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ADVANCES IN THE INTEGRATED CONTROL OF THE EUROPEAN RABBIT IN SOUTH AUSTRALIA

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ABSTRACT: In South Australia, success in control of the European rabbit has been based on an understanding of rabbit biology and behaviour.

Drastic population reduction is obtained by use of Compound 1080. This method is much more effective when carried out during midsummer to late autumn. At this time, territorial boundaries are relaxed and the young have been weaned and are feeding aboveground. To ensure that the greatest number of rabbits can receive a lethal dose, it is necessary to pre-feed the population with unpoisoned bait over a period of 8 to 10 days. Oat grain has been chosen as the preferred bait material because of its acceptability and to minimize possible off-target effects.

As warrens are an essential factor in rabbit survival, warren destruction is a vital part of any effective control programme to prevent a resurgence of the population. Poisoning followed by ripping of warrens and then fumigation provided effective control in the most cost-efficient manner. Warrens can be destroyed with minimal disturbance to areas of valuable native vegetation.

By promoting this system of integrated control and by explaining to landholders the biological reasons for its effectiveness, the major rabbit problems of South Australia's agricultural lands have been overcome. In addition to the improvements in farm productivity in both the short and long term, rabbit control often appears to be an essential tool in the management of native vegetation and native herbivores.

In the low-rainfall parts of the state, the low productivity of the land makes it difficult to justify this system of integrated control in terms of cost-efficiency. Ripping of warrens by itself has been shown to provide reasonable control in hilly country with 250 to 300 mm of rainfall, when control takes place late in summer when rabbit numbers are low. However, biological control in the form of myxomatosis provides the most likely means of keeping rabbit numbers at a low level throughout the low-rainfall areas. European rabbit fleas from the arid parts of Spain are expected to be introduced soon to help spread myxomatosis more effectively in the arid parts of South Australia.

INTRODUCTION

The European rabbit (Oryctolagus cuniculus) has been the most important vertebrate pest in the southern half of Australia following its introduction and rapid spread in the second half of the last century. In the State of South Australia, rabbits soon became established in the southern and coastal areas, where clearing of the natural vegetation for cereal-growing and for the establishment of improved pastures made conditions even more suited to colonization by rabbits. In the cereal-growing areas, the light sandy soils were ideal for rabbits to establish their systems of underground burrows or warrens which provide shelter from predators and harsh climatic conditions. The southern and coastal parts of South Australia have a Mediterranean climate, with mild, cool winters and hot, dry summers. Further north, conditions are more severe and 80% of the state receives an average annual rainfall of less than 250 mm. This rainfall is usually erratic, with isolated torrential downpours being separated by long periods of drought. Daytime summer temperatures often rise above 40°C. The low productivity of these areas has meant that it has not been worthwhile economically to try to improve the forage available by introducing annual grasses or by applying fertilizers. Despite the severe conditions, rabbits were able to colonize most arid parts of the state because they shelter in their warrens during the midday heat and emerge to feed on the scant vegetation late in the day, at night, and early in the morning.

Landholders soon become aware of the serious damage that rabbits could inflict on crops and pastures. Farmers in the southern parts of the state tried any method that they could think of to rid their properties of high rabbit numbers. These methods included trapping, shooting, poisoning, and various attempts at destroying warrens, coupled with exclusion by netting fences. However, early attempts at control were poorly coordinated and often ineffective. In the 1940s, rabbit numbers increased markedly as a result of favourable conditions and a wartime lack of manpower to carry out control work on farms.

The viral disease, myxomatosis, was introduced in the early 1950s and the spread of this method of biological control brought immediate relief to landholders. Myxomatosis resulted in over 90% mortality in rabbit populations during the disease's initial establishment phase in 1950 to 1953. However, there soon appeared attenuated field strains of the myxoma virus and increasing resistance to the disease amongst rabbit populations in the field. Those concerned with protecting the state's resources from rabbits realized that long-term rabbit control would need the systematic application of other control methods to supplement and back-up the effects of myxomatosis.

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In South Australia, landholders have always been responsible for rabbit control on the land which they own or lease. However, the Vertebrate Pests Control Authority, a government-appointed body comprised of landholders and state departmental officers, was established primarily to develop rabbit control methods suited to South Australian conditions and to promote their use throughout the state. This paper outlines the development of these methods, which have been based on an understanding of rabbit ecology and behaviour.

POPULATION REDUCTION BY THE USE OF 1080

In the 1950s, investigations by the CSIRO, a federal research organization in Australia, found that Compound 1080 (sodium fluoroacetate) was highly toxic to rabbits. This compound was readily accepted by rabbits without any signs of bait shyness and is apparently tasteless and odourless (Rowley 1963). At about the same time, detailed studies were undertaken on the biology and behaviour of rabbits in the field and in large enclosures. These studies confirmed that there is a regular annual change in population size, with breeding being dependent on the availability of actively growing green feed (Poole 1960). Typically, breeding commences in late autumn or early winter, decreases during midwinter and reaches its peak during spring when plant growth is at its greatest. At this stage the rabbit population is at its highest level but the onset of the long dry summer in most of southern Australia results in a rapid decrease in population size. The young born early in the breeding season are the animals most likely to survive to become the main breeding stock for the next year. The size of the annual increase in population and the size of the population which survives the summer are influenced by predation, seasonal conditions, and outbreaks of myxomatosis. However, a fivefold increase in numbers during the breeding season is possible for most Australian rabbit populations. In years of particularly favourable climatic conditions, a population may increase greatly and not suffer the expected crash in summer. In such a situation, the controlling influence of factors such as predation become unimportant (Fenner and Ratcliffe 1965).

Myers and Poole (1961) found that rabbits live in well-defined social groups, with each group being generally confined to its own territory during the breeding season. The size of each territory is directly dependent on the overall density of rabbits in the area. Hence if poisoning takes place in the breeding season, an adequate amount of poisoned bait has to be laid through the territory of each group of rabbits to achieve a major reduction in population. An additional problem is that some unweaned young can survive even if their mothers are killed. The last part of the nonbreeding season seems the most desirable time for poisoning as territories are then less closely defended, rabbits wander over greater distances, and there are no unweaned young at this time (Poole 1963).

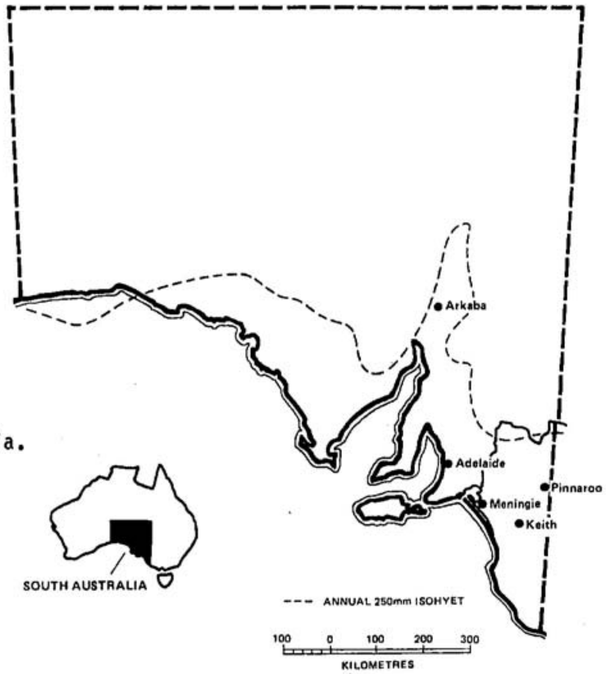
The advantages of late summer poisoning, i.e., during the rabbits' nonbreeding season, have been demonstrated in field trials as summarized in Table 1. The locations of these and other sites are shown in Figure 1. In each case, unpoisoned bait material was laid first (free-feeding) to ensure that all rabbits became accustomed to the new bait base. Rowley (1963) found that the greatest uptake of poisoned oat grain was achieved when rabbits were free-fed three times with untreated oats, and when free-feeds were spaced 3 days apart. This provides a long training period and results in the maximum number of rabbits accepting this new type of feed.

Table 1. Percentage reduction of rabbit populations by poisoning[a]. Percentage reduction figures are based on the reduction in rabbits sighted on counts standardized with respect to time and in locality over a marked transect. The highest of at least three counts carried out in weather conditions favourable to rabbit emergence was used as the prepoisoning count. The same applied to the postpoisoning count and these two counts were used to determine the percentage reduction.

	Types of bait material used			
	Carrots		Oats	
	Section 1	Section 2	Section 1	Section 2
1. Meningie experiment				
Summer	99	99	98	99
Winter	95	85	74	86
2. Keith experiment				
Summer	98	100	100	96
Winter	79	87	78	84

[a]Data supplied by J. E. Bromell.

Figure 1. Location of study sites in South Australia.



As can be seen from these results, when poisoning takes place in winter there is generally a reduction in rabbit numbers of only about 80%, regardless of which bait material is used.

By contrast, poisoning late in the nonbreeding season results in a reduction of over 95% of the prepoisoning population. The advantages of summer poisoning are even more important when the reduction in real numbers of rabbits in a population is considered. To illustrate this, a hypothetical population in a certain area may increase during the breeding season to 500 individuals. If poisoning takes place when the population is at this high level, i.e., during the breeding season, numbers can be reduced to about 100. Harsh climatic conditions over summer decrease the numbers surviving to about 50. By contrast, if poisoning is delayed until the end of summer, the effects of summer conditions will cause a much greater reduction as competition for food, water, and good burrows is much greater in the larger population. Hence, the springtime maximum population of 500 may decrease to only 100. If poisoning then takes place, the numbers surviving to the next breeding season can be reduced to five or less individuals. In this case, it will obviously take much longer for the population to recover as compared with poisoning during the breeding season.

The results in Table 1 also demonstrate that there was no significant difference in the effectiveness of poisoning with carrots or oat grain, particularly when poisoning took place in summer. Bait-choice trials had previously shown that rabbits preferred carrots to oats (Rowley 1963), but in the trials shown in Table 1 the rabbits had no choice; they were presented with only one bait material or the other. A comparison of the areas baited with carrots with the areas baited with oats is possible as the sections were paired to maximize uniformity in type of country, free-feeding, and poisoning. The results show that, when oat grain is the only bait material presented, it is readily accepted to the extent needed to ensure a very good poisoning result. This has led to a standard poisoning technique which uses oat grain mixed with 0.04% W/W of 1080, laid in a shallow furrow in infested areas at a rate of 2.8 kg/km, with 24 kilometres of this trail being laid per 100 ha. This method of poisoning, preceded by free-feeding with unpoisoned oats, is now recommended and used throughout most agricultural areas of the state. Oat grain as a base material has a number of advantages over carrots and other readily accepted baits. It is readily available throughout the agricultural regions, is easily stored and transported, and it does not need any processing before mixing with the poison. It is also a material that presents a relatively low risk to off-target species when used with 1080, as it is not as attractive to livestock and native herbivores as carrots. In addition, the native species of grain-eating parrots are less at risk using oat grain bait as these birds discard the husk of the oats which contains most of the 1080.

HABITAT MODIFICATION

Without man's direct intervention, the factors most likely to limit a rabbit population under Australian conditions are predation, scarcity of food and water, and disease. The relative effects of these factors are influenced by the density of rabbits which, in turn, is influenced by the size and number of warrens. The underground warren is essential for survival, providing protection from the harsh climate and from most predators. The ability of a female rabbit to breed successfully and raise litters to the point of weaning is very much dependent on her ability to gain and maintain a nesting site near the centre of a warren.

A significant reduction in numbers should be regarded as only the first step in long-term rabbit control as their prolific rate of breeding will enable the residual population to recover to prepoisoning levels within a few years. Therefore, landholders in South Australia are encouraged to destroy warrens to help prevent a resurgence in numbers. In land used repeatedly for cropping, warrens are often destroyed during mechanical cultivation. However, roadside verges, wasteland, and land preserved because of its valuable natural vegetation cover, are all areas where warrens persist and which enable rabbits to damage agricultural productivity and the ability of natural vegetation to regenerate.

Some protection from the resurgence of populations is gained by simply covering warrens after poisoning, using a set of disc harrows. This method is particularly suited to the agricultural parts of the state with light sandy soils and where warrens are readily accessible. In most areas suited to disc harrowing, rabbits have now been controlled. However, there was still a need for a cost-efficient means of long-term control for use in other areas, particularly one that could be used along roadsides without disturbing native vegetation.

Such areas of roadside vegetation are valued as often being the only surviving tracts of the natural vegetation that previously covered the surrounding farmland. As such, these areas are havens for native birds and animals. The natural roadside vegetation is less flammable than dry annual vegetation in summer and it therefore reduces the fire risk in the hot, dry summer months. It also acts as a barrier to the spread of weeds and provides valuable shelter for livestock in adjacent paddocks during winter. However, some landholders would still prefer to have the roadside vegetation removed as they believe that it robs nutrients and moisture from adjacent crops and that it must be removed as the first stage of rabbit control.

Roadside trials took place in the cereal-growing zone of the state, near the township of Pinnaroo, to find the most cost-efficient control strategy. Each experimental plot consisted of 1 km of roadside covered in mallee (Eucalyptus) vegetation and adjoining farmland (Cooke 1981).

Poisoning was carried out using the recommendation already outlined, i.e., three free-feeds of oats each separated by 3 to 4 days, followed after a similar interval by a poison feed of oats containing 0.04% W/W of 1080. Poisoning took place in late February, late in the nonbreeding season.

Ripping consists of pulling a single-tine ripper, mounted on the three-point linkage of a tractor, through the warren structure to a depth of 45 cm. After ripping in one direction in close parallel lines right across the width of the warren, the operation was repeated at right angles to ensure the most complete destruction of the warren. Where the vegetation was too thick to enable the tractor to operate, warren entrances were filled in with a shovel.

For fumigation, aluminium phosphide tablets (Phostoxin® or Gastoxin®) were chosen as they had previously been shown to be effective and cost-efficient. They have also been found to be very convenient and relatively safe for the operator. For each warren entrance, a tablet is wrapped in tissue paper, moistened, and placed as far down the entrance as possible. The entrance was then filled in with soil and tramped down to seal in the fumigant. Both ripping and fumigation took place in March.

The effectiveness of each treatment or combination of treatments was assessed by counting the number of warren entrances which were obviously being used in the middle 400-m section of each 1-kilometre-long experimental plot. Each treatment or combination of treatments was replicated three times. Active entrances were counted immediately after treatment in April and then again in November to assess the longer term effects of the treatments. Costing for operations was based on standard rates at the time of treatments in 1974.

As can be seen in Table 2, all treatments and combinations of treatments resulted in significant reduction in the number of active entrances. However, each control method individually did not prevent damage to the adjoining crops. Of the four combinations of methods, all except ripping followed by fumigation were able to prevent damage in the following growing season. It was concluded that rabbits could be controlled and warrens destroyed without significantly affecting roadside vegetation. Poisoning followed by ripping and then fumigation proved to be the most cost-effective strategy when compared with other treatments and considering the losses previously occurring in adjacent crops.

Table 2. Mean effects of each treatment, crop damage in adjoining wheat crops and total costs of trials at Pinnaroo, South Australia.

Treatment	No. of active entrances April	November	Crop damage in November	Total cost (A$)- including November refumigation
None	104	202	Severe	-
Poisoning	44	115	Moderate	Not refumigated
Ripping	26	74	Slight - Mod.	Not refumigated
Fumigation	18	69	Slight - Mod.	Not refumigated
Ripping + Fumigation	13	46	Slight	Not refumigated
Poisoning + Ripping	8	30	Nil	72
Poisoning + Fumigation	4	20	Nil	78
Poisoning + Ripping + Fumigation	3	5	Nil	70

Landholders can no longer use rabbit control as an excuse for removing native roadside vegetation. Indeed, such vegetation may present significant advantages in terms of rabbit control as undisturbed native vegetation is less attractive as rabbit fodder than the introduced grasses that invade an area after native vegetation is removed.

DISCUSSION

These trials have led to the standard recommended procedure for rabbit control in the agricultural areas of the state. Landholders carry out poisoning in late summer or autumn after free-feeding three times with untreated oats. A week or two after poisoning, all accessible warrens are ripped and inaccessible warren entrances filled in by hand. Fumigation of any reopened entrances takes place after the first winter rains because the toxic fumes reach a maximum concentration in the warren when soils are moist.

This system has resulted in a satisfactory level of rabbit control in most cropping and high-rainfall pastoral lands. The landholder is legally responsible for rabbit control on his own land and on half the width of any adjoining roadsides, thus infestations of rabbits on roadsides are controlled by those who have most to gain from that control. A complaint of landholders has been that rabbit problems always come from neighbouring properties. However, most rabbits forced to live away from a warren are killed by predators or harsh climatic conditions. Therefore, a landholder who controls his own rabbits by population reduction followed by warren destruction will be able to maintain that control, regardless of his neighbours' rabbits. Control can be maintained by fumigation of reopened burrows discovered during routine annual inspections. An annual poisoning around the boundary of a controlled area reduces any risk that rabbits will reinvade from surrounding land.

The greatest numbers of rabbits are destroyed in country where control is easy to carry out, while populations in more difficult areas are subjected to less effective control or to no control at all. As a consequence, large tracts of native vegetation, areas with sheet limestone just beneath the surface, and areas along steep river banks all remain areas of high rabbit numbers. Landholders often remain unconvinced that the extra effort needed in dealing with these difficult problems is warranted and the role of our extension staff, employed at both State and Local Government levels has been to encourage landholders in this regard. When efforts to persuade landholders to bring about satisfactory control have been exhausted, legislative enforcement is used and consequently, landholders may face financial penalties through fines and sometimes the cost of control work carried out by the state vertebrate pests control authority or its agents may be debited against the landholder.

In cropping areas, the benefits gained from control work have been mainly in terms of improved productivity, but native vegetation in areas such as national parks has also benefited greatly from control, or preferably, eradication of rabbit populations. Cochrane and McDonald (1966) found that in an area of native vegetation where rabbits were excluded, biomass, percentage groundcover, and the number of native plant species were more than double the figures found in rabbit-infested areas. Cook and Chinner (unpubl.) have found in coastal vegetations near Meningie that the exclusion of rabbits can result in a succession from introduced weeds and annual grasses to native shrubs and perennial native grasses. A community with perennial grasses as a major component seems to be important for native herbivorous vertebrates, such as the eastern grey kangaroo (*Micropus giganteus*) and the common wombat (*Vombatus ursinus*). The wombat requires a supply of perennial grasses in summer for successful breeding while the ability of an area to support a certain population of native herbivores is adversely affected by the degradation of native pastures and the competition brought about by rabbits. (Mallett and Cooke, unpubl.).

CONTROL IN THE ARID ZONE

The arid or pastoral regions comprise more than 80% of South Australia's total area but they contribute less than 5% of the State's agricultural production. As the pastoral region has low annual rainfall (less than 250 mm annually) and in most years a sparse vegetation cover, many properties need to be hundreds of square kilometres in size to be economically viable. In much of this pastoral country, the maximum stocking rate permitted by the state government is no more than two cows for every 5 square kilometres. However, after 2 or more years of favourable seasonal conditions, rabbit numbers have been known to be as high as 3,500/sq km (Cooke 1974), equivalent in terms of grazing pressure to 44 cattle/ sq km.

In this arid environment, the recommended strategy of poisoning followed by ripping and fumigation could be done but only at a cost out of all proportion to the total productivity of the land. For example, the value of cattle slaughtered in 1984 was about A$300 per beast, and yet the cost of controlling rabbits on the area needed for that beast to graze would have been around A$2000. This cost is based only on poisoning and ripping a moderately infested area (0.5 warrens/ha) and does not include fumigation or later retreatment.

Because there are limits on the stocking rates for most of the pastoral lands, a landholder usually cannot increase the number of livestock following control of rabbit populations. The benefits to be gained from rabbit control, such as improved regeneration of the shrub and tree cover and a decreased risk of erosion, are long term advantages that landholders find difficult to equate with the immediate costs of large-scale control operations.

Nevertheless, recent research has shown that significant rabbit control can be achieved in semiarid (250 to 300 mm rainfall) country simply by destroying warrens thoroughly by tractor ripping. Cooke and Hunt (unpubl.) compared the effects of ripping, poisoning and poisoning followed by ripping, in the steep hills of Arkaba Station in the southern Flinders Ranges. Work was carried out in late summer when rabbit numbers were relatively low and the soil was very dry. The effectiveness of each treatment was assessed by counting the number of active warren entrances found in the centre of each treatment block 1 month after treatment. As can be seen from Table 3, all three treatments reduced the activity of the warrens. Ripping by itself and poisoning followed by ripping were much more effective than poisoning alone. However, the slightly better result achieved by the poisoning/ripping treatment is not enough to justify the great expense of poisoning in this type of country. Provided that treatment takes place when rabbit numbers are relatively low, ripping alone provides an effective and economical treatment.

Table 3. Mean effects of each rabbit control treatment, (as calculated from the analysis of variance), from experiments conducted at Arkaba Station, Southern Flinders Ranges.

Treatment	Mean number of active warren entrances 1 month after treatment
None	72.2
Poisoning	27.1
Ripping of warrens	7.3
Poisoning + ripping of warrens	3.5

The search is continuing for effective control in the even drier parts of the state. These parts contain very large sheep and cattle holdings as well as significant areas controlled by aboriginal communities and by the state and federal governments, especially the National Parks Service. As these bodies derive very little income from much of this land, there is little economic incentive for them to carry out any form of mechanical or chemical control.

Biological control in the form of myxomatosis provides the most likely means of keeping rabbit numbers to a relatively low level in the future. Although this disease has been found in rabbits living in the pastoral lands since the 1950s, this has not prevented major rabbit plagues from occurring in 1955-56, 1969-70 and 1974-75. The main reason for this lack of successful control has been the lack of suitable vectors to spread the disease between rabbits. Mosquitoes (Anopheles spp. and Culex sp.) were responsible for the dramatic outbreaks of the disease in the 1950s and still help to spread the disease in the more temperate parts of the state. The European rabbit flea (Spilopsyllus cuniculi), first released in South Australia in the early 1970s, has been more effective than mosquitoes at spreading the virulent strains of the virus and has led to outbreaks of the disease in winter, rather than the summer outbreaks caused by mosquitoes. In areas where the flea can persist, this has resulted in lower population levels over summer, although annual seasonal fluctuations still occur (Parer et al. 1985). However, the types of flea currently in Australia are unable to survive the hot dry conditions found in areas of South Australia that have an average annual rainfall below 200 mm. One reason for this is the sporadic rainfall in these areas. Not uncommonly, drought may extend for over 12 months, and during this time there is no actively growing green grass available to start the rabbits breeding. As the rabbit flea requires hormones from a pregnant rabbit to stimulate its own breeding, the flea dies out whenever the period between rains is greater than the flea's life span.

One reason for the flea's inability to survive in these areas may be that those released in the 1970s were bred from fleas imported from England, where the flea could have adapted to the temperate climate, especially the regular seasonal rainfall. In 1986, fleas will be imported from the arid parts of Spain, where they survive in conditions similar to those in South Australia's pastoral lands. After their release, their survival will be monitored in the low-rainfall areas of South Australia. Rabbit numbers will no doubt continue to fluctuate in accordance with the erratic occurrence of good and bad seasons. However, the aim of our work in the arid parts of the state is to reduce rabbit numbers overall and to restrict the ability of rabbits to increase to plague numbers in particularly favourable years. The possibility of the pastoral lands recovering from 100 years of overgrazing is an exciting prospect.

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