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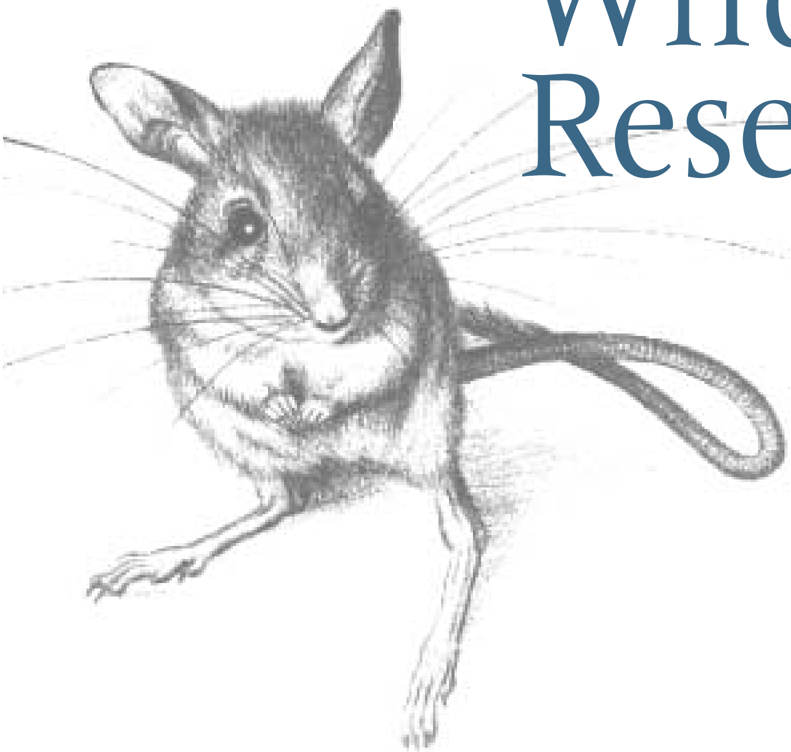

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Observations on the impacts of rabbit haemorrhagic disease on agricultural production values in Australia

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Abstract. Rabbit haemorrhagic disease (RHD) may be the most important rabbit control agent to be made available to graziers in Australia since the advent of myxomatosis. Documenting the benefits of RHD to agricultural production values is an important process in determining best-practice strategies for the use of the disease in controlling rabbit populations. In this paper we review previous studies on the impact of rabbits and present recent Australian case studies that tracked the effects of RHD on agricultural production as the disease first spread across the continent. Indirect consequences of RHD, such as changes in costs of rabbit control as monitored through the use of 1080 (sodium monofluoroacetate), are reported. Potential negative impacts such as adverse effects on the wild rabbit fur and meat trade and in the spread of woody weeds are also discussed.

Introduction

The European rabbit (*Oryctolagus cuniculus*) has long been perceived to have a negative impact on agricultural production in Australia, mostly experienced by pastoral industries. The rabbit is adapted to Mediterranean climates characterised by warm, dry summers and cool, wet winters. These conditions also characterise much of southern Australia (Wilson *et al.* 1992). Soils are a major factor influencing the local and regional distribution of rabbits in Australia (Williams *et al.* 1995), and soils preferred for the establishment of warrens are also some of the most productive for livestock production (Mutze *et al.* 1991).

Rabbit haemorrhagic disease (RHD) may be the most important rabbit control agent to be made available to graziers in Australia since the advent of myxomatosis. Optimising the effect of RHD on rabbit populations and hence reducing the impact of rabbits on agricultural production requires careful consideration (Saunders and Kay 1999). Rabbit impact and cost of control are important economic factors in relation to farm viability and, in many instances, unrealistic expectations were held for the efficacy of RHD when it was first released. Reliable information demonstrating an economic benefit of the disease needs to be produced so that best-practice strategies that integrate RHD with other rabbit control techniques are adopted. This in turn will help maximise the improvements in agricultural production and risk management realised by producers as a consequence of RHD (Saunders and Kay 1999).

In this paper we discuss some of the direct and indirect consequences that RHD has had on agricultural production values generally, and livestock productivity specifically. By way of examples we present case studies from New South Wales and South Australia.

Previous observations on agricultural impacts by rabbits

The rabbit quickly assumed pest status following its introduction last century. Since then, various measures of its impact on agricultural production have been derived (Williams *et al.* 1995). Impacts on agriculture have primarily been estimated for the pastoral industry, where rabbits can compete directly with livestock. Other impacts on agriculture include undesirable changes to pasture composition, reduced crop yields, forestry and tree plantation losses, and costs of rabbit control. Less-tangible impacts include soil erosion, reduced drought preparedness, loss of biodiversity on agricultural lands and research costs associated with rabbit management. Most reported estimates of these impacts are subjective or anecdotal and few involve formal quantification (Fennessy 1966; Hone *et al.* 1981; Croft 1986; Williams *et al.* 1995). Nonetheless, the weight of evidence does indicate that rabbits adversely affect agricultural production.

Earlier attempts to quantify the economic losses caused by rabbits were based on improvements in production values following the release of myxomatosis. For example, Reid (1953) estimated that the reduction of the rabbit population

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by myxomatosis in 1952–53 resulted in an increase of 32 million kilograms in wool production (5.47% of total Australian production), which was valued in the 1990s at A$590 million (Williams *et al.* 1995).

A popular measure of the impact rabbits have on livestock production is the number of additional dry stock equivalents (DSEs) that could be supported by a farming system if rabbit density was reduced. Recent estimates of the number of rabbits that constitute a single DSE for sheep range from 9 to 16 (Short 1985; Croft 1986), with subjective estimates of 10–12 most often quoted (Myers *et al.* 1994). By assuming that additional DSEs could be supported by reducing rabbit density regardless of the prevailing availability of pasture, this approach implicitly assumes that all pasture consumed by rabbits would be available to increase the number of livestock carried (Choquenot 1992). Studies have also been conducted that attempt to quantify the national cost of rabbits by incorporating DSE or similar estimates of the production value foregone as a consequence of the presence of rabbits. Henzell (as quoted in Williams *et al.* 1995), for example, estimated that rabbit damage in pastoral areas of South Australia caused losses of at least $17 million a year. In a survey of the Australian wool industry, Sloane *et al.* (1988) estimated an economic loss from rabbits to the wool industry of $94.5 million a year, which included a $5 million estimate for the annual cost of existing rabbit control. ACIL (1996) estimated that the annual cost of rabbits was $600 million, which was equal to 3% of the annual gross value of agricultural production in 1993, but this estimate assumed that any wool product could have been sold at 1993 wool prices.

Modelled consequences of RHD

Manson (1998; as cited in Saunders and Kay 1999) used an equilibrium-displacement model to investigate the benefits of RHD through its impact on the Australian wool industry. This was done by assuming that RHD-induced declines in rabbit abundance result in a percentage reduction in wool production costs. To provide a more realistic regional distribution of benefits from the release of RHD, Manson used a cost-reducing scenario in which costs were reduced by 25% in the pastoral zone, 5% in the wheat–sheep zone, and 2.5% in the high-rainfall zone of Australia and New Zealand. Under these modelled scenarios, he estimated that wool producers in the pastoral zone benefited the most, by A$111 million a year or nearly half the gross annual benefit from the release of rabbit haemorrhagic disease virus (RHDV). Manson's (1998) modelling suggests that wheat and sheep producers gained more than $50 million a year from the release of the disease.

Case studies

NSW Central Tablelands

The effect of RHD on pastoral production was studied at three sites in the Central Tablelands of New South Wales: Euchareena, Thatchers and Bathurst. These sites had previously been used in a larger experiment to determine the costs and benefits of rabbit control on agricultural land. RHDV arrived at all sites within the space of 6 months and was confirmed at Euchareena in June 1996 and at Thatchers and Bathurst in January 1997. Between the spring of 1994 and the autumn of 1996, rabbits were poisoned annually and their warrens ripped on the Euchareena and Thatchers sites; no rabbit control was undertaken on the Bathurst site. Rabbit density, pasture growth and pasture offtake had been estimated on all sites since late 1994, two years before the arrival of RHDV, and continued to be monitored until winter 1999, 3 years after the arrival of RHDV (see Choquenot *et al.* (1998) for details of methodology). Data are presented here for the period up to the winter of 1998. Changes in rabbit density on the three sites are shown in Fig. 1. Evidence of RHD corresponded to a marked decline in rabbit density on the Euchareena site only, although rabbit densities remained low on the Thatchers site despite the cessation of the annual warren-ripping program.

Effect of RHD on pasture growth and offtake

With the exception of the Thatchers site, pasture offtake closely mirrored pasture growth, suggesting that rabbits, sheep and other herbivores consumed most of the new pasture growth, or that there was almost perfect and instantaneous compensation in pasture growth for pasture offtake. The pattern was less clear on the Thatchers site, probably reflecting the abundant unpalatable vegetation, which obscured variation in growth and offtake of palatable pasture species on this site (Choquenot and Saunders, unpublished data).

It is likely that compensatory pasture growth contributed to the close match between measured growth and offtake on the Bathurst and Euchareena sites. This complicates estimation of the effect that variation in rabbit densities (including variations due to RHD) had on pastoral productivity. If the degree of compensatory growth was high, offtake by herbivores other than stock would have contributed little to the amount of pasture consumed by

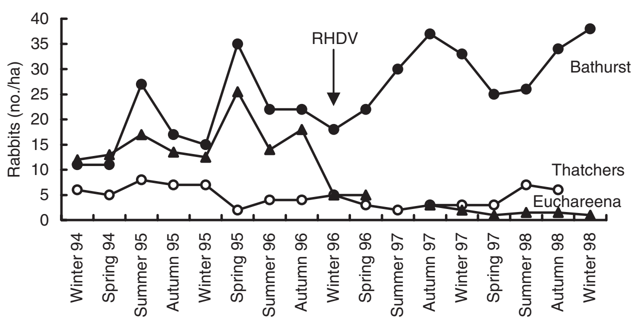

Fig. 1. Variation in the density of rabbits on the three sites monitored. Timing of the probable arrival of RHDV at the sites is indicated.

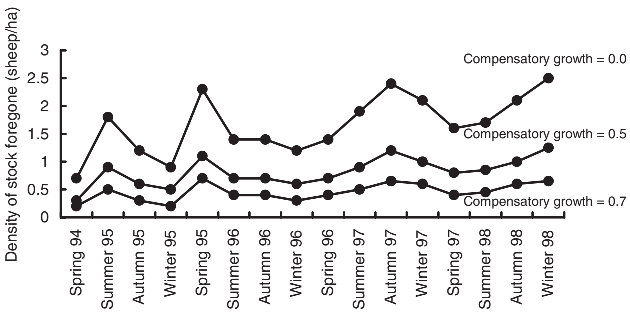

Fig. 2. Variation in the estimated density of stock foregone through the effects of rabbit grazing on the Bathurst site, under three assumed levels of compensatory pasture growth. Estimated densities of stock foregone assume that sheep require 40 kg dry weight of pasture per month at maximum productivity.

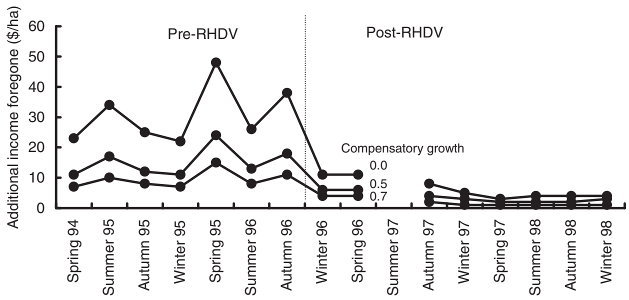

Fig. 3. Variation in estimates of additional annual income foregone through the effects of rabbit grazing on the Euchareena site, under three assumed levels of compensatory pasture growth.

stock. Conversely, if the degree of compensatory growth was low, offtake by herbivores other than stock would have reduced the amount of pasture consumed by stock. For example, Fig. 2 shows variation in the density of stock foregone on the Bathurst site because of the effect of rabbit grazing on pasture availability, assuming the proportion of variation in pasture biomass due to compensatory pasture growth is 0, 0.5 or 0.7. The differences in average stock density foregone are substantially different for the three assumed levels of compensatory pasture growth, ranging from 0.6 to 2 additional sheep per hectare where compensatory pasture growth is assumed to account for 70% and 0% of variation in pasture availability, respectively. Hence the degree to which pasture growth compensates for pasture offtake has a major influence on the relative value accruing from reductions in rabbit density associated with RHD.

Effect of RHD on the value of pastoral production

The value of RHD on the Euchareena site can be estimated by valuing the additional stock that could be carried in the absence of rabbits before and after RHDV arrived in the winter of 1996, assuming progressively higher proportional contributions (0, 0.5 or 0.7) of compensatory pasture growth to variation in residual pasture biomass (Fig. 3). Depending upon which scenario of compensatory pasture growth is adopted, the average value of RHD on the Euchareena site varied from \$24.73 to \$7.42 ha^{-1} (Table 1). The value of RHD on the Thatchers site is difficult to estimate because rabbit densities had already been reduced, which constrained the degree to which RHD could improve pastoral production (Fig. 1). Similarly, RHD had no appreciable effect on rabbit densities on the Bathurst site (Fig. 1), and hence no apparent effect on the density of stock foregone before and after RHD (Fig. 2).

Flinders Ranges, *South Australia*

Direct measurement of benefits to pastoral production in the semi-arid interior of South Australia is difficult, even though the impact of RHD has been greater and more temporally stable than in coastal agricultural areas (Mutze *et al.* 2002). Rainfall in the pastoral zone, and hence pastoral production, is highly variable so it may be some years before broad-scale trends in agricultural production become apparent. The benefits that ultimately accrue from RHD will depend not only on grazing competition, but also on changes in pasture composition and native herbivore numbers. Preliminary information comes from a study in the Flinders Ranges in which the interaction between rabbits, sheep grazing patterns, kangaroo numbers and perennial plant recovery was examined. The study was originally established using warren ripping as the main treatment effect. The advent of RHD provided an opportunity also to monitor its effects. Replicated field trials to examine the effect of rabbits on native pastures, and the grazing response of other herbivores to rabbit control, began in 1992. The study site was located

Table 1. Pre- and post-RHD estimates of the density and value of stock foregone on the Euchareena site through the effects of rabbit grazing, under three assumed levels of compensatory pasture growth
The value of stock is calculated assuming a net margin of \$29 per sheep per year

Assumed influence of compensatory pasture growth	Pre-RHD		Post-RHD	
	Average stock foregone (sheep ha^{-1})	Average value of stock foregone (\$ ha^{-1})	Average stock foregone (sheep ha^{-1})	Average value of stock foregone (\$ ha^{-1})
0	1.06	30.8	0.21	6.06
0.5	0.53	15.2	0.09	3.03
0.7	0.32	9.2	0.06	1.82

Table 2. Changes in mass of sheep dung collected from transects following rabbit control and the subsequent arrival of RHDV in the Flinders Ranges, South Australia

Time	Treatment	Ripped ($g\ m^{-2}$)	Unripped ($g\ m^{-2}$)	Ripped/ unripped	Treatment effect
May 1992	Pre-ripping	2.4	2.2	1.1	
May 1993–95	Pre-RHDV	3.2	2.1	1.6	+42%
May 1997–98	Post-RHDV	3.1	4.5	0.7	–37%

Table 3. Changes in total numbers of perennial plants on 24 vegetation transects recorded before RHD, from May 1992 to November 1995

Significant difference was determined by 2 × 2 *G*-test (Crawley 1993); data from 'no change' are excluded

Change	Unripped (rabbit grazed)	Ripped (no rabbits)	Significance
No. of transects with perennial plant numbers increasing or decreasing			
Increase	2	9	$P \leq 0.01$
Decrease	5	1	
No change	5	2	
Mean change in no. of perennial plants per transect per year			
	–1.6	+4.2	

on the northern boundary of Flinders Ranges National Park and the adjoining section of Gum Creek Station, 500 km north of Adelaide. Four treatment blocks of 3–4 km^2 were cleared of rabbits by warren ripping in 1992–93, one each in two soil types in sheep-free and sheep-grazed areas (either side of the Park boundary). Four matching untreated, rabbit-infested blocks were also monitored. Spotlight counts of herbivores and foxes were made along 2-km transects within each of the eight blocks (details in Mutze *et al.* 1998*a*, 1998*b*, 2002). Total dung mass deposited by rabbits, kangaroos and sheep was recorded annually at seven fixed 5.6-m^2 sites along each spotlight transect. Dung was aged by visual comparison with a 12-month-old dung sample from another site in the Flinders Ranges. Vegetation was monitored bi-annually on three vegetation transects in each block. Data are presented here for all perennial species recorded on fixed-position transects 100 m long by 4 m wide.

Maximum stocking rates on Gum Creek Station were set by the South Australian Government through the pastoral lease at 17 sheep per km^2. Stocking rates were not increased following the arrival of RHDV in October 1995. However, the paddocks were destocked in July 1998, and remained destocked for most of the ensuing 2 years, because of pasture damage by plague locusts and drought. Consequently, data are presented only for the period to May 1998. Recurring natural outbreaks of RHD since October 1995 have kept rabbit populations at about 15% of pre-RHD levels (Mutze *et al.* 2002). Rabbit numbers in treated areas have been kept at 1% of pre-ripping average counts.

Sheep grazing and total grazing pressures on Gum Creek were estimated from 1992 to 1998 using dung weight collected on standard transects. Sheep grazing levels were affected by changes in grazing patterns of the flock within the paddock. At the start of the study, sheep spent much of their time grazing in the rocky hills along the eastern edge of the study area, where there were few rabbits. As rabbit grazing pressure was reduced, sheep spent more time grazing in the fertile, rabbit-prone valley. Removal of rabbits by warren ripping increased dung deposition by sheep in ripped blocks by about 35% (or 42% relative to unripped control blocks; Table 2). After the arrival of RHDV, sheep grazing doubled in the unripped blocks while RHD caused little change to sheep grazing levels in ripped blocks.

At the start of the study in 1992, rabbits contributed 70% of total grazing pressure as estimated by dung collection. Total grazing pressure from rabbits, sheep and kangaroos was reduced by approximately 30% as a consequence of ripping, despite increases in kangaroo and sheep dung. Total grazing pressure on ripped blocks in 1997–98 was reduced by an extra 20% (due mainly to dispersal of kangaroos from those blocks) after RHD took effect and on unripped blocks by 20% because the reduction in rabbit dung outweighed the substantial increase in sheep.

The precision of dung transects as indices of grazing intensity is limited by the capacity to account for the uneven spatial distribution of dung and for variable rates of breakdown. At Gum Creek, we checked the influence of breakdown rates by comparing total dung weight with the weight of dung less than 12 months old. The two estimates of contribution to total grazing pressure in the first year fell within 5% for each species. Kangaroo dung was consumed by termites more rapidly than was sheep or rabbit dung (tending to deflate the annual estimate of kangaroo grazing),

Table 4. Changes in perennial plant numbers on 24 vegetation transects recorded after RHD, from November 1995 to May 1997

Non-significant difference was determined by 2 × 2 *G*-test (Crawley 1993); data from 'no change' are excluded

Change	Unripped (rabbit grazed)	Ripped (no rabbits)	Significance
No. of transects with perennial plant numbers increasing or decreasing			
Increase	5	8	$P \leq 0.9$ (none)
Decrease	1	2	
No change	6	2	
Mean change in no. of perennial plants per transect per year			
	+5.2	+4.2	

but that effect was offset because kangaroos moved in and out of the valley seasonally and were most abundant during the 6 months before dung collection in May (tending to inflate the annual estimate). Concentrations of dung deposited in buck-heaps by rabbits and in campsites by sheep (in the hills) and kangaroos (under bushes) were not sampled. Consequently, dung density is underestimated for each species but probably by similar proportions, so that the index of relative values was unaffected.

Before RHDV reached the study site, the number of perennial plants was increasing steadily only in rabbit-free treatment blocks (Table 3). On the rabbit-grazed (unripped) blocks, the number of perennials fluctuated seasonally with recruitment and with increases in abundance during wetter seasons balanced by higher mortality in dry periods. Over the 42 months of data collection, the proportion of transects where perennial plants increased was significantly higher in rabbit-free blocks than in rabbit-grazed blocks. The most common perennials recorded in the transects were *Acacia victoriae*, *A. calamifolia*, *Senecio magnificus*, *Ptilotus obovatus*, *Atriplex stipitata*, *Cymbopogon ambiguus* and *Aristida nitidula*. These species are considered only moderately palatable but all are grazed by rabbits; some, such as *Acacia victoriae*, are considered valuable stock feed and provide an integral stage in recovery of degraded pastures.

After RHD reduced rabbit populations, the treatment differences between ripped and unripped blocks were no longer significant and the mean rate of increase in perennial plants was very similar but slightly higher on the unripped (rabbit-grazed) blocks (Table 4).

Gum Creek Station was severely degraded by over-stocking last century, with stock numbers often exceeding currently permitted levels by a factor of ten. The damage to pastures caused by overgrazing was compounded by the subsequent arrival of rabbits. Most of the very palatable perennial plants have become too rare to monitor using standard techniques, so it is not clear whether these species could have recovered under continued sheep grazing, regardless of any effect RHD had on rabbit density. Many young shrubs were severely defoliated by browsing euros and sheep during the drought conditions in mid-1998, but almost all survived and put on new growth in spring. However, one of the primary justifications for rabbit control in the pastoral rangelands is to provide more stable productivity during drought. In this case, where historical over-stocking had depleted perennial pastures, RHD did not prevent the necessary destocking of the property during drought.

Effect of RHD on costs of rabbit control

A tangible benefit to agricultural production from the spread of RHDV would be a reduction in ongoing costs for rabbit control. In 1997–98, for example, the government and industry expenditure on pest animal control in New South Wales was estimated to be $11.4 million (Korn *et al.* 1998). This estimate is inclusive of all vertebrate pests. It may be possible to isolate the contributions to rabbit control before and after RHD; however, the direct labour and material investment in rabbit control provided by private landholders is more difficult to estimate.

A more reliable indicator of reduced investment in costs of control as a consequence of RHD can be derived from usage figures for 1080 (sodium fluoroacetate). Poisoning of rabbits with 1080 is one of the most widely employed methods of control. The amount of 1080 distributed in each Australian State and Territory has been closely monitored for legislative reasons since 1980. Rural Lands Protection Boards (RLPBs) in New South Wales and the Animal and Plant Control (APC) Boards in South Australia are the agencies responsible for maintaining accurate 1080 poison records in their respective States. Data for the period 1980–87 were excluded from the South Australian comparisons owing to the absence of established rabbit control across the State at that time. For comparative purposes, data were converted to kilograms of 1080 carrot bait (the most commonly used bait in New South Wales) and 1080-treated oats (most commonly used in South Australia).

The quantity of carrot bait used to control rabbits in New South Wales was plotted over a 20-year period (Fig. 4). The quantities used vary considerably from year to year. This is in response to environmental factors such as drought, the

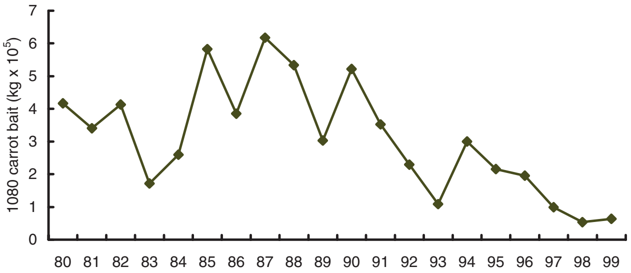

Fig. 4. Total 1080-treated carrot bait used in New South Wales from 1980 to 1999.

implementation of management strategies such as group baiting campaigns, and the general health of rural industries that influence the availability of funds for rabbit control. While the data are short term for the post-RHD period, they do show a trend toward reduced usage of 1080 carrot bait in New South Wales after the arrival of RHDV in 1996.

Given the influence that seasonal conditions can have on the use of 1080 for rabbit control in NSW (Saunders and Kay 1999), we attempted to compare the 4 consecutive years after the advent of RHD with 4 similar consecutive years before RHD. This comparison used the percentages of the State declared as drought stricken throughout each particular year (as per legislative requirements for payment of drought subsidies in NSW). The 4-year period most similar to 1996–99 post-RHD conditions (mean 7% drought declared) was 1987–90 (mean 19% drought declared). Total 1080 carrot bait used in 1987–90 was 2388 tonnes compared with only 412 tonnes after RHD (1996–99), which is equivalent to a reduction of 83%. On the basis of figures provided by three RLPBs in central NSW, we estimate the total costs associated with 1080 carrot bait application to be \$2.41 per kg of bait. This figure is inclusive of carrot (free feed and poisoned), 1080, signs, equipment and labour, and is based on an average application rate of 5 kg ha^{-1}, which obviously will vary across the State. Calculating from the similar 4-year periods before and after RHD, approximately \$1.2 million per year have been saved in the cost of poisoning programs since the advent of RHD.

In South Australia, 1080-treated oats are used in summer and autumn to control rabbits that bred during the previous year. In this situation, the extent of rabbit control is closely linked to rainfall in the previous year. Although some individual sites experienced dry years, overall no evidence indicated that the use of 1080-treated oats for rabbit control post-RHD should have deviated from the pre-RHD average because of seasonal effects. Average 1-year-lagged rainfall for the 39 APC baiting centres during the 3 post-RHD years fell within 3% of the average for the 10 years preceding RHD. For regions within the State, rainfall from baiting centres in the three drier regions fell within 5% of the pre-RHD average figures, and the wettest region (the south-east) fell within 10% of average.

The APC Board records (Table 5) show that the amount of 1080-treated oats used for rabbit control was reduced by about 56 tonnes per year after the spread of RHDV. This reduction was mostly attributable to a change in bait use in the Murray Mallee, although on a percentage basis the reduction was also very large on the Eyre Peninsula. The finding that bait use declined more in drier areas (Table 5) is consistent with published accounts of greater reductions in rabbit numbers due to RHD in hot, dry inland areas than in cool, moist areas (Bowen and Read 1998; Mutze *et al.* 1998*a*; Neave 1999; Saunders *et al.* 1999). The number of landholders using 1080 after RHD declined by 49%, indicating that many landholders are still using bait but in reduced quantities.

Costs associated with Table 5 were estimated assuming that APC Board contractors lay all of the bait used. Landholders have additional hidden costs associated with the collection of bait and equipment, and adjustment to and returning of baitlayers; they are generally less efficient than contract operators. Average costs were calculated from APC Boards with different cost-recovery structures, which account for their particular terrain, vegetation and equipment used. Baitlayers drawn by four-wheel-drive utilities had an average cost from four APC Boards of \$8 per kg of oats used in the operation. Operations using four-wheel-drive all-terrain-vehicle baitlayers had an average cost from four APC Boards of \$12.30 per kg of oats. The overall average cost is taken as \$10 per kg of 1080-treated oats used. On that basis, the total cost of rabbit baiting in South Australia has been reduced by \$0.56 million per year with reductions of \$0.46 million per year in the Murray Mallee alone.

Table 5. Annual use of 1080-treated oats in South Australia before (1987–96) and after (1997–99) RHD

Site	Mean annual rainfall (mm)	Mean annual 1080 oat usage 1987–96 (tonnes)	Mean annual 1080 oat usage 1997–99 (tonnes)	Change per year (tonnes)	Change per year (%)
State total		82.0	26.2	–55.8	–68
South-east	593	13.3	7.0	–6.3	–47
Murray Mallee	337	63.1	16.9	–46.2	–73
Eyre Peninsula	335	4.0	1.1	–2.9	–72
Central	485	1.6	1.2	–0.4	–24

RHD-induced changes to the rabbit fur, skin and meat trade

The Australian rabbit industry is a historically significant but comparatively small industry, based primarily on the harvesting of wild rabbits. The structure of the industry involves professional and sporting shooters who sell the rabbits they obtain, either through field agents or directly to processors. The size of the harvest fluctuates with prevailing seasonal conditions, with an average of 2.73 million rabbits being taken annually (Foster and Telford 1996). There is obviously a potential for RHD to affect the harvest of wild rabbits, particularly in areas where the disease has the highest impact on rabbit abundance. How the industry recovers from the initial effect of reduced rabbit density is less clear because the long-term effect of RHD on rabbit abundance is not known (Foster and Telford 1996).

Export market

The total export of rabbit meat, skin and fur from Australia since 1985 has been variable, peaking at around 1 million kg in 1991–92 (Fig. 5). This peak could have been due to increased demand following outbreaks of RHD in international rabbit farms (Ramsay 1994). The figures are based on customs returns and include farmed rabbit products. Most of the trade is based on meat and edible meat offal, with skin and fur making up only a small component of the market. The value of all rabbit products exported from Australia has declined markedly since the 1991–92 peak. Interestingly, this decline occurred 4 years before the introduction of RHDV. This probably confirms that the export market for rabbit product is driven by demand rather than limited by supply. The export market for all rabbit products is currently less than 5000 kg annually.

Domestic market

The domestic market is more difficult to value as the industry is fragmented with no central authority to maintain national statistics. The magnitude of wild rabbit harvests is particularly difficult to track. Ramsay (1994) estimated the domestic rabbit meat market to be worth about \$5–5.6 million in 1992. Figures from the Australian Bureau of Statistics indicate that the domestic trade is more valuable than the export trade, with most of the value coming from domestic consumption of rabbit meat. On average the domestic trade was valued at around \$7.76 million for the 1988–95 period (Foster and Telford 1996).

An indicator of the impact that RHD has had on the domestic market comes from changes in the source of furs for the production of felt hats by Akubra Hats Ltd. In 1995, before the introduction of RHDV, Akubra Hats sourced 70333 kg of rabbit skins from Australian harvesters. In the year following the introduction of RHDV, this figure fell to 36986 kg and declined to 22312 kg in 1998. Akubra Hats made up the shortfall by importing skins from international producers. The local trade in harvested skins was affected almost immediately, with the number of suppliers to Akubra Hats dropping from eight to one over a course of 3 weeks during the peak of the RHD outbreak (S. Kier, Jr, Akubra Hats Ltd, personal communication 1999). Figure 6 illustrates the change in rabbit fur imports from 1995 to 2000.

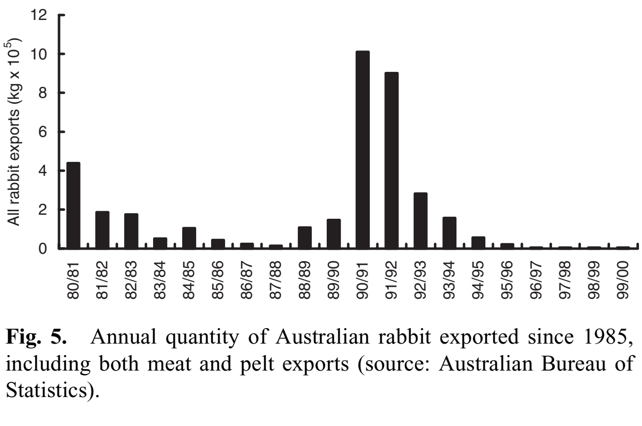

Fig. 5. Annual quantity of Australian rabbit exported since 1985, including both meat and pelt exports (source: Australian Bureau of Statistics).

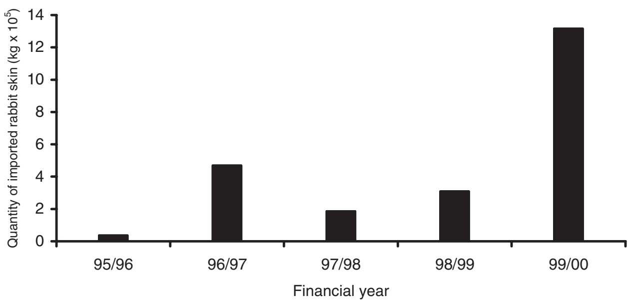

Fig. 6. Quantity of rabbit skins imported to Australia from 1995 to 2000 (source: Australian Bureau of Statistics).

Improved viability of rabbit farms

Rabbit farming is an emerging industry in Australia. New South Wales and Western Australia are currently the major producing States while Victoria is developing a breeding base that will begin to supply the domestic market over the next 3–5 years. Over 750 commercial licences have been issued in New South Wales, but most operations are relatively small with an average breeding base of fewer than 25 does. Fewer than 50 farms have more than 100 breeding does (200 breeding does are required for an operation to be commercially viable). Current national production provides 3000–5000 farmed rabbits per fortnight destined for the domestic meat market. At current market prices of \$8.50 kg^{-1}, the industry is potentially worth, at current production levels, \$1.657 million per year. Further expansion of the industry will see this value rise significantly over the coming years. The industry reputedly lost large numbers of rabbit stock when RHDV first escaped on to mainland Australia in 1995. Since that time rabbit farms have recovered but are burdened with the added production cost of vaccinating rabbits against RHD. Vaccination costs vary from $3 per injection when the vaccine is supplied, to $15 per injection when a practising veterinarian conducts the vaccination (G. Fullerton, Commercial Rabbit Breeders Association, personal communication 1999).

Discussion

Overall, the potential for improved agricultural production from the introduction of RHDV into Australia appears substantial. Almost all regions that previously suffered from high rabbit densities have reported reductions in rabbit abundance following the spread of the virus (Neave 1999). However, the impact of RHD on agricultural production may not be immediately apparent. The variable effect of RHD throughout Australia means that trends will not necessarily be consistent across bioclimatic regions. Factors such as pasture quality, stocking rates and production levels will take many years to equilibrate in relation to reduced rabbit abundance. Many external influences will also need to be considered, including the effects of climate (especially drought), changes in market values and shifts to alternative enterprises.

Many areas, such as the NSW and South Australian examples reported in this paper, have observed increases in pasture biomass, estimated through direct assessments or through indicators, following declines in rabbit abundance due to RHD. These increases may support higher sustainable stock densities, and elevate production per unit of stock or area. Where RHD substantially reduced rabbit density, its effect on the value of pastoral production was dependent on the degree to which pasture compensated for the reduced level of herbivory and consumption by stock, and how much other herbivores modified their rate of pasture intake. However, as demonstrated in the NSW case study, even where high compensatory growth is assumed (0.7), the increase in value was significant. What appears to work against a widespread economic benefit from RHD is its patchy effect on rabbit population densities.

In a broader sense, land management agencies have reported improved pastoral conditions, particularly in the rangelands where rabbit abundance and the potential for competition with livestock were previously high (Saunders and Kay 1999). While these improvements are difficult to quantify, it is likely that graziers, particularly those in the more arid parts of Australia, will be in a much better position to cope with droughts in the absence of the added grazing pressure from rabbits.

In addition to improving production and viability, the effect of RHD on rabbit density has reduced efforts at rabbit control in many parts of Australia. In particular, the use of 1080 poison to control rabbits appears to have decreased substantially in some areas, leading to direct savings for agricultural producers. Some of the reduction in 1080 usage may simply represent a shift of convenience to the reliance on RHD as an alternative to conventional control. However, in some cases, 1080 usage has declined despite increased rabbit control using harbour destruction to capitalise on the effects of RHD and to enhance revegetation programs. Bait use for conservation purposes at 2 of the APC Board's 39 sites in South Australia increased even though bait use by landholders and average rabbit numbers declined in those areas. In addition to the economic benefit of reduced reliance on 1080 baiting, any decrease in the use of chemical toxins that results from the impact of RHD on rabbit abundance will be viewed by many people as a desirable outcome in its own right. The use of some rabbit control methods, particularly warren ripping, increased immediately following the release of RHDV in response to reduced rabbit abundance and because funding became available through various government grants (e.g. the Natural Heritage Trust). This 'follow-up' work was considered vital if land managers were to take full advantage of the impact of RHD. However, the intensity of follow-up control will probably decline if rabbit densities remain low and such funding arrangements change.

Industries such as the wild rabbit fur and meat trade may have been adversely affected by initial reductions in rabbit densities. The impact of RHD on these industries is difficult to assess owing to their fragmented nature and reliance on field harvesting. However, it seems likely that RHD has had a negative impact on the economic viability of these industries, at least in the short term. The long-term impact on these industries will only become clear over time and will depend on any recovery of rabbit populations from the initial effects of RHD. Conversely, the rabbit-farming industry may benefit from the introduction of RHDV albeit with the additional costs of vaccinating breeding stock against RHD. However, the economic benefit of these industries to the national economy remains small relative to that of the pastoral industry.

Evidence exists that reduced rabbit grazing might produce a negative impact through the recruitment of native pine (*Callitrus glaucophylla* and *Callitrus collumelaris*) and other woody plants. Other negative impacts of RHD on agricultural production may include increased grazing pressure from herbivores that gain from the decline of rabbit populations and increased predation on livestock by foxes in the absence of rabbit as a major dietary item. Again, these will not become evident for many years.

At a national level, indications are that RHD has benefited agricultural production. However, with current market values and enterprise options, it is unlikely (at least in the short term) that any decrease in rabbit abundance will result in a corresponding increase in stocking rates. Hence any response on agricultural lands is more likely to be realised as benefits in the sustainability of pastoral enterprises. It is likely that a more complete accounting of the economic benefit of RHD to graziers will emerge from a longer-term evaluation of factors affecting the well-being of the entire industry than can be achieved from the study of changes in pasture growth and offtake over the 4 years considered here.

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References

ACIL Economics and Policy Pty Ltd (1996). The economic importance of rabbits on agricultural production in Australia. Report prepared for the International Wool Secretariat.

Bowen, Z., and Read, J. (1998). Population and demographic patterns of rabbits (*Oryctolagus cuniculus*) at Roxby Downs in arid South Australia and the influence of rabbit hemorrhagic disease. *Wildlife Research* **25**, 655–662.

Choquenot, D. (1992). The outsiders: competition between introduced herbivores and domestic stock in rangeland grazing systems. In 'Australian Rangelands in a Changing Environment. Proceedings of the 7th Biennial Conference of the Australian Rangelands Society, Cobar'. pp. 106–116.

Choquenot, D., Druhan, J., Lukins, B., Packwood, R., and Saunders, G. R. (1998). Managing the impact of rabbits on wool production systems in the Central Tablelands of NSW: an experimental study and bioeconomic analyses. In 'Proceedings of the 11th Australian Vertebrate Pest Conference, Bunbury, Western Australia'. pp. 367–374. (Promaco Conventions: Perth.)

Crawley, M. J. (1993). 'GLIM for Ecologists.' (Blackwell Scientific Publications: Oxford.)

Croft, J. D. (1986). The impact of rabbits on livestock production. In 'Animal Production in Australia. Proceedings of the 16th Biennial Conference of the Australian Society of Animal Production'. pp. 82–84. (Pergamon Press: Sydney.)

Fennessy, B. V. (1966). The impact of wildlife species on sheep production in Australia. In 'Proceedings of the Australian Society of Animal Production. Vol. IV'. (Ed. G. R. Pearce.) pp. 148–156.

Foster, M., and Telford, R. (1996). Structure of the Australian rabbit industry: a preliminary analysis. ABARE report prepared for the Livestock and Pastoral Division, Department of Primary Industries and Energy, Canberra.

Hone, J., Waithman, J., Robards, G. E., and Saunders, G. R. (1981). Impact of wild mammals and birds on agriculture in NSW. *Journal of the Australian Institute of Agricultural Science* **47**, 191–199.

Korn, T., Saunders, G. R., and Leys, A. (1998). Pests, people, policy and practice – management in NSW. In 'Proceedings of the 11th Australian Vertebrate Pest Conference, Bunbury, Western Australia'. pp. 69–74. (Promaco Conventions: Perth.)

Manson, A. (1998). Identification of public and private benefits from agricultural research, development and extension: some preliminary results from a study of the Australia New Zealand Rabbit Calicivirus Program. Contributed paper to the 42nd Annual Conference of the Australian Agricultural and Resource Economics Society, Armidale, New South Wales.

Mutze, G. (1991). Long term effects of warren ripping for rabbit control in semi-arid South Australia. *Australian Rangelands Journal* **13**, 96–106.

Mutze, G., Cooke, B., and Alexander, P. (1998*a*). The initial impact of rabbit hemorrhagic disease on rabbit populations in South Australia. *Journal of Wildlife Diseases* **34**, 221–227.

Mutze, G., Linton, V., and Greenfield, B. (1998*b*). The impact of rabbit calicivirus disease on the flora and fauna of the Flinders Ranges, South Australia. In 'Proceedings of the 11th Australian Vertebrate Pest Conference, Bunbury, Western Australia'. pp. 153–157. (Promaco Conventions: Perth.)

Mutze, G., Bird, P., Kovaliski, J., Peacock, D., Jennings, S., and Cooke, B. (2002). Emerging epidemiological patterns in rabbit haemorrhagic disease, its interaction with myxomatosis, and their effects on rabbit populations in South Australia. *Wildlife Research* **29**, 577–590.

Myers, K., Parer, I., Wood, D., and Cooke, B. D. (1994). The rabbit in Australia. In 'The European Rabbit: The History and Biology of a Successful Coloniser'. (Eds H. V. Thompson and C. M. King.) pp. 108–157. (Oxford University Press: Oxford.)

Neave, H. M. (1999). Rabbit Calicivirus Disease Program Report 1: Overview of effects on Australian wild rabbit populations and implications for agriculture and biodiversity. A report of research conducted by participants of the Rabbit Calicivirus Disease Monitoring and Surveillance Program and Epidemiology Research Program. Prepared for the RCD Management Group. Bureau of Rural Sciences, Canberra.

Ramsay, B. J. (1994). 'Commercial Use of Wild Animals.' (Bureau of Rural Sciences, Australian Government Publishing Service: Canberra.)

Reid, P. A. (1953). Some economic results of myxomatosis. *Quarterly Review of Agricultural Economics* **6**, 93–94.

Saunders, G. R., and Kay, B. (1999). Rabbit Calicivirus Disease Program Report 5: Implications for Agricultural Production in Australia. A report of research conducted by participants of the Rabbit Calicivirus Disease Monitoring and Surveillance Program and Epidemiology Research Program. Prepared for the RCD Management Group. Bureau of Rural Sciences, Canberra.

Saunders, G. R., Choquenot, D., McIlroy, J., and Packwood, R. (1999). Initial effects of rabbit haemorrhagic disease on free living rabbit (*Oryctolagus cuniculus*) populations in central-western New South Wales. *Wildlife Research* **26**, 69–74.

Short, J. (1985). The functional response of kangaroos, sheep and rabbits in an arid grazing system. *Journal of Applied Ecology* **22**, 435–447.

Sloane, Cooke and King Pty Ltd (1988). The economic impact of pasture weeds, pests and disease on the Australian wool industry. Report prepared for the Australian Wool Corporation.

Williams, C. K., Parer, I., Coman, B. J., Burley, J., and Braysher, M. L. (1995). 'Managing Vertebrate Pests: Rabbits.' (Bureau of Resource Sciences and CSIRO Division of Wildlife and Ecology, Australian Government Publishing Service: Canberra.)

Wilson, G., Dexter, N., O'Brien, P., and Bomford, M. (1992). 'Pest Animals in Australia.' (Bureau of Rural Resources and Kangaroo Press: Canberra.)

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