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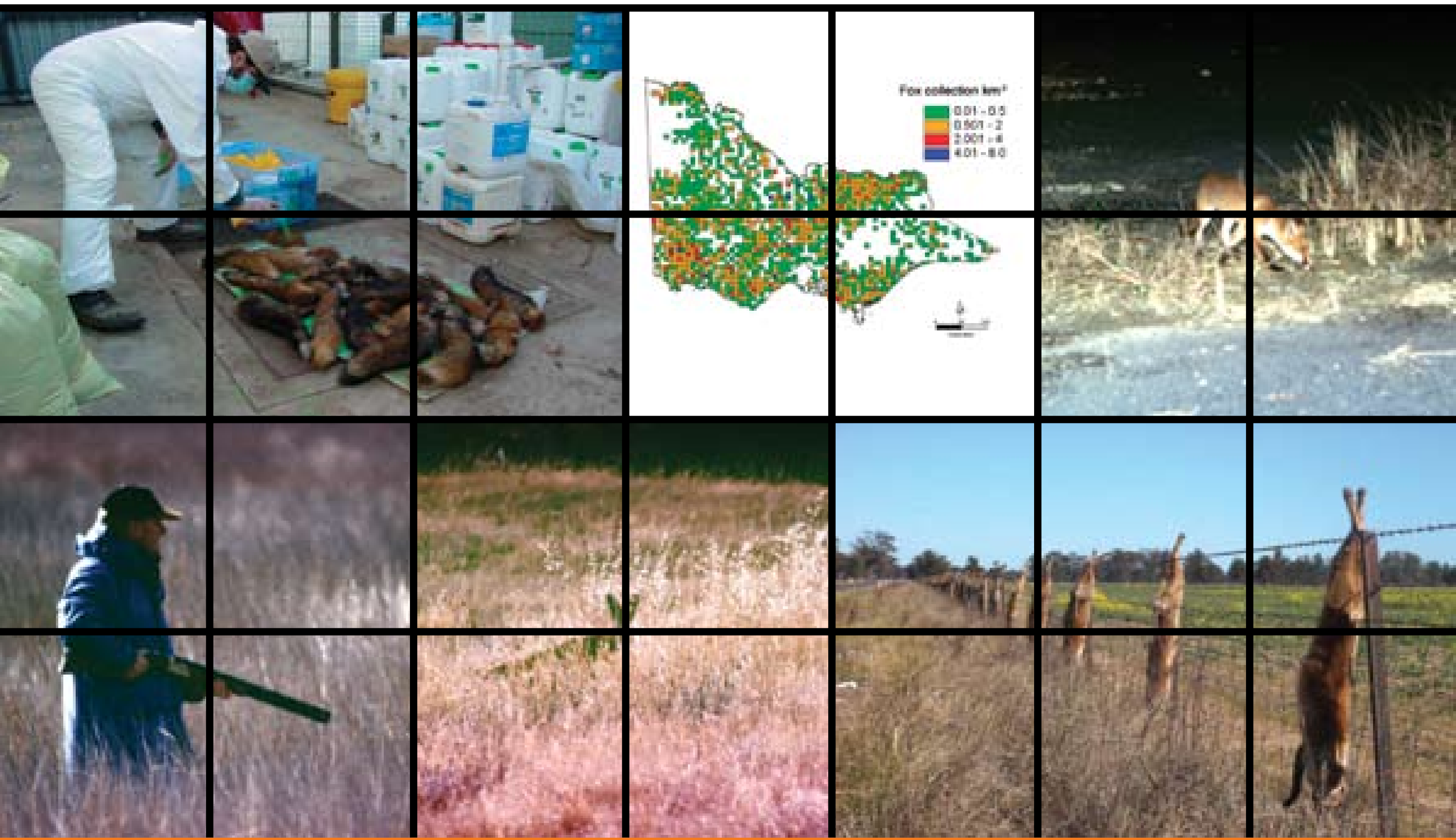

Vertebrate Pest Research

Evaluation of the 2002/03 Victorian Fox Bounty Trial

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The Place To Be

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Left to right:

Top row - marking fox tails (Victorian Department of Primary Industries); fox collection map; fox at night (Tim Bloomfield, Victorian Department of Sustainability and Environment).

Bottom row - fox hunter (Tim Bloomfield); fox (Tim Bloomfield); fox carcasses with tails removed at Savernake, NSW (NSW Department of Primary Industries).

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Preamble

This report presents an evaluation of the 2002/03 Victorian fox bounty trial. It has been prepared primarily as a discussion document for policy advisers, pest animal management practitioners and Catchment Management Authorities. It presents an analysis of the bounty trial based on the available data at the time of preparation and scientific evidence from the literature.

This document updates an earlier report (ISBN 1 74106 6468) published on the Department of Sustainability and Environment web site at: www.dse.vic.gov.au

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Summary

- A fox bounty trial was introduced in Victoria in July 2002. As part of the trial a scientific evaluation of the scheme was undertaken to assess its efficacy. The evaluation was based on location information provided by bounty participants at the time they presented fox tails at collection centres. The intensity of fox collection across different regions of the state and in different habitats was determined and the level of control attained during the bounty period was assessed against the known requirements to achieve population reduction in the red fox. This assessment was based on data collected up to week 52 of the trial.

- Fox populations are highly resilient to conventional lethal methods of control. A sustained annual population reduction of more than 65% would be a realistic goal before fox populations could be expected to decline across Victoria. Such a decline could not be achieved if the potential for reinvasion from South Australian and New South Wales populations was not addressed (section 3.3).

- Phillip Island has ideal conditions for the application of conventional control largely through either spotlight or day shooting techniques. A closed population of foxes subjected to intensive control using conventional methods has not declined and each year fox reproduction easily replaces the number of animals killed. If an annual reduction in fox numbers cannot be achieved on a small (100 km^2) closed island population through coordinated shooting by skilled and motivated persons, it is unrealistic to expect that this can be done in an open population in a much greater area (section 4.3).

- A number of the short-comings inherent in the use of bounty systems were identified and indicated that such schemes cannot provide the level of broad scale, consistent control required for a population reduction of a widespread, abundant species with a high reproductive rate (section 5).

- The statewide pattern of fox collection during the bounty trial was highly clustered. Broad scale population reduction did not occur and the trial probably only achieved a temporary and insignificant reduction (section 7.2).

- It is likely that in areas where the highest numbers of foxes were taken (greater than 2 foxes km^{-2}), temporary reductions in local fox populations will be observed (section 7.2).

- The level of statewide fox removal observed was too low to contribute in any significant way to sustained population reduction. Removal of >1 fox km^{-2} occurred in only approximately 13 % of the state. Fox density in temperate grazing land in south eastern Australia has been estimated to be between 4-7 km^{-2}. Removal of foxes approaching the level required to have a lasting effect upon populations if sustained occurred in less than 4 % of the state (section 7.2).

- The bounty may stimulate or "prime" reproductive rates through moderate reductions in abundance that disrupt fox social groups. The likely result of increased reproductive rates will be a return to pre-bounty density or greater (section 7.5).

- Fox collection was no higher in sheep production areas than in other agricultural areas. Despite protection of sheep flocks being a major objective of the trial, sheep production areas did not appear to be specifically targeted (section 7.4).

- A survey of shooters attitudes would be valuable as anecdotal evidence was received and highlighted in various media that shooters reduced their activity during fox breeding periods to ensure "next year's crop". This potentially reduces the effect of any population reductions achieved by allowing ready replacement (section 5).

- The bounty being paid on the production of tails did not take account of how the fox actually died, with payment being available for "road kills", fox skins stored over a long period and animals taken outside the trial bounty time frame or interstate (section 5).

- Control efforts should be based on an understanding of the relationship between fox numbers, damage levels and the required impact of control on the target population. A bounty based on maximising the number of animals killed across the state does not fit within a strategic approach. The setting of a statewide target number of foxes without reference to what this means in terms of population reduction or benefit is an inadequate approach to vertebrate pest management and will not achieve long-term damage reduction (section 8).

- It is recommended that the bounty trial not be continued but replaced with targeted and coordinated programs to assist landholders to achieve a sustained reduction in fox abundance for a defined benefit (section 9).

1. Introduction

A trial fox bounty was introduced in Victoria in July 2002, as part of the Government's increased focus on fox control. The initial bounty period (July - September) was timed to assist sheep farmers to manage lamb predation during a period when foxes can cause significant economic losses. As a result of the popularity of the trial, the bounty period was extended until the end of August 2003. As part of the trial, an evaluation was required to assess its efficacy as a fox control measure across Victoria. This report forms part of that assessment and is based on data collected up to week 52 of the trial.

The objectives of the report are to provide an:

1. Overview of the rationale, priorities and key targets for fox control in Victoria;

2. Overview of the requirements for population reduction of the red fox; and

3. Assessment of statewide and regional control intensity and benefit derived from the bounty scheme.

The first section of the report provides a synopsis of fox impacts, biology and control within Victoria and a background on previous bounty programs. Section two provides an evaluation of the current Victorian scheme in terms of its likely contribution to fox impact reduction both at a statewide and local scale within selected habitat types. The report includes a case study of intensive control of a closed fox population on Phillip Island. The results of the Victorian bounty program are compared with the case study and a series of recommendations are made to assist in the development of strategic, regional fox control programs that involve local communities.

PART 1: ESSENTIAL BACKGROUND

2. Victorian Fox Impacts and Requirement for Impact Reduction

2.1 Biodiversity Impacts

The red fox has had a dramatic impact on medium-sized Australian mammals (35–5550 g) and ground-nesting birds since its introduction to mainland Australia in the 1870s. Australian fauna did not co-evolve with the fox and susceptible prey species have few adaptive strategies to avoid predation. The impact of the fox has probably been exacerbated by habitat fragmentation and modification since European settlement.[1] Subsequent to its establishment, the fox was probably a direct or contributing factor in the extinction of many highly susceptible species. It has been implicated in the extinction of six mammal species in the Victorian Mallee.[1]

Many native species may presently be confined to refuge areas as a result of fox predation. These areas may provide exaggerated shelter from predation and close proximity to food. Populations confined to refuge areas will be more at risk of local extinctions due to susceptibility to environmental stresses (eg fire, drought, floods and disease). The often-fragmented nature of isolated refuges reduces the incidence of gene flow in the population, increasing the chances of genetic bottlenecks, and affects the overall viability of the population.[1]

Unabated and continual local extinctions may lead to total species extinction. For instance, the eastern barred bandicoot declined from an extensive range in the western Victorian grasslands. Re-introduction programs for black-footed rock-wallaby and brush-tailed bettong have implicated fox predation as a major cause of reduced population recruitment in Western Australia.[2] Foxes may also present significant competition for resources that affect the distribution and abundance of the spot-tailed quoll, which is listed as a threatened taxon under Schedule 2 of the *Flora and Fauna Guarantee Act 1988*.[1] The environmental impact of the fox has been quantified in economic terms and is estimated to be $190 million per annum.[3]

2.2 Agricultural Impacts

The economic impact of foxes in Australia has been poorly studied but the principal losses almost certainly involve newborn lambs.[2, 3] Studies quantifying the impact of foxes on lamb production have suggested that foxes may take from 10–30% of lambs in some areas.[2] The importance of fox predation on lambs as a cause of significant economic losses will vary in extent from area to area and year to year. Fox predation may have a large impact in areas where foxes are common and lambing occurs early in the season. Extensive lamb loss can occur when lambing is out of step with or isolated from neighbouring flocks.[2] A recent evaluation of the economic impact of pest animals in Australia has estimated the impact of fox predation on the sheep industry in Australia to be $17.5 million per annum.[3] When this is combined with the environmental cost and the annual cost of control, the total annual economic impact of the fox in Australia is estimated to be $227 million.[3] In Victoria, the annual loss to agricultural production due to fox predation is estimated to be $5.2 million and the total annual economic impact of foxes in the state is estimated to be $39 million (T. Morfe, 2005, [Primary Industries Research Victoria] *pers. comm.*).

Recent observations suggest that the fox may be a predator of cattle but reported instances are sporadic and mostly restricted to small rural holdings on semi-urban subdivisions and intensive dairy production areas. When it occurs, fox predation on cattle can be substantial with calves dying as a direct result of predation or cows requiring euthanasia as a result of fox attacks during calving.[2] Losses of other farm livestock to foxes are generally not of economic significance but can be a major animal welfare issue. Fox predation of poultry is well known but most commercial poultry farming operations use intensive or battery farming and the animals are well protected. Most commonly, it is the small domestic poultry flocks that are affected by foxes. While of major concern to the individual operator, these losses are not of major statewide economic significance. Foxes may be an increasing problem for emu and ostrich farms and goat herds.[2]

2.3 Disease management

Worldwide the fox is a known rabies vector and if the disease were introduced into Australia the fox could become the major carrier. However the risk of fox rabies being introduced to Australia is considered to be low. If rabies became established the distribution and abundance of foxes in Australia would make control an extremely difficult task. As the urban fox populations are extensive the introduction of rabies into Australia could have major public health impacts.[4] Existing contingency plans for the control of rabies in Australia focus on preventing entry of the disease into the country and on rapid elimination at the point of introduction if detected.[2]

Foxes carry a variety of parasites including a number of tapeworm and round worm species that may be transmitted to domestic animals. These include canine roundworm and heartworm.[5] In some areas foxes are an important host for the hydatid tape worm (a potentially serious human health risk).[6] Foxes also carry a range of fleas, ticks and mites. Sarcoptic mange may be a significant cause of fox mortality and this disease may be transmitted to other species.[2]

2.4 Nuisance activity

Foxes can be a major nuisance to landholders especially hobby farmers through loss of household or hobby stock. Urban foxes have become a significant nuisance problem in a number of Australian cities. In parts of Melbourne the estimated fox density is up to 16 km^{-2} .[4] Urban areas that support high densities of foxes also provide reservoirs that can replenish rural populations. Control of urban foxes also presents a problem as conventional lethal techniques (eg shooting, poisoning and trapping) cannot be used in most built up areas.[7]

2.5 Victorian objectives for fox control

To succeed, pest animal control must be based on a sound understanding of the biology and population dynamics of the target animal. It must be strategic, targeted and have a clear objectives.[2] Historically, much of the management of fox damage in Australia has been reactive and conducted by individual landholders. There has been relatively little emphasis on larger-scale coordinated programs in Victoria. Fox control must be viewed in a similar way to rabbit control in that it requires large-scale management programs involving groups of landholders or entire districts. As is the case with rabbits, recolonisation of small controlled areas is likely to be rapid. A common deficiency in Victoria has been the lack of measurable goals for reducing fox damage. A dearth of benchmark data on fox densities and population sizes compounds this problem.

A strategic approach to fox management has been developed through Victorian Pest Management – A Framework for Action (VPMF), which provides broad strategic directions in pest management and more specific policy frameworks.[8] The Fox Management Strategy under the VPMF details goals, objectives and performance indicators for fox control together with a strategic basis for managing foxes throughout the state.[9] The long-term vision for fox control in Victoria is that the state's biodiversity and primary industries are not threatened by fox predation. In terms of biodiversity outcomes this relates to a measurable increase in the abundance and distribution of native wildlife (particularly medium-sized mammals) achieved through managing fox populations in a coordinated cross-tenure approach. The objectives for biodiversity conservation include both threatened and non-threatened species. However, recovery of threatened species is a key element of the state's commitment to biodiversity conservation and is a high priority. The agricultural objectives are to reduce the economic impact of foxes to a community acceptable standard, predetermined by the value of the enterprise and threat to adjoining neighbours.

The fox bounty trial was initially introduced for a three-month period across Victoria during the months of July, August and September 2002, with the aim of providing additional protection to sheep during lambing. However, the State Government stressed that the bounty was "not a magic solution and landholders needed to keep up with other strategic fox control programs such as baiting".[10] The bounty was to be only one aspect of the Government's broader approach to combat foxes throughout the State.[11] The trial was initially capped at $0.5 million in bounty payments (ie. up to 50,000 foxes killed) but it was extended with a further $1 million available in total, including the administration costs, and concluded on August 31, 2003.

3. Important Biological Factors

The following sections provide an overview of fox population biology and the requirements of any control program to make an impact on fox populations.

3.1 Breeding biology

The fox breeds only once a year, usually mating during winter, although reproduction is not always synchronised and variation of greater than two months can be expected across Victoria. The fox reproductive cycle varies due to latitude and its duration may also vary annually. The period when the majority of vixens can be assumed to be pregnant in south-eastern Australia is over the two months from 1 August until 1 October. Usually between 3 and 5 cubs are born after a 52 day pregnancy and they become sexually mature from ten months of age.[1]

3.2 Population densities and social organisation

Abundant prey (particularly rabbits), a good supply of carrion (eg. sheep carcasses) and numerous denning sites makes many Victorian habitats highly favourable to the fox. Density is higher in summer than in winter and varies in response to food availability and habitat type. Densities in rural areas range from < 1 fox km^{-2} in arid areas to > 4 km^{-2} in central Victoria and up to 16 km^{-2} in urban habitats[2] (see Table 1). Foxes live in social or family groups of varying complexity that generally occupy well-defined territories.[1] The terrain and patchiness of the habitat probably also influence territory size. The density of foxes in many habitats is poorly known because no accurate technique to measure fox density has been developed.

The two common types of social organisation for red foxes are the mated pair system and the dominance hierarchy.[12] The mated pair system is characterised by all adult males and females breeding and raising their cubs independent of other foxes. In dominance hierarchies, the dominant vixens may sometimes suppress the reproduction of subordinate vixens and so fewer vixens breed successfully.[12, 13] The type of social system prevailing in an area is likely to influence how rapidly a fox population responds to any reductions in population density. Fox populations appear to be sufficiently flexible to allow changes in social organisation to readily occur in response to environmental changes and control by humans.[14, 15] This flexibility has contributed to foxes being able to successfully exploit a range of environments and altered circumstances and may partly explain their persistence in spite of continued control efforts .[12]

Table 1. Density estimates for Australian fox populations in various habitats (adapted from Saunders *et al.* 1995).

Location	Habitat	Fox density km^{-2}	Reference No.
Central Victoria	Temperate grazing	3.9	16
Northern Tablelands NSW	Temperate grazing	4.6–7.2	17
South Coast NSW	Dry sclerophyll forest	0.2	17
Western NSW	Semi-arid grazing	2.0	18
Western NSW	Arid grazing	0.9	2
South east NSW	Sub-alpine	1.8	2
Western Aust	Semi arid rangelands	0.46– 0.52	12
Melbourne	Urban	0 –16	4

3.3 Resilience to control

Fox populations are highly resilient to conventional lethal methods of control. Rapid re-invasion of areas where control has been applied demands that it be carried out intensively over a large area and for a sustained period.[2] Natural fox population turnover appears to be rapid and natural mortality rates are high.[2] For example, in a sample of 317 foxes killed by hunters in central Victoria it was found that 54% of animals were less than 1 year old and 71% less than two years old with few (4%) surviving beyond 4 years.[19] In a similar study in south western NSW, around half the fox population was estimated to be replaced each year.[20] The number of young produced each year is surplus to the number needed to maintain the population at equilibrium (commonly referred to as "the doomed surplus"). Increases in mortality (such as an increase in hunting) are countered as fewer animals compete for the same resources resulting in an increase in the survival and productivity of the population the following year. Reproductive output is known to be largely regulated by the number of vixens within a social group that become pregnant.[21] Reproduction may be suppressed by social pressure from dominant animals in the group.[12] The disruption of social groups through various levels of control may result in an increase in the proportion of vixens that become pregnant in the following year.[15, 22] Control efforts that are not sustained at a high level may therefore result in the reproductive rates of the population being stimulated or "primed" for the following year.

The maximum rate of increase of a wildlife population under ideal conditions when no resource is limited is termed the intrinsic rate of increase.[23] In order to reduce the abundance of a pest species in a closed population its population growth must be ideally kept below a critical level and its intrinsic rate of increase must be negative. In a study of three important introduced mammal pests, the house mouse, rabbit and red fox, Hone[23] estimated the proportions of each these pest animals that must be controlled annually to achieve population reduction (Table 2). Based on the intrinsic rate of increase for foxes in different habitats in Australia, Hone determined that an annual population reduction of greater than 65% would be required before fox populations could be expected to decline in some areas. This study has important implications for control programs such as the Victorian fox bounty. In the absence of other control techniques the bounty would have to achieve at least a 65% reduction in fox populations over a large area of the state in order to have an impact on populations.

It should be noted that population reduction below a critical level to achieve a negative rate of increase is only possible in ideal conditions when foxes exist in a closed population. The Australian fox population is extensive and reinvasion from outside areas is well documented. This suggests that a Victoria-wide decline in fox populations cannot be achieved if control strategies ignore the neighbouring South Australian and New South Wales populations.

Table 2. Annual rates of increase and proportion of population to kill to stop population growth returning to pre-control levels within 12 months for three vertebrate pest species (adapted from Hone 1999).

Species	Maximum observed rate of increase per year (%)	Proportion of population to kill to stop maximum population growth (%)
Rabbit	206	87
Red Fox	105	65
House Mouse	341	97

The main recolonisation of de-populated areas probably occurs in autumn when yearling foxes are dispersing but this may be continual in some habitats.[2] Populations in areas where no control has been carried out become source populations for areas where foxes have been removed. Evidence from a number of studies suggests that reinvasion occurs rapidly in areas without strategies in place to maintain low population levels during the dispersal phase of foxes.[22, 24] In a recent study in eastern Victoria, the effects of repetitive control on foxes in forest habitats was investigated.[22] Baiting was carried out during summer and winter of two consecutive years. As older resident foxes were removed the mean age of animals collected progressively declined. This was consistent with young dispersing foxes occupying vacant habitats after summer control and progressive removal of older resident animals from the population. Intensive control removed foxes every 6 months yet this was insufficient to prevent re-invasion and maintain reduced population abundance between control periods. Repetitive control is likely to have prevented the establishment of social groups by continual removal of related animals. This pattern of continual reinvasion and breaking up of social groups is unlikely to result in a fox population maintaining a low density unless effort is extensive and sustained at a high level. Small areas of 10,000 hectares or less require frequent, effective control because they are rapidly recolonised. Infrequent or poorly coordinated fox control efforts in small areas, that are rapidly recolonised, are likely to be of little value.[22]

4. Constraints upon shooting to reduce the fox population

The predominant assumed technique for controlling foxes during the Victorian bounty trial was spotlight shooting. There are a range of factors which affect the efficacy of shooting as a means of controlling fox populations in all habitats.

4.1 Age structure bias

Spotlight shooting often relies on the on the ability of the hunter to either lure inquisitive and inexperienced animals into shooting range by rabbit whistle or to approach animals without them retreating. Fewer foxes are taken by spotlight shooting as the season progresses due to either rapid removal of young inexperienced animals or learned avoidance behaviour over time.[19, 25]

4.2 Habitat restrictions

Where foxes exist close to human habitation, there are few safe, effective and target-specific methods of control. Foxes that exist in proximity to or within urban developments threaten some Victorian wildlife populations, including eastern barred-bandicoots, little penguins and mountain pygmy possums.[1] Spotlight shooting is predominantly conducted from a vehicle and is restricted to open habitats. The technique is not appropriate for heavily vegetated areas and areas of remnant vegetation that are likely to restrict effectiveness.[2, 25] Foxes can also find sanctuary in locations where shooting is not allowed, for example national parks, wildlife reserves, restricted areas and on free-hold land where managers will not allow this activity to take place.

In a fox removal experiment in NSW[18] a very large effort was required to remove foxes by shooting. Replacement of shot foxes was high, particularly during the period when young foxes were dispersing. Foxes that have been shot at and survived will be more wary of vehicles and spotlights in subsequent years. The problems with reliance on shooting as a control technique are exemplified by the following case study of an intensive fox control program (predominantly based on shooting) on Phillip Island.

4.3 Phillip Island case study

Phillip Island is a 10,000ha island at the entrance to Western Port, Victoria, in south-eastern Australia. It is a unique example of a closed population (island) of foxes on a comparatively small land area (100 km^2)[26] where a coordinated fox control program has been ongoing since 1980.[27] Foxes are considered to be the greatest land-based threat to little penguins, have contributed to the decline of hooded plovers and also threaten colonies of short-tailed shearwaters.[27] The fox control program between 1994 and 1999 predominantly involved intense spotlight shooting and day hunts with foxhounds.[27] Given the largely ideal situation favouring conventional fox control the island offers a unique insight into the success of intensive shooting as a fox control method.

The objective of the Phillip Island control program is eradication of foxes from the island. The size of the fox population on the island has been conservatively estimated to be between 100–150 individuals. Despite a well-coordinated control program involving the local community both in control efforts and in reporting fox sightings to assist in targeting control, analysis has revealed that on average only 50% of the fox population is taken each year (van Polanen Petel and Kirkwood unpublished data).

The success of different control techniques on Phillip Island is dependent on habitat. Spotlight shooting is restricted to open areas away from settlements and the majority of shooting is done from roads. Roadside vegetation is also a limiting factor in spotlighting. Shooting with foxhounds was most effective in small patches of vegetation, but ineffective in larger patches. Shooting with dogs or spotlights may result in aversion and subsequent avoidance behaviours in survivors and this has been well demonstrated in the Phillip Island population as foxes are extremely difficult to observe and they retreat from spotlights.

The number of hours spent on the different control techniques was determined and a "catch per unit effort" was calculated as the number of foxes taken per 1000 hours effort. During 2000 spotlight shooting was carried out on 72 nights (400 person hours) across the island and 12 foxes were shot. Hunting with foxhounds was carried out on 31 days at 36 locations (1445 person hours) and 17 foxes were shot. The catch per unit effort for spotlight shooting on the island has been calculated to be 30 foxes per 1000 hours.[27] The number of foxes known to be alive each year was determined by undertaking a retrospective age structure analysis based on the ages of foxes taken across Phillip Island between 1994 and 1999 (Van Polanen Petel and Kirkwood unpublished data). For example, foxes taken in a particular year and determined to be 2 years of age were assumed to have been present in the population during the previous year and the current year. As age data were accumulated the maximum number of foxes known to be alive each year could be determined. This analysis revealed that annual fox control between 1994 and 1999 reduced the total population size temporarily by approximately 50% each year (van Polanen Petel and Kirkwood unpublished data, Figure 1). Even when a reduction of 68% was achieved in 1998, fox numbers built up again the following year.

Despite a closed population of foxes, intensive control using conventional methods and high motivation, there is no evidence to suggest that the population of foxes on Phillip Island has declined. In fact from 1994-1998 the number of foxes known to be alive each year steadily increased from 58 to 130 (Figure 1). This lesson suggests that under these conditions a sustained population reduction of 65% as determined by Hone's[23] analysis has not been met and each year fox reproduction easily replaces the number of animals killed during control.

In an open Victorian population with 2,280 times the land mass, a fox population reduction can only be anticipated if a control intensity greater than that achieved on Phillip Island is maintained state-wide for a prolonged period and is not affected by re-invasion from NSW and SA (Figure 2). If control effort is patchy, foxes in areas that are not subject to control will rapidly re-invade areas where they have been removed.

Figure 1. Fox control on Phillip Island. Number of foxes known to be alive and number killed 1994–1999 (adapted from van Polanen Petel and Kirkwood unpublished data).

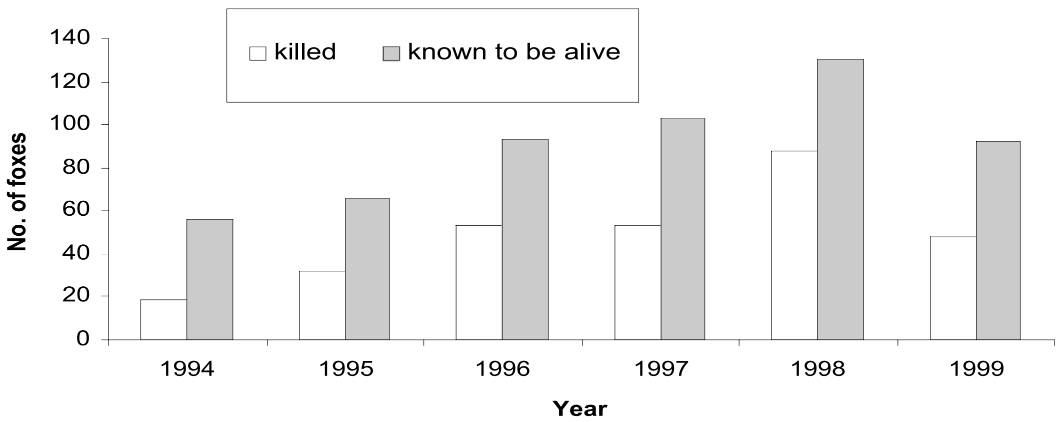
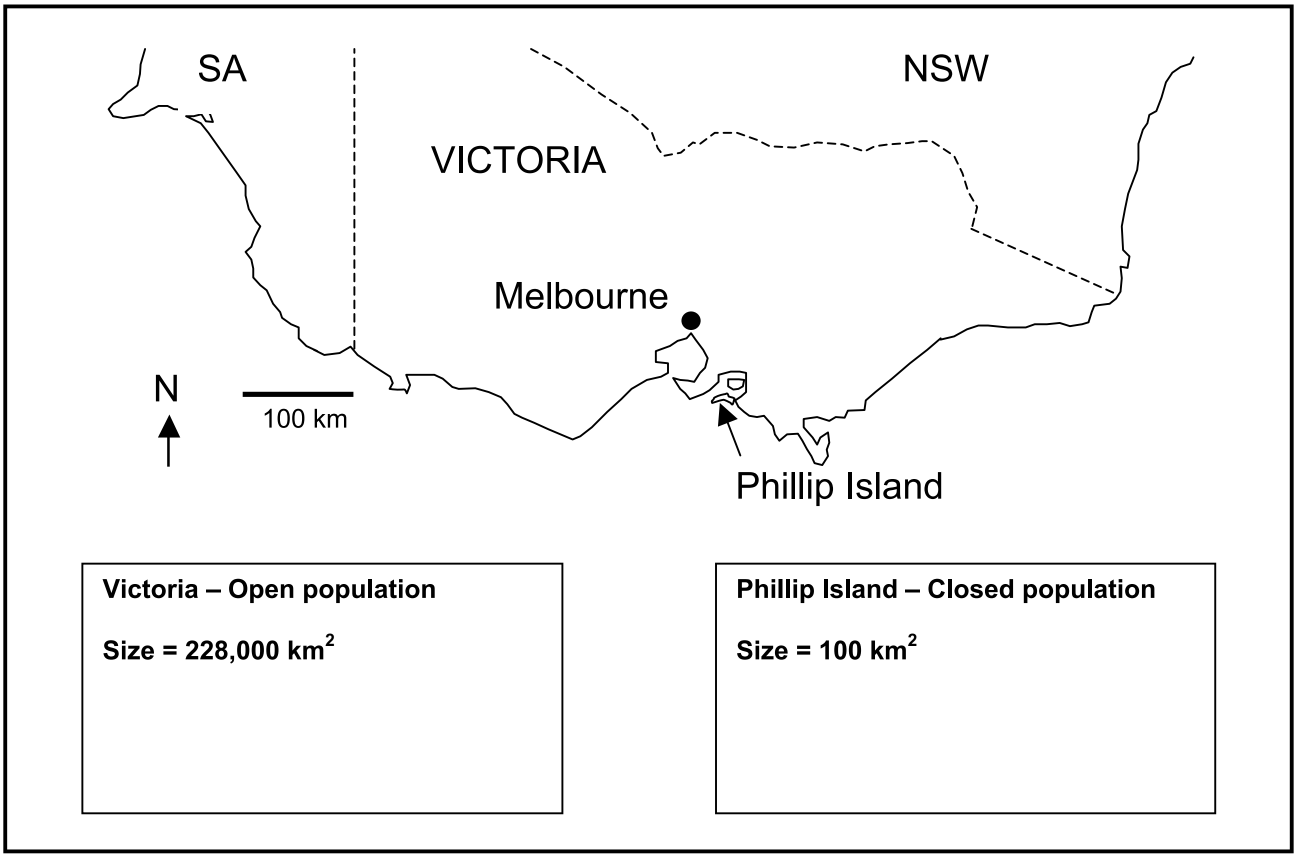


Figure 2. Comparison of control effort between Phillip Island (a closed population) and Victorian mainland (an open population).



Population reduction above a minimum level must be sustained in order to achieve a long-term decline. As animals are removed from the population, removal of a sufficient proportion of the remaining animals becomes increasingly difficult and greater effort is required.[19] In effect, a law of diminishing returns applies. In order to maintain a population at low levels, highly efficient control methods are needed. Spotlight shooting becomes increasingly less efficient as numbers are reduced, allowing the remaining population to recover from the initial reduction. It is likely that this has been the case on Phillip Island.

5. Efficacy of Former Bounty Systems

Bounties were first offered for foxes in 1893, twenty years after they were introduced to Australia.[2] Two recent comprehensive reviews of the role of bounties in vertebrate pest management concluded that the schemes are an ineffective form of pest animal control.[28, 29] There are several key reasons for this and these are briefly discussed below.

5.1 Benefit and cost-effectiveness of control

Harvesting and Fraud

Bounty payments create an income source and therefore dampen efforts to eradicate or reduce the pest species population on a permanent basis. In the past, such payments have been capable of providing a significant income through continuous and sustainable harvest. The bounty payment system has the potential to discourage the use of more suitable control options in favour of less efficient techniques which allow a continual harvest. When large numbers of participants are involved in bounty programs, the potential for fraud increases. Presentation of "out of area" animals is a potential problem for widespread species such as the fox. This issue as well as the theft of fox tails already presented for the bounty was identified during the current Victorian bounty trial (R. Williamson, Department of Sustainability and Environment, *pers. comm.*). Anecdotal evidence was received and highlighted in various media that shooters reduced their activity during fox breeding periods to ensure "next year's crop". This potentially diminishes the effect of any population reductions achieved by allowing ready replacement.

Rapid reproduction of controlled species and failure to provide long term relief from pest impact

Most Australian vertebrate pest species have a high natural rate of increase and dispersal so the benefits of control activities will quickly diminish. This has been discussed in relation to foxes in the previous sections.

Lack of damage focus

Bounty schemes have tended to focus on reducing pest population size as opposed to attempting to minimise the damage caused by the pest population.[29] Their objective is to kill as many pests as possible rather than considering alternative management options to reduce the level of damage. This approach also means there are no set objectives or targets such as reducing populations by a certain proportion. Without defined objectives, no measurement of success can be made. In planning any control campaign it is essential to have enough information to determine its impact on the target population. This requires an understanding of the relationship between pest numbers, damage levels and control efforts.[2]

Mis-allocation of resources

In effect, a bounty can be a subsidy for existing activities (that is, no more effort expended but a reduced cost to the landholder for existing measures) or even a reduced effort to allow greater earnings later. Bounties are intended to induce increased efforts to control pest animals. The payment is made on all animals destroyed and not just those over and above the number that would have been taken without the bounty. In an economic evaluation of bounty systems for the Bureau of Resource Sciences, Hassel and Associates[29] point out that such programs are likely to cost significantly more and reduce the population significantly less than anticipated. During the Victorian trial, the bounty being paid on the production of tails did not take account of how the fox actually died, with payment being available for "road kills", fox skins stored over a long period and animals taken outside the trial bounty time frame or interstate.

Selective removal of surplus animals

Bounties are paid on all animals of the target species taken. This results in large numbers of younger, inexperienced animals being removed, while more elusive, older animals escape. Older animals are the most likely to breed successfully and hence they are important targets for control. The high natural mortality rate and population turnover demonstrated in fox populations[19, 20] suggests that a large proportion of individuals taken are surplus animals. Often bounty programs have operated in areas of ideal habitat for the identified pest where it is arguable that any control effort would have failed. For example, high effort in the pastoral regions of Victoria may result in high numbers of animals taken at a local scale. However, little control effort may occur in more heavily vegetated areas where spotlighting is not possible. Even with high effort on a local scale, the requirement for a sustained >65% reduction in the fox population would still need to be met to produce a population decline.[23] It is unlikely that such a sustained reduction could be achieved without statewide coordination of control efforts.

In Britain, a ban on fox hunting for nearly a year during the outbreak of foot and mouth disease in 2001 provided an opportunity to quantify the impact of fox hunting on fox numbers. A study, which compared indices of fox abundance (based on scat counts) before and after the hunting ban[30] showed that the ban had no impact on fox numbers in Britain (suggesting that hunting pressure had little impact on fox numbers).

Table 3. Problems associated with former bounty schemes and current Victorian scheme.

Problem/Issue	Identified in 2002 Victorian bounty
Fraud	✓
Lack of damage focus	✓
Rapid reproduction rate	✓
Subsidisation of existing activities	✓
Selective removal of surplus animals	✓

PART 2: VICTORIAN BOUNTY TRIAL

6. Analysis of the Fox Bounty Trial Database

Detailed records were taken each time fox tails were handed in at a collection centre. The records included the number of tails handed in and the location of where the foxes were taken (grid reference). This enabled the intensity of fox collection to be mapped across the state and in different habitats.

6.1 Methods

Collection of fox tails and payment of the bounty commenced at 24 collection centres on July 1 2002. When applicants presented fox tails at a collection point, the location where foxes were taken was recorded as a grid reference on 1:100,000 topographical map sheets for the approximate centre of that area. The location and the number of foxes taken for each point was recorded in a database. The statewide distribution of foxes taken between July 1 2002 (week 1) and June 30th 2003 (week 52) was mapped using a Geographic Information System (GIS). A grid was overlaid on the state map dividing it into a series of 10 x 10km (100 km^2) grids. The number of fox records that occurred within each 100 km^2 grid cell was calculated and expressed as a mean figure of foxes per square km (km^{-2}). A general assumption was made that foxes recorded as coming from a point location were likely to have been taken within the 100 km^2 grid. An index of dispersion *(d-statistic)*[31] was used to determine the degree to which fox control was concentrated (or clustered).

The impact of the bounty at a local scale was assessed using the state coverage of 1: 100,000 map sheets (average area = 1790 km^2). The number of foxes taken within each of four broad habitat types (sheep industry, other farming, forest and "other land use") was determined for each 1: 100,000 map sheet within the state and expressed as the mean reduction in foxes km^{-2} for each habitat type. The four habitats were defined using the Victorian corporate geospatial data library and Australian Bureau of Statistics (ABS) census data as follows:

- *Sheep Industry:* The major sheep production areas within Victoria were defined using ABS census data for 1997 which showed the total number of sheep recorded by parish on 30 March 1997. These data were converted to the number of sheep ha^{-1} for each parish within the state.

- *Other agriculture:* Farmland where sheep production was not a major industry was defined as all agricultural land that did not fit the sheep industry definition above.

- *Forest cover:* Forest cover and remnant vegetation on private and public land.

- *Other land use:* Land use categories such as urban settlements that did not fit into the three broad categories above.

A chi-squared (χ^2) test was used to determine whether the observed frequency of foxes taken km^{-2} was consistent with the expected frequency if fox collection rate within each habitat category was random.

6.2 Limitations of the data

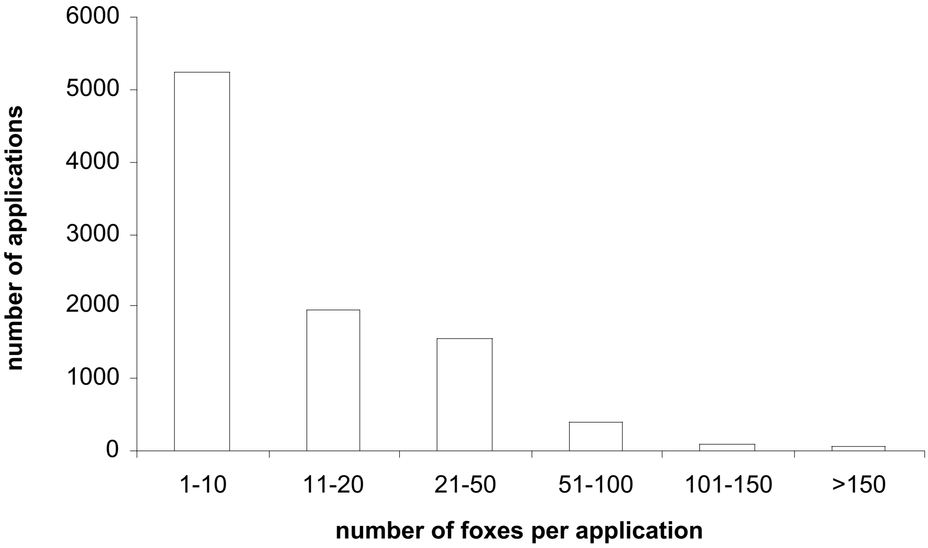
The locations where foxes were taken were provided by participants at collection centres and recorded as grid references. This meant that foxes taken over a particular area were recorded as point locations. To compensate for this effect, the data were mapped as the number of foxes recorded within 100 km^2 grid cells (10km X 10km), allowing the broad pattern of control intensity within the state to be described. Analysis of fox collection data was undertaken for 98,857 (65 %) of the 150,822 foxes collected up to week 52 of the trial. The remaining 51,965 foxes (35 %) could not be mapped due to failure to record grid references.

7 State Wide Results and Implications

7.1 State-wide and regional returns

A total of 150,822 fox tails were returned up to week 52 of the bounty trial (Table 4). During this period 9,901 applications were processed (mean number of foxes returned = 16, SD = 25, range = 1-830). The majority of returns (56%) were of 10 foxes or less and only 6% of returns were for more than 50 foxes (Figure 3). The number of foxes returned and the number of applications declined and remained at consistently lower levels from week 9 to week 43 of the trial (Figure 4). Return rates increased again towards the end of the trial. The drop in the weekly tally was consistent with a drop in weekly participation rate. This may have been due to reduced hunter effort following an initial peak in activity. An increase in returns at week 25 was probably due to the anticipated conclusion of the bounty in December 2002 with hunters returning accumulated tails. Collection centres were closed for Christmas during week 26. Bounty collection was affected by the north east Victorian fire emergency from week 28 to week 37. At least half the collection centres were closed during some of that period and this is reflected in low numbers for the period.

Figure 3. Frequency of fox returns up to week 52 of the bounty trial.



7.2 Distribution of fox collection across the state

The intensity of fox recovery across the state was mapped as the mean collection of fox tails km^{-2} within each $100km^2$ (10km X10km) grid cell (Figure 5). The “patchiness” of fox collection at week 52 is clearly illustrated by this distribution map. Approximately 83% of the foxes recorded in the analysis came from just 25% of the area of the state. The value of the *d statistic* (an index of the degree of clumping) for the statewide distribution of fox collection supports the conclusion that the pattern was clustered ($d = 767$, a value >1.96 indicates a clustered distribution). The distribution map (Figure 5) shows areas of high fox collection rate (>2 foxes km^{-2}) were surrounded by large areas where fewer foxes were taken (0-2 foxes km^{-2}). Large areas where no foxes were taken correspond to extensive areas of public land including national parks in the eastern highlands, Gippsland and the Mallee.

This patchiness in fox recovery is likely to reflect both the distribution of foxes and the ease with which foxes can be hunted in different habitats. The distribution may also reflect variations in control effort. An assessment of the broad scale impact on fox populations was made by determination of the average removal of foxes km^{-2} across the state. Fox removal at week 52 (Figure 5) of greater than 1 fox km^{-2} occurred in approximately 13% of the state (Figure 5, Table 5). Removal of greater than 2 foxes km^{-2} occurred in less than 4% of the state. The map (Figure 5) shows that there was some concentration of fox collection effort in the 0.5- 2 km^{-2} range (shown in orange). However, based on what is known of fox population biology, successful control would require a more intense effort over a large area. Additional control effort through baiting programs would be necessary to achieve a sufficient level of widespread population reduction. It is not known how much baiting was carried out during the trial but the bounty alone would have been unlikely to result in population declines.

Table 4. Total number of foxes returned and number of applications received at each collection centre at week 52 of the bounty trial.

Depot	Applications	Foxes
Bacchus Marsh	197	3341
Bairnsdale	451	4481
Ballarat	847	16368
Benalla	442	8034
Bendigo	836	16584
Broadford	288	4357
Camperdown	182	4191
Colac	274	4785
Ellinbank	226	5719
Geelong	331	5087
Hamilton	1112	16764
Horsham	852	14382
Irymple	182	3822
Lilydale	204	2525
Orbost	90	773
Ouyen	197	1706
St Arnaud	274	3132
Swan Hill	355	5097
Traralgon	358	3503
Wangaratta	372	4199
Warrnambool	836	8820
Wodonga	498	7047
Wonthaggi	236	3192
Yarram	261	2913
Total	**9901**	**150822**

Figure 4. Total number of fox tails received and total number of applications from week 1–52.

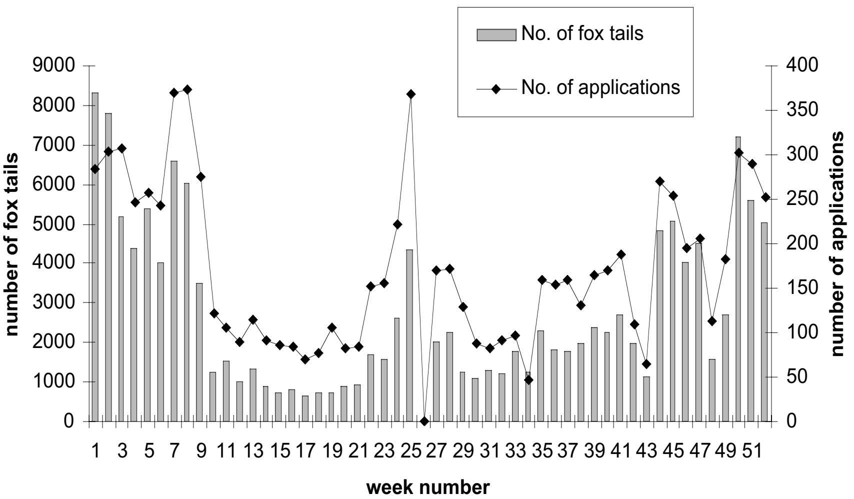


Table 5. Proportion of state subject to different levels of fox removal (due to the bounty trial) at week 17 (immediately after spring lambing) and week 52 of the trial.

Average collection of foxes km^{-2} in 100 km^2 grids	Proportion of state (%) At week 17	Proportion of state (%) At week 52
0	55.4	41.0
<0.5	32.3	33.8
0.5–1	7.6	12.5
1 - 2	3.5	9
>2	1.2	3.7

Figure 5. Statewide distribution of control measured as average collection of foxes (km^{-2}) in each 100 km^2 grid (weeks 1-52).

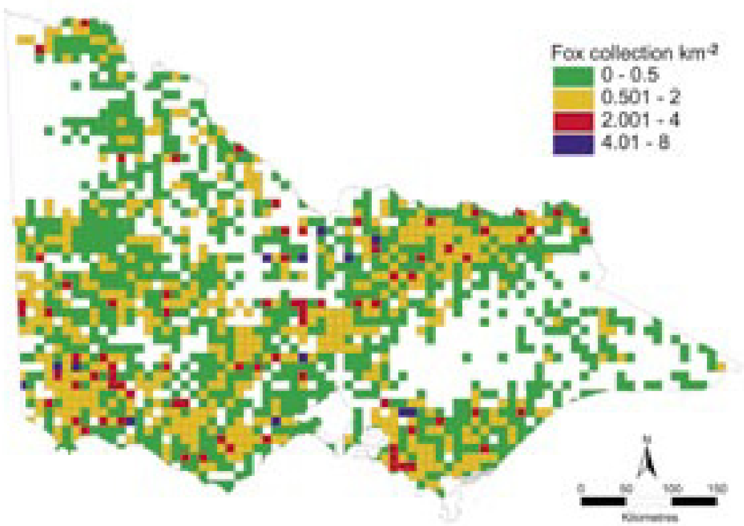
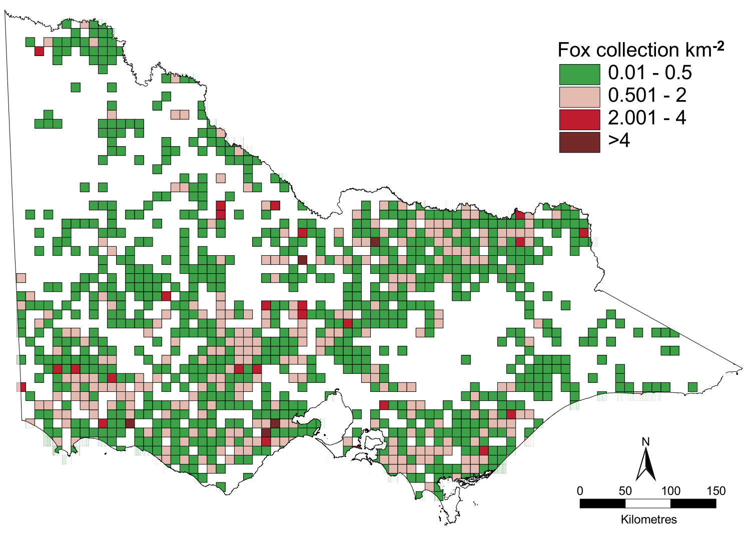


Figure 6. Statewide distribution of control measured as average collection of foxes (km^{-2}) in each 100 km^2 grid (weeks 1-17).



7. 3 Contribution to fox control in different habitats

When the data for the mapped fox records were examined as the average fox collection km^{-2} in different habitat categories the bounty did not generally favour any habitat type (Table 6). The actual levels of fox collection km^{-2} were very low relative to estimated fox densities in agricultural areas, although collection in forest habitat appeared to be high relative to estimated density (Table 6).

An earlier analysis of the bounty was undertaken at week 17 immediately following the spring lambing period using data from 48,696 foxes collected at the time. The bounty was originally timed to assist sheep farmers manage lamb predation during a period when foxes can cause significant economic losses. The pattern showed a very patchy distribution of fox collection during this period (Figure 6) with areas of high collection rate surrounded by areas of much lower collection rate. Despite protection of sheep flocks being a major objective of the trial, sheep production areas did not appear to be specifically targeted during the lambing period ($\chi^2 = 0.06$, 1 d.f., NS). Over the entire 52 weeks of the trial fox collection rate was higher in sheep production areas (Table 6) but this was not a statistically significant departure from random fox collection rate ($\chi^2 = 0.39$, 3 d.f., NS).

The state was divided into 1:100,000 map sheets to examine fox removal at a more localised scale. Average fox collection km^{-2} per map sheet is shown in Figure 7. In the majority of the map sheets the distribution of frequencies of foxes taken at week 52 (foxes km^{-2}) in each habitat category indicated no preferential targeting of sheep production areas.

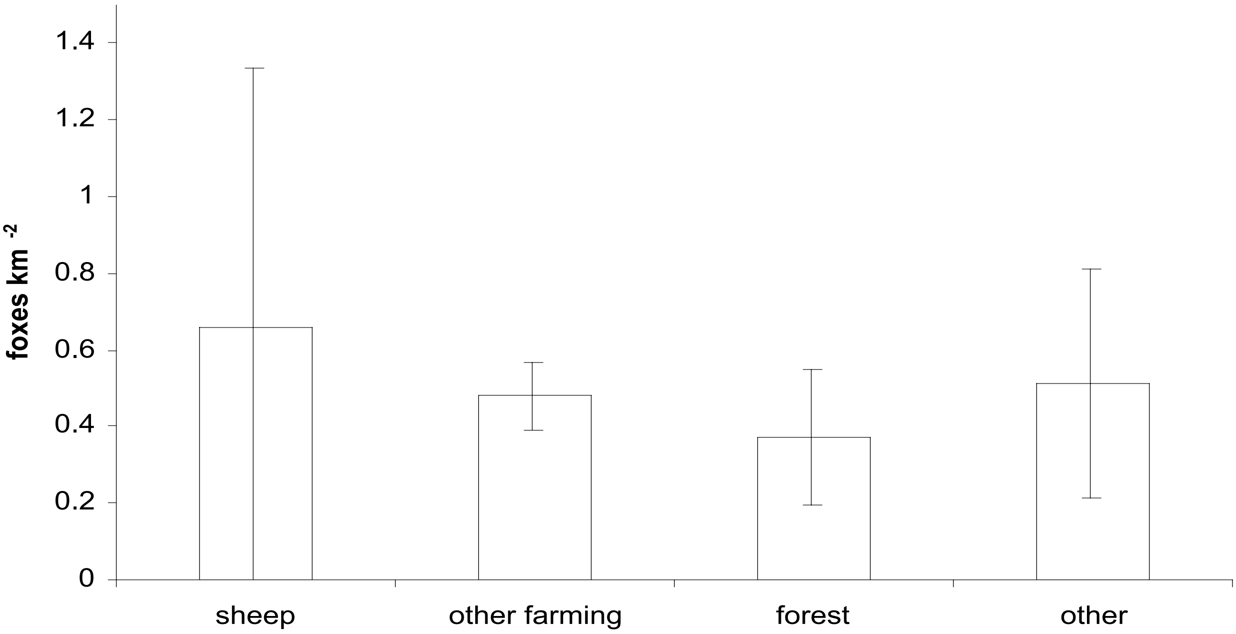
In contrast to other habitats the collection rate of foxes (foxes km^{-2}) in forests (State Forest and National Parks) appeared to be high relative to their estimated density in these habitats (Table 6). However, this result requires some qualification. The density estimate cited in Table 6 is conservative. Abundance of foxes in forest habitats varies depending on a range of environmental factors[32, 33] but appears to be particularly related to distance from cleared agricultural land.[27] Foxes tend to favour forest edges (the zone between farmland and bushland), which offer both good cover and a wide range of food sources.[32, 33] Foxes have been found to be less abundant further into the interior of the forest (> 1km).[32] It is likely that most of the foxes taken in forest habitat during the bounty were taken at forest edges or on forest roads close to farmland as foxes are difficult to shoot in heavily vegetated areas.[25, 27] There are no published estimates of fox density at forest edges but it is reasonable to assume that it is higher than the estimate for forest habitat as a whole cited in Tables 1 and 6.

Table 6. Statewide contribution to fox reduction in different habitats during the bounty trial up to week 52 and estimated fox density expressed as foxes km^{-2} in each habitat. Estimated densities are based on previous research.[1]

Habitat Category	Sheep	Other farming	Forest habitat including remnant vegetation	State forest/ National park	Other
Number of foxes recorded as taken	37111	46197	7152	7200	1192
State wide mean of foxes taken km^{-2}	0.71	0.53	0.4	0.1	0.51
Estimated fox density (foxes km^{-2})	4.0–7.2	0.9–4.0	No estimates available	0.2 (conservative estimate)	No estimates available

[1] Little is known about fox density in forests and what is known comes from a few studies in interiors of large forest blocks. The estimate 0.2 foxes km^{-2} cited in table 6 is for forest interiors. Fox density at forest edges and in smaller forest patches is likely to be much higher than in forest interiors.

Figure 7. Mean number of foxes collected km^{-2} per map sheet in each broad habitat category. Error bars are 95% confidence intervals.



7.4 Predicted short, middle and long term impact on fox populations

Based upon the best available data, fox density in many agricultural areas of Victoria may be conservatively estimated to be 4 foxes km^{-2}. According to Hone's[23] analysis a minimum annual removal of greater than 2.6 foxes km^{-2} (65% population reduction) across the agricultural regions of the state would be initially required before a lasting effect on populations could be observed. The map of fox collection patterns at week 52 (Figure 5) shows some areas of higher collection rates (red and blue squares on the map). Localised high reductions of foxes (> 2 km^{-2}) were likely to have had a short term impact on populations but examination of Figure 5 reveals that areas of more intense fox control were isolated and surrounded by large areas of low level control. These highly localised reductions are likely to be negated by the influence of reinvasion from non-bounty areas or where control was less intense.

In only approximately 13% of the state was the contribution of the bounty trial to fox reduction above 1.0 km^{-2} (Table 5). Removal of foxes approaching the level required to result in a general population decline if sustained only occurred in less than 4% of the state's area (Figure 5, Table 5). Based on Hone's[23] estimate of the requirement for a >65% population reduction, it is unlikely that the level of fox collection due to the bounty was sufficient to contribute in any significant way to population reduction on a broad scale.

Fox collection rate was higher in sheep production areas than in other habitat categories. However, this was not significantly higher than the expected collection rate had sheep areas not been specifically targeted. Despite the apparently large number of foxes collected, the low level of collection intensity (foxes taken km^{-2}) across most of the state indicates that population impacts would be minimal.

In most regions of the state, where control effort was highly variable, the impact of the bounty may be to stimulate or "prime" reproductive rates through moderate reductions in abundance and disruption of social groups. The likely result of increased reproductive rates will be a return to pre-bounty density or an increase in density over subsequent breeding seasons.