG.

Toxicity is presented as the oral LD_{50}, which is the amount required to kill 50% of a large test population. This provides a consistent comparison across the different poison types. This index, however, does have limitations. One such limitation arises with the anticoagulant rodenticides such as warfarin and coumatetralyl. These are more effective with sequential baiting over several days using very low amounts of poison, rather than ingestion of a single large dose. In this case, an LD_{50} presented as dose by number of times administered, may be a better way to present toxicity data for these rodenticides.

Australian rodents have a wide variation in their sensitivity to sodium fluoroacetate (King 1994). McIlroy (1982) gives LD_{50} values for sodium fluoroacetate for black rats (*R. rattus*).

Agricultural applications

Information on the agricultural applications of these rodenticides is given in Table A2. Reference should be made to relevant state authorities for specific applications permitted at the time of use.

Baiting with acute rodenticides may be appropriate for reducing rodent numbers at plague densities (Mutze 1995) but can be ineffective because large areas need to be treated to achieve a significant reduction. Baiting with anticoagulant rodenticides is too expensive for widespread use at this time and there have been some non-target and residue problems with broadacre use. Nevertheless, anticoagulants may be cost-effective for dealing with low population densities. By monitoring rodent numbers at strategic sites around a farm, a build-up can be identified early and action taken promptly. Strategic baiting can contribute to population control, particularly around storages, and at this stage the use of the highly efficacious anticoagulant rodenticides is recommended.

The rapid population turnover of rodents means that resistance to a given rodenticide can develop if it is used repeatedly for a long period of time at one location. Consequently, the type of rodenticide used should be changed at regular intervals.

Rodenticides are hazardous chemicals and proper care must be taken when they are used in and around buildings, particularly domestic areas. Commercially available tamper-proof bait stations can be used but the smell of decaying rodents makes use of poisons around the house less desirable. Where there are small children or pets, it is safer to use break-back traps. Often when mice are present in a house there are fewer than 50, despite impressions to the contrary. This number can be dealt with easily, safely and cheaply by persistent trapping.

Table A2: Australian applications for the range of rodenticides presented in this appendix. Reference should be made to relevant state authorities for specific applications permitted at the time of use.

Rodenticide	Application	Bait concentration (g/kg)
Alphachloralose	Alphachloralose is only used experimentally for rodent control at the time of writing.	approximately 20–40
Brodifacoum	ICI Australia markets Talon™ All Weather Rodenticide Wax Blocks and Talon-G™ Rodenticide Pellets for the control of rodents in and around commercial, domestic, industrial and public services buildings. Talon-G™ Rodenticide Pellets have been used under temporary approval for perimeter baiting of cereal crops in New South Wales and Queensland. Talon-G™ Rodenticide Pellets are also used in New South Wales for the control of rats in macadamia plantations. For this application the pellets are presented in covered bait stations.	0.05
	ICI Klerat™ Rodenticide is used for rat control in Queensland sugarcane crops.	0.065
Bromadiolone	Rentokil markets a range of products containing bromadiolone under the Bromakil™ trade name which can be used for control in and around commercial, domestic, industrial and public services buildings. Bromakil™ products are also used in New South Wales for the control of rats in macadamia plantations with the bait presented in covered bait stations. In addition Temporary Approvals have been granted in New South Wales, Queensland and Victoria for the use of bromadiolone-containing products (either name brand or government authority prepared) for perimeter baiting of cereal crops.	0.05
Cholecalciferol	Quintox Defender™ Rat and Mouse Baits are registered for use in and around commercial, domestic, industrial and public services buildings. However, this product has been withdrawn from sale.	0.75
Coumatetralyl	Bayer Racumin™ can be used for rodent control in and around commercial, domestic, industrial and public services buildings.	0.37
Flocoumafen	The main formulation available, under the trade name Storm™, is a wax briquette that can be used around buildings and sheds in urban, industrial and agricultural situations.	0.05
Sodium fluoroacetate (1080)	Sodium fluoroacetate has been used in Queensland by government authorities for specific rodent control problems, particularly rats. It is not registered for use with the National Registration Authority.	1.3
Strychnine	Under emergency provisions, strychnine has been used in New South Wales, Queensland, Victoria and South Australia by government authorities for the control of mouse plagues in cereal crops. It is registered for use around farm buildings and sheds in South Australia.	2.7
Thallium sulphate	Thallium sulphate was used in Queensland for the control of rats in sugarcane but has been withdrawn from sale.	2.5
Warfarin	Hortico Ratsak™ can be used for rodent control in and around commercial, domestic, industrial and public services buildings.	0.5
Zinc phosphide	Zinc phosphide has been used experimentally in grain bait form for mouse control in grain crops at a rate of 1 kilogram per hectare (2.5% zinc phosphide). At the time of writing commercial interests are preparing applications for registration with the National Registration Authority following safe and effective use in Queensland, Victoria, South Australia and Western Australia in 1997.	25

APPENDIX B

Control of rats and mice in and around farm buildings and food storages

Information on the control of rats and mice in and around farm buildings is provided in advice sheets issued by the various state departments. These are summarised below.

Problems with mice in small storage facilities and farm buildings can be reduced by the following procedure:

- remove all rubbish (especially weeds and harbour) from areas around storage facilities and buildings (if possible, it is recommended that a 200 metre wide buffer zone is created and where practical, the zone is ploughed or heavily grazed);
- store seed and other susceptible goods on platforms raised at least 50 centimetres from the ground (see below);
- store building materials upright;
- check regularly for signs of mouse activity and if detected, try to locate and destroy harbour;
- in appropriate locations, set traps or lay out bait in bait stations (see below);
- keep the minimum of stored grain and fodder;
- feed farm animals such as poultry, caged birds, dogs and cats limited amounts of food or remove uneaten food after 30 minutes;
- clean up any grain spilt after filling silos, bins and other storage vessels; and
- construct temporary storage facilities away from channel banks, road verges, existing buildings or the edges of crops.

Mouse-proofing storages

To exclude mice, storage facilities need to be raised off the ground with galvanised caps between the stumps and floor bearers. Further details are given in Section 7.4.2 and Saunders and Robards (1984). Another method is to erect an enclosing mouse-proof fence. The recommended construction is illustrated in Figure B1.

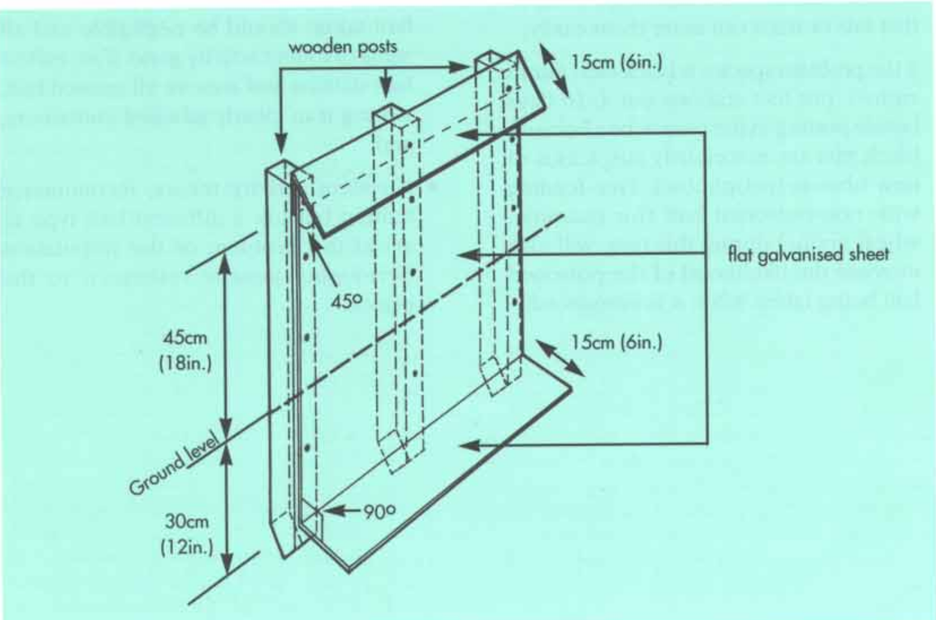

Figure B1: A mouse-proof fence (after Saunders and Robards 1984).

Bait stations

Baits should be placed in areas of high rodent activity. For safety reasons it is preferable to use bait stations which prevent access to bait by small children and non-target animals such as dogs and birds. Bait stations also provide shelter which encourages rodents to feed and, very importantly, keep the bait in one location so that the rate of take can be monitored effectively.

Bait stations can be small containers with lids and a hole cut in one side, or PVC pipe (less than 10 centimetres diameter and 30–40 centimetres long), or simply a tray under a piece of board laid against the wall at an angle.

The following points should be considered when setting up bait stations around farm sheds and buildings:

- follow bait manufacturer's directions displayed on the label of the product;
- place bait stations along the edges of walls, near small openings or where signs of rodents can be seen, and align them so that rats or mice can enter them easily;
- if the problem species is black rats (*Rattus rattus*), put bait stations out 4–10 days before putting in the poison bait because black rats are notoriously suspicious of new objects (neophobic). Free-feeding with non-poisoned bait (for example, wheat grains) during this time will also increase the likelihood of the poisoned bait being taken when it is introduced;
- if targeting rats, a spacing of ten metres between bait stations reaches most animals; if targeting mice, place them three metres apart;
- when distributing bait, allow 20–50 grams per station for mice and 200–300 grams for rats;
- check baits daily. If using a first generation (multiple-dose) anticoagulant (for example, warfarin), top up bait every day; if using a second generation (single-dose) rodenticide, replace bait every four to five days;
- pulse baiting can be used if using a second generation rodenticide to reduce the amount of bait taken prior to rodents losing their appetite. Pulse baiting involves leaving the bait out for 2–3 days, removing it for 4–5 days and then putting it out again for 2–3 days and so on, until bait take drops off completely. This saves on bait and reduces the toxic load of anticoagulant in rodents that might be eaten by non-target species;
- after two to three weeks, the amount of bait taken should be negligible and all signs of rodent activity gone. If so, collect bait stations and remove all unused bait, storing it in clearly labelled containers; and
- if rodent activity recurs, recommence baiting but use a different bait type to avoid the problem of the population developing genetic resistance to the poison.

APPENDIX C

Economic strategies for rodent management

(Bomford and workshop participants 1995)

Land managers who wish to determine the optimal economic strategy for managing a problem caused by rodents could use the stepwise approach outlined in this appendix. We recognise that often the information necessary to complete the steps is lacking. Nonetheless, the exercise of attempting to go through the process, recording the assumptions and making best-guess estimates, may prove a useful aid to decision making for rodent management.

STEP 1 *Identify desired outcomes and estimate a dollar value for each of these.*

Where outcomes are commodities, such as increasing crop yield by a given percentage, this should be reasonably easy. Where outcomes are difficult to measure or intangible, such as a reduction in the social stress to rural communities during mouse plagues, land managers may be obliged to estimate how much they consider is an acceptable amount to spend to achieve that outcome.

STEP 2 *List all control options and how much they would cost to implement.*

Control options can be different techniques or combinations of techniques, or different levels or frequencies of application of techniques (Section 7.4). It is important that the options for control are expressed as activities that a manager can select either to do or not to do.

STEP 3 *Estimate the relationship between rodent density and damage for each resource damaged by rodents (see Figure C1).*

In Figure C1, line A might represent the situation where the presence of even a few rodents has a significant impact, for example, in a hospital where maintaining hygiene standards is paramount. Line B could represent direct competition between rodents and stock for feed in an intensive poultry farm or piggery. Line C demonstrates full compensatory regrowth in a crop for damage levels occurring below a threshold rodent density, but only partial compensation above that threshold. The shape of these lines will depend on the type of resource being affected and other variables such as seasonal conditions. For example, if rodents are reduced by 90%, how much will this increase crop yield? There may be interactions between pest density and other farm management practices which will need to be taken into account. For example, the increase in crop yield caused by reducing rodent densities by 90% may vary with different crops or at different stages of crop growth.

STEP 4 *Estimate the effectiveness of each control option.*

That is, how much will a given effort using a particular control option reduce pest density.

STEP 5 *Use the information from Steps 1–4 to estimate costs and benefits of implementing each control option, including options which combine more than one technique.*

Costs will be those associated with implementing control options, and may include costs of monitoring rodents and planning. Benefits will be the value of the reduction in damage to resources (that is the value placed on desired outcomes listed under Step 1 above). Different pest management options will generate different cost–benefit relationships.

Estimates of benefits and costs can be discounted back to net present values (usually using a discount rate equivalent to the interest rate the landholder pays on financing the control operation). This will reduce the value of costs and benefits accruing in the distant future relative to those accruing in the near future.

STEP 6 *Carry out a marginal analysis (Figure C2)*[13].

Plot both the incremental marginal change in the cost of rodent control and the incremental change in the cost of damage caused by rodents against the level of rodent control contemplated. Where the two lines cross is theoretically the optimal level of pest control. Further increases in control activity do not cause commen-surate reductions in damage, so at higher levels of control beyond this point, costs will exceed savings in reduced damage.

The problem for rodent managers is that because they often do not have good information on the damage–density relationship it is hard to estimate the optimal control point. Further, even if they can make a good guess, it is not usually practical with most control techniques to simply cut off control efforts at some pre-determined rodent density. It is preferable to have a range of control options ranked along the x-axis, with their associated cost and benefit values for implementation, so a manager can select which option is optimal. For example, different frequencies of baiting could be put along the x-axis.

STEP 7 *Construct a table listing all the control options and their associated costs and benefits (this is called a pay-off matrix).*

Managers may wish to construct different matrices for different conditions, such as different seasons or commodity values for grains, legumes etc. Managers will also need to consider time-scales when constructing these matrices – what time span is covered and how will this affect costs and benefits?

These matrices can then be used to select the option(s) which best meet the manager's desired outcome. If the manager

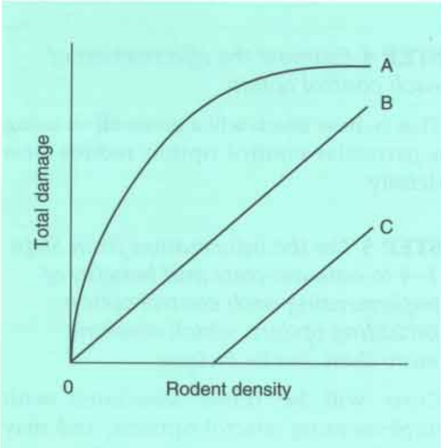

Figure C1: Possible relationships between rodent density and damage as described in Step 3 (see text).

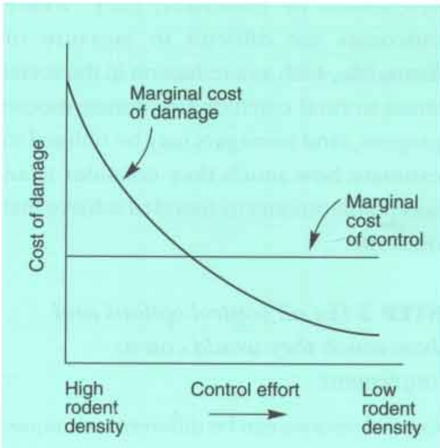

Figure C2: A marginal analysis[13] as described in Step 6 (see text) (units on the x-axis are level of control effort not rodent density).

13 A marginal analysis is an analysis of the relative shift in cost and benefit values that occur as incremental changes are made in the level of pest control effort.

is risk-averse, the best options will be those that bring in reasonable returns under all conditions. If the manager's priority is to maximise profit, the preferred options will be those that are likely to give the highest returns on investment, despite the risk of having no returns or even a loss if the seasons and prices are poor.

Pay-off matrices can also be used by a land manager to compare returns on investment in rodent control with returns on using the money for some other purpose, such as purchasing a more efficient harvester.

Implementing Steps 1–7

Steps 1–7 complete the basic model. The model can be made more accurate by adding additional features. Incorporation of such features will make it more complex, but including at least some of them may be necessary to make the model accurate enough to be useful. Some additional features that might be worth including are:

- social benefits in Step 1, such as off-site effects and good neighbour relations;
- disease risks in Step 1;
- contribution of other species, such as birds and insects, to crop losses (Step 3); and
- effects of government intervention on costs (in Step 2) such as tax incentives or direct assistance with implementing rodent control.

Much of the information needed to follow the steps outlined above is not available. Appropriate levels of control required to reduce some of the environmental damage caused by rodents cannot be determined because the cost of the damage is intangible. While some techniques are available which attempt to quantify such intangible effects (Braysher 1993) these are complex and expensive to use and of limited reliability. Despite these problems, the steps outlined above, especially Steps 1–5, enable managers to assess the most appropriate actions to achieve the desired reduction in damage.

ACRONYMS AND ABBREVIATIONS

ANZFAS	Australian and New Zealand Federation of Animal Societies
BRS	Bureau of Resource Sciences
BSES	Bureau of Sugar Experiment Stations
CAS	Chemical Abstracts Service
CPPB	Cane Protection and Productivity Board
EMC	Encephalomyocarditis
FIS	Fauna Impact Statement
GRDC	Grains Research and Development Corporation
LCM	Lymphocytic choriomeningitis
MRLs	Maximum residue limits
MSDS	Material Safety Data Sheet
NRA	National Registration Authority for Agricultural and Veterinary Chemicals
QGGA	Queensland Grain Growers Association
SCARM	Standing Committee on Agriculture and Resource Management
VPC	Vertebrate Pests Committee of SCARM

GLOSSARY

1080: Sodium fluoroacetate. An acute metabolic poison without antidote.

Abortifacient: Agent causing abortions.

Arboviruses: Viruses transmitted by arthropods such as fleas and mosquitoes.

Arrhythmia (cardiac): Irregular heart beat.

Arthropod: Animal with hard outer skeleton and jointed legs (includes insects, mites, spiders and crayfish).

Bait station: A place for feeding poison that is usually only accessible to target species.

Build-up: Rapid local population increase due to favourable conditions.

Carcinogenic: Agent causing cancer.

Carrying capacity: Density of a population that is in equilibrium with its resource supply (particularly food), predators and competitors.

Chemical repellent: Substance which repels animals due to its unpleasant smell, taste, appearance or through an animal having an unpleasant response after swallowing it and so learning to avoid it in future.

Commensal: A species living in association with other species, in this case, rodents and people.

Conservation farming: A farming system that creates a suitable environment for crop production but emphasises conservation of soil and water resources consistent with sound economic practices through processes such as stubble retention, minimum tillage, crop rotation, contour banking and windbreaks.

Cost-efficacy: Cost of an action relative to the benefits gained from it, that is, the cost–benefit ratio.

Density index: Indirect measure of abundance of a species useful for monitoring changes over time.

Donor habitat: Refuge areas, such as roadside verges and fencelines, where rodents breed. Their offspring disperse into adjacent crops.

Fecundity: The number of fertile eggs produced by the female of a species.

Granivorous: Grain-eating.

Half-life: The length of time it takes half the active ingredient in a poison to break down in the environment.

Hantavirus: Primarily rodent-borne, hantaviruses can cause severe human illness through diseases such as haemorrhagic fever with renal syndrome (HFRS) and hantavirus pulmonary syndrome (HPS).

Harbourage: Term used in sugarcane areas to describe non-sugarcane habitats (other than native bush) where rats live or shelter. Examples include channel banks, fencelines, track and road verges, banana crops, pasture, stubble fields, drains, riverbanks and other water courses. 'Harbourage' is synonymous with 'refuge' or 'donor' habitat for cropping regions where mouse plagues occur.

Headlands: Term used in sugarcane districts to describe land with native bush that adjoins crop growing areas.

Immunocontraceptive: Substance that triggers an immune reaction that causes sterility in treated animals, acting as a contraceptive.

Insectivorous: Insect-eating.

Landcare: Local voluntary groups in rural areas whose primary aims are to reduce natural resource degradation and develop more sustainable resource management.

LD_{50}: The dose (per kilogram of body weight) that will on average kill 50% of treated animals.

Lodging of crops: When plants fall over in wet or windy conditions or for other reasons. It is difficult to get a clean harvest from a lodged crop.

Morbidity: Serious illness.

Nematodes: Unsegmented worms with elongate rounded bodies, pointed at both ends. Examples are round worms, thread worms and eel worms.

Neophobic, neophobia: Fear or avoidance of new things in an animal's environment.

Non-target poisoning: Poisoning of animals other than the target species.

Oncogenic: Agent causing tumours.

Organochlorines: Organic chemicals with chlorine radicals.

Outbreak: Noticeable manifestation (of disease or rodent numbers).

Pathogen: Disease-producing micro-organism.

Per se: In or by itself, intrinsically.

Plague: A loosely defined term, implying a pest (or pathogen) at high densities.

Primary poisoning: When an animal is poisoned directly from eating baits containing the poison, or absorbing poisoned bait or contact poisons.

Pulse baiting: Involves baiting with a second generation rodenticide for 2–3 days, removing it for 4–5 days, baiting again for 2–3 days, and continuing until bait take drops off completely.

***r*-selected:** A species where evolution has favoured the selection of parameters such as high fecundity and early maturity. Such species tend to be short-lived.

***r*-strategist:** A species showing *r*-selected characteristics.

Raptor: Bird of prey.

Rate of increase (*r*): Rate of change in the numbers of animals in a population over unit time, calculated by the equation $r = \ln (N_t/N_0)$ where ln is the natural logarithm, N_t the number at time t, N_0 the number at time zero.

Ratoon: Regrowth from the root stock.

Refuge habitat: See donor habitat.

Scouring: Diarrhoea.

Secondary poisoning: When an animal is poisoned indirectly by eating an animal that has been poisoned.

Serological survey: Testing of blood, collected from a sample of animals in a population, for disease organisms or antibodies.

Silviculture: Tree-growing.

Social odours: Scents produced by animals to facilitiate communication between individuals.

Teratogenic: Agent causing abnormal foetuses.

TOPCROP: Landholder monitoring program where information on crop condition is recorded by farmers on score sheets in a standardised format. These landholder programs are coordinated by regional state government agricultural officers and funded by GRDC.

Toxicosis: Symptoms induced by a toxic compound.

Trash blanketing: A minimum tillage technique where 'trash' (green tops and dry leaf material) is left as a 'blanket' on the ground to suppress weed growth, prevent soil erosion and increase organic matter.

Triticale: A cereal grain developed from wheat and rye.

Ultrasonic device: Electronic device that emits a sound signal that is above the upper hearing range of people.

Vector: Carrier for spreading disease or biological control agent.

Zoonotic disease, zoonosis: A disease spread from animals to people.

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Australian crops are damaged by mice, black rats and four species of native rodents. There has been a mouse plague somewhere in the Australian grain belt every four years on average since 1900. In the last twenty years plagues have increased to one every year or two. The 1993–94 plague in south-east Australia cost the grains industry an estimated $65 million. Rat damage to Queensland sugarcane crops amounts to $2–9 million annually. Rodents also have significant social and environmental impacts and can spread disease to people and livestock.

Managing Vertebrate Pests: Rodents provides a comprehensive review of the biology of pest rodents in Australia, the damage they cause and community attitudes to these problems and their solutions.

Key strategies for successful rodent control are recommended by the authors, who are scientific experts in rodent management. These strategies are illustrated by case studies.

Managing Vertebrate Pests: Rodents is an essential guide for policy makers, farmers and all those interested in pest rodent management.