# ERADICATION OF AUSTRALIA'S VERTEBRATE PESTS: {PRIVATE }
# A FEASIBILITY STUDY

Mary Bomford, Bureau of Resource Sciences, PO Box E11 Queen Victoria Terrace ACT 2600, Australia.

Peter O'Brien, Bureau of Resource Sciences, PO Box E11 Queen Victoria Terrace ACT 2600, Australia.

## ABSTRACT

Eradication of introduced pest animals seems an attractive alternative to continuing control. But no well-established introduced pests have been eradicated from any continent despite numerous attempts. Eradication is an intense, time-limited process offering perpetual freedom from the pest, its effects and control costs. By contrast, control is a recurrent activity with continuing damage and control costs. This paper establishes biological, technical and social criteria for choosing between eradication and continuing control.

Eradication can be achieved only when:

(1) rate of removal exceeds rate of increase at all population densities,
(2) immigration is zero,
(3) all reproductive animals are at risk,

and it is the preferred option only when:

(4) animals can be monitored at low densities,
(5) discounted benefit-cost analysis favours eradication over control,

(6) there is a suitable socio-political environment.

Because these criteria are met for few sites or species, it is highly unlikely that any widespread pest species could be eradicated on a national scale using current techniques.

Regional eradication is likely to be neither feasible nor cost-effective for most species and situations, though our criteria can be used to identify some exceptions to this generalisation. Wildlife damage management should usually be based on continuing control rather than inappropriate eradication attempts.

**Key words**: eradication, vertebrate pest, pest control, fox, rabbit, feral goat.

## INTRODUCTION

It is a common perception that many Australian vertebrate pests could be eradicated if sufficient effort was made, and that eradication would be the most desirable solution to the problems they cause. But Caughley (1977) warned "Most attempts to eliminate populations have ended up as unplanned and undesired exercises in sustained yield harvesting. Most attempts were ecologically unjustified and economically impractical". Despite numerous large-scale attempts, no eradication campaign against any well-established introduced vertebrate pest has been successful on any continent (Caughley 1977; Macdonald *et al*. 1989; Usher 1989). Is the popularity of eradication as a pest management objective based on a misperception of the feasibility of success?

Taking action to get rid of pest animals `once and for all' by eradication is an appealing solution because it offers perpetual freedom from the pest, from its harmful effects and from recurrent high costs of continuing control. Despite high levels of both public and private spending, current techniques used for pest control are not always effective in preventing environmental and agricultural damage (Usher 1989; Wilson *et al*. 1992a; Bomford *et al*. 1994, in press). Eradication also attracts interest because of increasing awareness of moral and animal welfare issues associated with conventional pest control techniques, particularly poisoning and shooting, which could be stopped if eradication were achieved. Eradication would also solve some environmental problems associated with continuing control, such as the killing of non-target species.

This paper establishes six criteria for deciding whether eradication is technically possible and preferable to continuing control for managing vertebrate pests. We assess three case studies against our criteria. Our purpose is to assist managers in assessing the most appropriate management strategy for pest animals. `Eradication' is defined as the complete and permanent removal of all wild populations from a defined area by a time-limited campaign. `Time-limited' is important in this definition - eradication needs to be achieved by a fixed date. An eradication campaign without a specified end point is *de facto* continuing control. `Continuing control' is defined as harvesting or killing a proportion of a population on a sustained basis.

## CRITERIA FOR ERADICATION

In developing these six criteria, we have drawn on work eradicating feral goats (*Capra hircus*) from offshore islands in New Zealand (Parkes 1984, 1990), coypus (*Myocastor coypus*) in England (Gosling and Baker 1987, 1989; Gosling *et al*. 1988; Gosling 1989), and attempts to eradicate infectious human diseases (Yekutiel 1980).

Criteria 1 - 3 are seen as essential for achieving eradication. Criteria 4 - 6 are seen as desirable and determine whether eradication is a preferable management option to continuing control.

### 1. Rate of removal exceeds rate of increase at all population densities

If the removal rate does not exceed the rate of replacement at all densities, eradication will not be achieved. This may seem simple and obvious, but in practice, it is an extremely stringent requirement for pest populations for three main reasons. Firstly, populations subjected to control usually show compensatory responses. Secondly, many culled pest populations have high rates of increase. Finally, as density declines, it takes progressively more time and expense to locate and remove individual animals, though in some instances this problem can be mitigated by technical solutions or by attributes of the pest's biology.

Reducing populations can lead to compensatory increases in breeding and survival due to increased availability of resources (Caughley 1977, 1985; Caughley and Krebs 1983). There may also be increased immigration or decreased emigration. These compensatory changes hasten the population's return to its original density. Although there is little information on the extent to which compensation occurs for most pest species, annual rates of increase in culled populations have been estimated at 86% for feral pigs (*Sus scrofa*), 20% for feral horses (*Equus caballus*), 23% for feral donkeys (*E. asinus*) and 75% for feral goats (Giles 1980; Eberhardt *et al*. 1982; Choquenot 1990; Henzell 1992).

The most difficult part of an eradication campaign is the removal of the last few animals. The costs of finding and removing pests often increase exponentially as density declines, as is demonstrated for feral buffalo (*Bubalus bubalis*) in Fig. 1. Hence removal rates due to pest control operations tend to decline at low population densities, and if the removal rate declines to less than the rate of increase, the population will not decline further. This is both a technical and a management problem. There must be a motive and resources to continue removing animals at low densities, when numbers caught and damage inflicted are extremely low.

Sometimes special techniques can be employed to assist the removal of pests once they are at low densities. Hunting with dogs was particularly valuable for locating and removing possums (*Trichosurus vulpecula*) from Kapiti Island in New Zealand once densities were too low to make further trapping effective (Cowan 1992). Radio-collared Judas goats join up with remnant feral goats, assisting their location when trapping fails to further reduce populations at low density (Van Vuren 1992). Unfortunately, the Judas technique does not work on less gregarious species such as the feral pig (Soule 1990; Choquenot 1993).

For some species it may not be necessary to reduce a population to zero. When numbers are very low populations may decline to extinction without further intervention, due, in part, to difficulties in finding mates and demographic factors (Caughley and Sinclair 1994). Unfortunately, minimum viable population sizes are unknown for most pests. In some instances, a single fertile pair may be sufficient to allow a population to recover. In addition, extinction risks due to demographic factos in small populations are stochastic effects, with unknown probabilities of population recovery or demise.

The area over which eradication is attempted will significantly affect the ability to meet this criterion (Van Vuren 1992; Parkes 1993a). In smaller areas, it is possible to concentrate effort, which makes eradication more efficient and easier to achieve (Parkes 1990). In some situations it may be feasible to subdivide the eradication area into fenced sections to allow stepwise eradication (Van Vuren 1992).

To meet this criterion, it is desirable to remove the population as quickly as possible as control becomes more difficult over time (Parkes 1990). For example, the eradication of goats on Raoul island (Parkes 1984, 1990) took 12 years, which meant survivors of each annual cull learnt to avoid hunters and dogs, and allowed recovery of the vegetation. Both factors made hunting more difficult. The surviving goats had more food, enabling them to double their birth rate, which meant that proportional removal rates had to be twice as high to keep the population in decline.

**2. Immigration is zero**

If animals can immigrate onto the eradication area, or be released from captive populations, then eradication will be unachievable or transient. This criterion can be met most easily on remote offshore islands where immigration or releases of new animals can be prevented. There have been many eradications of introduced vertebrates from islands, for example rabbits (*Oryctolagus cuniculus*) from Philip Island in Australia, feral goats, possums (*Trichosurus vulpecula*) and feral cats (*Felis catus*) from islands in New Zealand (Hermes 1987; Parkes 1990; Veitch and Bell 1990;

Cowan 1992), feral sheep (*Ovis aries*) on Mauna Kea in Hawaii (Van Vuren 1992), and muskrats (*Ondatra zibethicus*) and coypus in Britain (Gosling 1989; Gosling and Baker 1989).

Zero immigration can be achieved for regional eradication on continents where the infested area is geographically restricted or where completely effective physical barriers are erected (Usher 1989). Zero immigration can also be achieved by control on the margins of the eradication area to create a barrier or buffer zone. Both fencing and margin control are expensive options with a continuing likelihood of failure (Van Vuren 1992). Hence, a potential benefit of eradication, perpetual freedom from recurrent costs, will not be achieved when continuing control of immigration is necessary on the margins of the eradication area.

Usher (1989) compares examples of isolated populations, where eradication or control to low numbers has been achieved, with widespread populations, where control attempts have failed, to emphasise the importance of controlling immigration. For example, the muskrat eradication campaign in Scotland, conducted against an isolated population of less than 5,000 individuals was successful, whereas on continental Europe where this species is widespread, control campaigns against this species failed. Similarly, Parkes (1993a) suggests that eradicating pests, that are isolated on habitat islands on mainlands, will be achievable for the same reasons that they can be eradicated from offshore islands. Nevertheless, Parkes considers there are few mainland sites in New Zealand where pest animals can be eradicated because they will reinvade after being removed.

The release of the pest species back into an eradication area must be considered as a potential obstacle to eradication. For example, recreational hunters are believed to have compromised feral goat control operations in Australia by releasing goats as quarry (Henzell 1992). Escapes or releases of livestock or domestic pets could prevent eradication of their feral counterparts. For example, eradication of feral cats is probably not possible in regions where they are kept as pets.

**3. All reproductive animals must be at risk.**

It is not necessary that the removal techniques take all animals at any attempt. But all reproductive and potentially reproductive members of the population must be susceptible to removal, for eradication to be feasible. If, for example, trap-shyness is inherited, or if animals develop neophobia or genetic resistance to poison baits, a subset of the population is not at risk and will not be eradicated. With many pest control techniques, some animals will not be susceptible.

Use of a combination of techniques may enable this criterion to be met. For example, eradication of possums from Kapiti Island in New Zealand was achieved by a combination of trapping, poisoning, and hunting with specially trained dogs, which ensured all possums were at risk (Cowan 1992).

**4. Animals can be detected at low densities.**

If animals cannot be detected at low densities, there can be no measure of population decline, and no way of determining if eradication has been achieved. It can be difficult to determine if eradication has been achieved (Usher 1989). An absolute measure of population size is not necessary. An index of numbers is sufficient as long as it is sensitive to change close to zero and intercepts the origin when plotted against true density.

**5. Discounted benefit-cost analysis favours eradication over control.**

We have few reliable, quantitative measurements for agricultural or environmental damage inflicted by vertebrate pests. Most information on damage is qualitative, correlative, or anecdotal, making cost-benefit analysis difficult (Bomford *et al*. 1994, in press). Eradication efforts should be based on accurate benefit-cost analyses and the data needed for these calculations are often not available.

Intuitively, we might think the value of perpetual freedom from a pest is high, but market discount rates have a major impact on the current value of control when compared to eradication. Eradication requires a large initial outlay, but, if successful there are no further costs, and benefits accumulate indefinitely. However, future benefits have a lower economic value than equivalent benefits achieved immediately because of discounting. Calculating discount rates involves using the reverse equation to that used for calculating interest rates on invested money. Discounting means that benefits which occur in more than 30 years time are perceived to have little current economic value. Hence market discount rates have a major impact on the current value of control as compared to eradication. The loss of value of the benefit of eradication is determined by the discount rate and the time until the benefit is attained. In Fig. 2 we compare hypothetical cumulative benefit/cost ratios (the benefits of protecting desired resources damaged by the pest and the cost of achieving eradication), for 3 different discount rates. If we assume a favourable benefit/cost ratio for eradication, and set a zero discount rate, eradication may be cost effective over a timeframe of 30 years. If we use the same data, but set a 10% discount rate, eradication is not cost effective. There is, however, considerable debate about the selection of appropriate discount rates, particularly when non-market values, such as conservation and animal welfare, are considered.

Even if eradication is more cost effective than no control, the benefits of eradication must still be weighed against alternative strategies. Continuing control may be a more cost-effective approach for meeting the objective of damage control. Where there is a risk of recolonization, the high cost of attempted eradication is unlikely to be justified. In California, there have been 27 `successful' eradication programs against insect species, but this includes one species (oriental fruit fly (*Bactrocera dorsalis*)) being eradicated 15 times (Dahlsten 1986)!

The benefits of retaining the target species also need to be considered. For example, there is a lucrative export of feral pig meat from Australia that would cease if eradication were achieved (Ramsay 1994). J. Parkes of N. Z. Landcare Research, (pers. comm.) suggests that eradication of thar (*Hemitragus jemlahicus*) from New Zealand's South Island would be difficult to justify due to their mixed pest/resource status. Compensation payments might be expected by those who lose income as a result of government instigated eradication campaigns.

Another consideration is the potential damage to resources resulting from an eradication program. For example, harm may be inflicted on non-target species by eradication techniques (DeBach

1964). The muskrat eradication campaign in Britain killed many non-target animals (Usher 1986). The ratio of muskrats to non-target species trapped was 1:7, including otters, thousands of water voles and native birds (Usher 1989). Gosling *et al*. (1988) suggest such high kill rates of non-target species would now be regarded as unacceptable.

The eradication of pests from islands is often considered cost effective, because these islands are the last suitable habitat for a range of endangered species (Coblentz 1990, Cowan 1992, Van Vuren 1992). It may be impossible to save island species from extinction unless exotic mammalian herbivores and predators are first eradicated (Vitousek 1988).

The chance of failure of an eradication attempt should be considered when deciding whether to opt for eradication or control as a management option. Eradication is a high risk undertaking, and a failed eradication attempt will waste a lot of money, because pest populations rapidly recover from low numbers.

**6. Suitable Socio-political Environment.**

Even when technical and economic criteria can be met, social and political factors can play an overriding role in determining the prospects for successful eradication. Conflicting community or administrative goals, or legal barriers can frustrate eradication attempts. Reliable information on the impacts of target species on production or environmental resources is usually needed to create the political will needed to achieve eradication (Van Vuren 1992). Strong support from the wider community is also needed before eradication should be attempted. Eradication is much more expensive than continuing control and few landholders are willing to make the extra commitment (Henzell 1992). Appropriate legislation must be in place to allow access by control personnel to private land to ensure all pests are eradicated.

The benefits of eradication as an alternative to continuing control must be convincing, mainly because of the resources required for an eradication attempt and because community attitudes may not favour killing large numbers of wild animals. Killing animals is unattractive to many people for moral, emotional, or cultural reasons, and these people could be expected to lobby against eradication attempts. A good example is provided by Van Vuren (1992) in his account of an attempt by the United States Navy to eradicate feral goats from San Clemente island, off California using helicopter shooting. They were sued by Give Our Animals Time (GOAT), and the navy was directed to restrict its activities to nonlethal control techniques which were ineffective. Community resistance to eradication is also likely if the techniques used affect non-target species or the environment.

Some proponents of eradication think it ought to be a management goal irrespective of whether or not it is achievable. They argue that, without eradication as the management goal, motivation for continuing control will wane, and hence pest control efforts will fail. This attitude, which is enshrined in law in New Zealand national parks (Parkes 1993b), and is often advocated for rabbit control in Australia (Coman 1993), fails to take account of benefit/cost considerations.

**Other factors in eradication**

The timing of an eradication attempt in relation to establishment will influence the probability of meeting our six criteria. The sooner eradication is attempted after establishment, the higher the chance of success (Usher 1989). A newly established population will be restricted to a relatively small area, which will assist eradication attempts and reduce costs. Also, public support is likely to be strongest before people become used to living with a pest.

Usher (1989) suggested a species' dispersal powers and the feasibility of isolating the species within the eradication area are the most significant factors affecting success of eradication attempts. Usher (1986) compared successful eradication campaigns conducted against muskrats and coypus to the unsuccessful campaign to eradicate mink (*Mustela vison*) in Britain. He suggests that the successful eradications were related to low dispersal rates rather than low rates of increase. Both muskrats and coypus have high natural rates of increase and low dispersal rates (Gosling and Baker 1989, 1991). In contrast, mink have much lower rates of increase but much higher dispersal rates (Chanin 1981).

Usher (1989) suggests that the high dispersal distances of rabbits and feral pigs in Australia would be a barrier to eradication. Similarly he suggests that the high mobility of birds is the reason why there are few examples of their successful control, let alone eradication.

## CASE STUDIES

Our six criteria determine whether eradication is technically feasible and preferable to continuing control. Eradication should only be selected as a management option when all six criteria can be answered in the affirmative. A negative in any one of the first three criteria will cause an eradication attempt to fail, and a negative in Criteria 4-6 will greatly reduce the feasibility and desirability of eradication.

### Feral goats throughout mainland Australia

We first use the six criteria to examine the possibility of eradicating feral goats from the entire Australian mainland (Table 1). We come up with one definite negative, three probable negatives and two question marks. The main reasons why eradication of goats appears unachievable on a national scale is that domestic escapees would prevent immigration being zero, and the extreme technical difficulty of finding and removing the last few goats in many habitats. Even if a range of techniques were used, catching all goats is impossible in many habitats, closing access to all water holes in some mountainous areas is difficult, solitary breeding females may escape detection, and the Judas goat technique may not pick up all stragglers at very low densities (Bomford and O'Brien 1993). It took 1 000 hunter days to find and remove the last feral goat on Raoul Island in New Zealand, and the cost of removing the last five goats was $10 000 each (Parkes 1990). This was in an area of only 2 943 ha. On the Australian mainland, where goats are far more widely distributed, it would be far harder, and cost much more.

Banning the keeping of domestic goats in the pastoral zone of Australia would also be necessary. This would be a major additional cost because domestic goats currently form the basis of a goat hair industry, and there could be opportunity costs associated with potential development of a goat meat industry (Henzell 1992). These costs, and the loss of revenue from the current feral goat harvesting industry would need to be offset against potential gains in pastoral production and reduced environmental damage. We conclude national eradication is not feasible or desirable for feral goats.

**Rabbits throughout mainland Australia**

We next use our criteria to assess whether it is feasible and desirable to eradicate rabbits from the entire Australian mainland (Table 1). We come up with one definite negative and three probable negatives. The main reasons why eradication of rabbits appears unachievable on a national scale is the extreme cost of the exercise, and the technical difficulties of finding and removing all reproductive rabbits at low densities, even if a range of techniques were used, including warren ripping, fumigation, dogging and poisoning. It is also unlikely that possible future biological control techniques, such as rabbit haemorrhagic disease (Munro and Williams 1994, in press) and virally vectored immunocontraception (Tyndale-Biscoe 1994, in press), would solve the problem of removing rabbits at low densities, though such techniques would greatly reduce the cost.

If rabbit eradication were achievable, it would probably be strongly supported by agricultural producers and conservation interest groups, but there could also be some resistance. For example, rabbits are valued by commercial and recreational hunters for their fur and meat (Wilson *et al*. 1992a), and Aboriginal people value rabbits for subsistence hunting (Wilson *et al*. 1992b). We conclude national eradication is not feasible for rabbits.

**European red foxes in an Australian reserve**

We might wish to pursue regional eradication of a pest species in a particular area to protect an endangered species. In Yathong Nature Reserve, in western New South Wales, an attempt has been made to eradicate European red foxes (*Vulpes vulpes*) to protect remnant breeding populations of the endangered mallee fowl (*Leipoa ocellata)* (D. Priddel, NSW National Parks and

Wildlife Service, pers. comm.). All resident foxes are believed to have been have been removed from an area of 20 400 ha. If this is correct, Criteria 1, 3 and 6 in Table 1 have been met. Regular baiting on the reserve and neighbouring pastoral properties is being conducted to prevent immigration of dispersing young foxes from the surrounding countryside onto the reserve (Criterion 2). Some foxes have penetrated onto the reserve, but increasing the width and baiting intensity of the surrounding properties may enable Criterion 2 to be met in future. An ability to meet Criterion 4, detecting animals at low densities, would assist decision making on the extent of margin control required to prevent foxes entering the reserve.

To assess the cost-effectiveness of the campaign (Criterion 5), we would need data on the future costs and success of margin control, plus assessments of the value of the endangered mallee fowl population and its future recovery and survival. Fox control by baiting, initially cost $18 000 excluding research. Margin control is costing about $16 000 per year (D. Priddel pers. comm.). Data on the value of mallee fowl are not available, but Australian society places a high value on endangered species protection. Therefore, if eradication is maintained and if mallee fowl populations recover, Criterion 5 may well be met.

This assessment applies to a single nature reserve. Fox eradication may be more difficult to achieve in other areas, but if this attempt is successful, other attempts will be justified.

## CONCLUSION

The major barriers to eradication include high costs relative to measurable benefits, lack of techniques to locate and remove pests at low densities, and a high risk of re-infestation especially from livestock and domestic animals. Research would be required to overcome these technical problems. Using our six criteria brings research needs into sharp focus for proposed eradication attempts.

Even if the identified problems can be solved by research, eradication even on a local scale, is often likely to be expensive and difficult and socio-political factors could compromise eradication attempts. Eradication should only be attempted when all six of our criteria can be met. Parkes (1993a) points out "Managers should remember that if eradication is the aim, an operation that kills 99% of the population is a failure."

Eradication has failed for good reasons. Our criteria indicate when to opt for eradication and how to go about it. With current techniques, our criteria indicate it is highly unlikely that any widespread pest species could be eradicated on a continental scale. Regional eradication is likely to be neither feasible nor cost-effective for most species and situations, though our criteria can be used to identify some exceptions to this generalisation. Wildlife damage management should usually be based on continuing control rather than inappropriate eradication attempts.

## LITERATURE CITED


Baker, S.J., 1986. Irresponsible introductions and reintroductions of animals into Europe with particular reference to Britain. *Int. Zoo. Yb*. **24/25**: 200-205.

Bayliss, P., and Yeomans, K.M., 1989. Distribution and abundance of feral livestock in the 'Top End' of the Northern Territory (1985-86), and their relation to population control. *Aust. Wildl. Res.* **16**: 651-676.

Bomford, M., Newsome, A. and O'Brien, P., 1994. In press. Solutions to feral animal problems: ecological and economic principles. *In* Conserving biodiversity: threats and solutions. NSW Nat. Parks and Wildl. Serv. Sydney.

Bomford, M., and O'Brien, P., 1993. Feral goat control or eradication? Assessment criteria for decision making. Pages 57-64 *in* Proc. Natl. Feral Goat Workshop ed by D. Freudenberger. Bur. Resour. Sciences, Canberra.

Caughley, G., 1977. Analysis of vertebrate populations. John Wiley and Sons, London, U.K. 205pp.

Caughley, G., 1985. Harvesting of wildlife: past, present and future. Pages 3-14 *in* Game Harvest Management ed by S.L. Beasom, and S.F. Roberson. Caesar Kleberg Wildl. Res. Inst., Kingsville, Texas.

Caughley, G., and Krebs, C.J., 1983. Are big mammals simply little mammals writ large? *Oecologia (Berl)* **59**: 7-17.

Caughley, G., and Sinclair, A.R.E., 1994. Wildlife management and ecology. Blackwell Sci. Publ., Melbourne.

Chanin, P., 1981. The feral mink - natural history, movements and control. *Nature in Devon* **2**: 33-54.

Choquenot, D., 1990. Rate of increase for populations of feral donkeys in northern Australia. *J. Mammal*. **71**: 151-155.

Choquenot, D., 1993. An evaluation of feral pig trapping. *Wildl. Res*. **20**: 15-22.

Coblentz, B.E., 1990. Exotic organisms: a dilemma for conservation biology. *Cons. Biol*. **4**: 261-265.

Coman, B.D., 1993. From national visions to local solutions: the future of rabbit control in Australia. Pages 3-5 *in* Proceedings of Australian Rabbit Control Conference, Adelaide, ed by B.D. Cooke.

Cowan, P. E., 1992. The eradication of introduced Australian brushtail possums, *Trichosurus vulpecula*, from Kapiti Island, a New Zealand Nature Reserve. *Biol. Conserv*. **61**: 217-226.

Dahlsten, D.L., 1986. Control of invaders. Pages 275-302 *in* Ecology of Biological Invasions of North America and Hawaii. ed by H.A. Mooney and J.A. Drake. Springer-Verlag, New York.

DeBach, P., 1964. Some ecological aspects of insect eradication. *Bull. Entomol. Soc. Am*. **10**: 221-224.

Eberhardt, L.L., Majorowicz, A.K. and Wilcox. J.A., 1982. Apparent rates of increase for two feral horse herds. *J. Wildl. Manage*. **46**: 367-374.

Giles, J.H., 1980. The ecology of feral pigs in western NSW. Ph.D. thesis. University of Sydney. 257 pp. Unpub.

Gosling, M., 1989. Extinction to order. *New Scientist* **1654**: 44-49.

Gosling, L.M., and Baker, S.J., 1987. Planning and monitoring an attempt to eradicate coypus from Britain. *Symp. Ecol. Soc. Lond*. **58**: 99-113.

Gosling, L.M., and Baker, S.J., 1989. The eradication of muskrats and coypus from Britain. *Biol. J. Linnean Soc*. **38**: 39-51.

Gosling, L.M., and Baker, S.J., 1991. Family Myocastoridae. Pages 267-275 *in* Handbook Brit. Mamm. (Third ed.) ed. by G.B. Corbet and S. Harris. Blackwell Sci. Publ. Oxford, U.K.

Gosling, L.M., Baker, S.J., and Clarke, C.N., 1988. An attempt to remove coypus (*Myocastor coypus*) from a wetland habitat in East Anglia. *J. Appl. Ecol*. **25**: 49-62.

Henzell, R., 1992. Goat biology and environmental impacts - implications for eradication. Pages 18 - 24 *in* L. Best, ed. Feral Goat Seminar Proceedings. South Aust. Nat Parks Wildl. Serv. Adelaide. Unpub.

Hermes, N., 1987. The eradication of rabbits from Phillip Island near Norfolk Island, South Pacific. *Proc. Vertebr. Pest Control Conf*. **8**: 65-68.

Macdonald, I.A.W., Loope, L.L., Usher, M.B., and Hamann, O., 1989. Wildlife conservation and the invasion of nature reserves by introduced species: a global perspective. Pages 215-255 *in* Biological Invasions: A Global Perspective SCOPE Series 37 ed by J.A. Drake, H.A. Mooney, F. Di Castri, R.H. Groves, F.J. Kruger, M. Rejmanek, and M. Williamson. Wiley and Sons Ltd, Chichester, U.K.

Munro, R.K., and Williams, R.T. (Eds), 1994. In press. Rabbit haemorrhagic disease: issues in assessment for biological control. Bureau of Resource Sciences, Canberra. 113 pp.

Parkes, J.P., 1984. Feral goats on Raoul Island. I. Effect of control methods on their density, distribution and productivity. *N.Z. J. Ecol*. **7**: 85-94.

Parkes, J.P., 1990. Eradication of feral goats on inlands and habitat islands. *J. Royal Soc. N.Z.* **20**: 297-304.

Parkes, J.P., 1993a. National feral goat control plan for New Zealand. Landcare Res. Contract Rep. LC9293/41. Christchurch, N.Z. Unpub.

Parkes, J.P., 1993b. The ecological dynamics of pest-resource-people systems. *N.Z. J. Zool*. **20**: 223-230.

Ramsay, B.J., 1994. Commercial use of wild animals in Australia. Aust. Gov. Pub. Serv. Canberra. 185pp.

Soule, M.E., 1990. The onslaught of alien species, and other challenges in the coming decades. *Conserv. Biol*. **4**: 233-239.

Tyndale-Biscoe, H., 1994. In press. Use of viruses as vectors for immuno-sterilisation of feral pest mammals. *In* Vaccines for Agriculture ed by D. Demeyer and J.E. Vercoe. CSIRO.

Usher, M.B., 1986. Invasibility and wildlife conservation: invasive species on nature reserves. *Phil. Trans. Royal Soc. Lond. B.* **314**: 695-710.

Usher, M.B., 1989. Ecological effect of controlling invasive terrestrial vertebrates. Pages 463-489 *in* Biological Invasions: A Global Perspective. SCOPE Series 37 ed by J.A. Drake, Mooney, H.A., Di Castri, F., R.H. Groves, F.J Kruger, M. Rejmanek, and M. Williamson. John Wiley and Sons Ltd, Chichester, U.K.

Van Vuren, D., 1992. Eradication of feral goats and sheep from island ecosystems. *Proc. Vertebr. Pest Conf*. **15**: 377-381.

Vitousek, P.M., 1988. Diversity and biological invasions of oceanic islands. Pages 181-189 *in* Biodiversity ed by E.O. Wilson. National Academy Press, Washington, D.C.

Veitch, C.R., and Bell, B.D., 1990. Eradication of introduced animals from the islands of New Zealand. Pages 137-146 *in* Ecological Restoration of New Zealand Islands. Conserv. Sci.

Pub. No. 2. ed by D.R. Towns, C.H. Daugherty, and I.A.E. Atkinson. Dept. Conserv. Wellington, N.Z.

Wilson, G., Dexter, N., O'Brien, P., and Bomford, M., 1992a. Pest animals in Australia: a survey of introduced wild mammals. Bur. Rural Resour. and Kangaroo Press, Canberra. 64pp.

Wilson, G., McNee, A., and Platts, P., 1992b. Wild animal resources: their use by Aboriginal communities. Australian Government Publishing Service, Canberra. 122pp.

Yekutiel, P., 1980. Eradication of Infectious Diseases: A Critical Study. S Karger, Basel, Switzerland. 164pp.

## ACKNOWLEDGMENTS

The authors wish to thank John Parkes and David Choquenot for providing constructive comments on the manuscript, and Dave Priddel for providing data on fox control in Yathong Nature Reserve.

## CAPTIONS TO FIGURES

*Fig. 1.* Relationship between cost per kill (dollar cost of helicopter time) and density of feral buffalo in northern Australia. The cost of finding and removing a single extra buffalo is extremely high at low densities. (Copied from Bayliss and Yeomans 1989).

*Fig. 2.* The effects of 3 different discount rates on a hypothetical data set of cumulative benefit-cost ratios for eradication. We have assumed the cost of eradication is relatively low (\$16 $ha^{-1}year^{-1}$) compared with the benefits (\$8 $ha^{-1}year^{-1}$ in perpetuity), and that eradication is achieved after 10 years with no further costs. These are probably highly optimistic assumptions for widespread pests.

*Table 1.* Feasibility/desirability criteria for the eradication of feral goats and rabbits from mainland Australia, and the regional eradication of European red foxes from Yathong Nature Reserve in western New South Wales.

| Criteria for eradication | Met for feral goats throughout Australia? | Met for rabbits throughout Australia? | Met for foxes in an Australian reserve? |
|---|---|---|---|
| 1. Rate of removal exceeds rate of increase at all population densities? | no? | no? | yes |
| 2. Immigration is zero | no | yes | ? |
| 3. All reproductive animals are at risk | yes? | no? | yes |
| 4. Animals can be detected at low densities | no? | no? | ? |
| 5. Discounted cost-benefit analysis favours eradication over control | no? | no | yes? |
| 6. Suitable socio-political environment | ? | yes? | yes |