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Feral goats in Australia: Impacts and cost of control

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FERAL GOATS IN AUSTRALIA: IMPACTS AND COST OF CONTROL

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ABSTRACT: Feral goats are both a pest and a resource in Australia. They are thought to compete with domestic livestock for food and water and endanger the survival of native flora and fauna. However, there is little quantitative information on the impact of feral goats on agricultural production or conservation values. Their presence on agricultural land is partly tolerated since they can be commercially harvested by mustering or trapping at water points. Where commercial harvesting is not possible, other control techniques must be used. Aerial shooting is the most commonly used technique to remove goats in inaccessible areas, but it is expensive. This paper reviews the status and impacts of feral goats in Australia. It then outlines some cost of control models that predict the cost of controlling goats at different densities using aerial shooting in inaccessible terrain in the semi-arid rangelands of Australia.

KEYWORDS: *Capra hircus*, feral goat, aerial shooting, cost of control, Australia

INTRODUCTION

This paper is about feral goats in Australia. It moves from a general overview of their history, geographic range, impacts and management to a specific example that describes aerial shooting of goats and some models that predict the cost of controlling goats using this method.

HISTORY

Feral goats (*Capra hircus*) are found world-wide but the highest densities are seen in Australia and New Zealand. Goats were introduced to Australia by European settlers who used them as a source of milk and meat (Mahood 1983). When the demand for these products declined many herds of town goats were released. This gave rise to the establishment of large groups of feral goats in many areas (McKnight 1976). In 1861, cashmere and angora goats were introduced to Australia for their fibre (Lever 1985). Escapees from these herds also added to feral goat populations. These populations have survived and expanded, which has been attributed to several factors, including: 1) lack of predators; 2) high levels of fecundity; 3) freedom from disease; 4) high mobility; and 5) a diverse diet (Henzell 1992).

GEOGRAPHIC RANGE

Approximately 2.6 million feral goats now occur widely in Australia with densities highest in the semi-arid pastoral regions of eastern and western Australia (Wilson et al. 1992; Parkes et al. 1996). They are generalist herbivores (Coblentz 1977) and will eat foliage, twigs, bark, flowers, fruit, roots, plant litter, seeds and fungi (Parkes et al. 1996). In the semi-arid areas of Australia the diet selected by feral goats is variable and largely determined by species availability and seasonal conditions (Harrington 1982). Herbs and grasses are favored when they are growing but once these dry out goats turn to browsing shrubs (Wilson et al. 1975; Harrington 1986). In general, they consume more trees and shrubs than the other large herbivores that share this environment (Dawson et al. 1975). This makes them particularly well suited to some parts of Australia's semi-arid rangelands where shrub densities have increased dramatically in many areas (Cunningham et al. 1992).

The distribution of feral goats in Australia is not as widespread as could be expected given their ability to eat an extremely wide range of food plants. Two factors that may limit their distribution are predation and disease (Parkes et al. 1996). The occurrence of feral goats may be partly influenced by dingo and feral dog predation. Where dingoes are controlled, goat populations have been seen to increase (Parkes et al. 1996). Goats are susceptible to a wide variety of parasites and diseases (Harrington 1982). The ability of diseases to affect goat populations appears to be minimal in dry areas, but their role in wetter areas is unclear. Liverflukes (*Fasciola hepatica*) and a bacterial disease, melioidosis, may be responsible for the absence of feral goats in some wetter areas of Australia (Parkes et al. 1996).

IMPACTS

Feral goats are of concern in Australia for several reasons. Firstly, they are perceived to affect the economic returns of pastoralists by competing with domestic livestock for resources such as food and water. Secondly, goats are considered a threat to conservation. "Competition and land degradation by feral goats" has been listed in the Commonwealth Endangered Species Protection Act 1992 as a threatening process. Finally, feral goats also have the potential to spread and complicate the eradication of exotic diseases, such as foot and mouth disease, due to their widespread abundance and freedom of movement (Wilson et al. 1992).

ENVIRONMENTAL

Feral goats are thought to be involved in the decline of four Australian fauna species. These are the yellow-footed rock-wallaby (*Petrogale xanthopus*) (Lim et al. 1992), the brush-tailed rock-wallaby (*Petrogale pencillata*) (Short and Milkovits 1990), the mallefowl (*Leipoa ocellata*) and the thick-billed Grasswren (*Amytornis textilis*) (Shepherd 1996). The evidence indicating that goats compete with native fauna is largely

circumstantial and there is no quantitative data available. It is most likely that the feral goat alone is not responsible for the decline of these species. Other factors, such as fox predation and habitat destruction, may also have a part to play in their decline.

Feral goats are also implicated in the decline of some native Australian plant species. Preliminary work indicates that feral goats do have a significant effect on certain Acacia species (Harrington 1986; Auld 1993; Davies 1995; Maas 1997). On Lord Howe Island goats are thought to have introduced weeds and caused the disappearance of native plant species (Pickard 1976, 1982).

AGRICULTURAL

The economic losses attributed to feral goats in Australian agriculture are estimated to be approximately A$25 million per year. This is made up of losses due to decreased sheep production (A$17.8 million), contingency costs to insure against an exotic disease outbreak (A$6 million) and money spent by government agencies supporting goat control operations (A$1.2 million) (Parkes et al. 1996).

The assumption under-pinning the estimate for lost sheep production is one of substantial dietary overlap and, therefore, competition between sheep and goats. Dietary overlap between sheep and goats can vary enormously (Wilson et al. 1975; Harrington 1986) but will only lead to competition when food is limiting (Choquenot 1992). As yet there is no quantitative evidence that supports the presence of competition between sheep and goats.

PEST OR RESOURCE?

Feral goats provide significant income and employment in the pastoral areas of Australia (Toseland 1992). In 1991 to 1992, the total value of goats and goat products exported from Australia was A$29 million (Ramsay 1994). The great majority of this was derived from feral goats. Harvesting of feral goats benefits many landholders and provides a living for commercial harvesters, abattoir workers, and exporters. Feral goats are also an important game species for recreational hunters and the revenue generated through the sale of sporting goods, vehicles, fuel and other provisions provide an uncalculated source of revenue in rural communities (Parkes et al. 1996). Some 1.2 million goats are harvested annually (Ramsay 1994) which is thought to mitigate some losses and damage attributed to goats. Where commercial harvesting of pests does not achieve densities needed to mitigate impacts then non-commercial control should be considered (Choquenot et al. 1995). It is felt by some that placing an economic value on pests may discourage their control below densities where impacts are mitigated for two reasons: 1) where the attainment of these densities are not commercially viable (Choquenot et al. 1995); or 2) it discourages attempts to achieve high level control or radication (Ramsay 1994). It is for these reasons that the Western Australian state government will make the commercial utilization of feral goats illegal in the year 2000. It is thought that at this time commercial utilization will have no further role to play in the management of feral goats because their densities will have been reduced to levels below which it

is commercially viable to harvest them (Feral Goat Eradication Steering Committee 1997).

MANAGEMENT

A range of approaches can be taken to manage feral goats in Australia, with the most common being radication and sustained control. The techniques used to achieve these depend on the habitat the goats occupy and the resources available. Other considerations, such as animal welfare and stakeholder preferences, also come into play.

Eradication

Feral goats have been eradicated from many islands worldwide, including some offshore islands of Australia (Daly and Goriup 1987; Allen and Lee 1995). On mainland Australia, it is very unlikely that all the criteria for successful eradication of feral goats could be met on a national or regional scale (Bomford and O'Brien 1992). This means that with the exception of some offshore islands, the management of feral goats in Australia will mostly be addressed by sustained control. Some agencies in Australia advocate eradication as a goal, while acknowledging that it is not possible. It is felt that this will facilitate the lowest possible densities being achieved by having people strive for "perfection."

Sustained Control

Sustained control requires ongoing commitment but it usually has the desired effect of reducing goat numbers. Ideally goat numbers are reduced to and maintained at a level where their impacts are considered acceptable (target density). As described earlier quantitative data describing the relationship between feral goat density and impacts are not available in Australia. In the absence of adequate impact data a process of trial and error based on the best available data is used for establishing target densities (Parkes 1993).

CONTROL TECHNIQUES

The most common control techniques currently used in Australia are mustering, trapping and aerial shooting. Mustering and trapping preferred because animals can be sold to offset control costs. Aerial shooting is most commonly used in inaccessible areas. Other techniques that are less commonly used or are currently under investigation are ground-based shooting, the Judas goat technique, poisoning, predation by dingoes, fencing and habitat manipulation.

There is no one technique that can be held up as being the best. The approach taken by land managers will depend on local environmental conditions, resources available and their individual circumstances. Often the most efficient and effective approach is to combine two or more techniques.

Mustering

This technique is labor-intensive and generally limited to flat terrain (Harrington 1982). It is most efficient at high goat densities. The two most common methods of mustering used in Australia are: 1) aerial mustering, using helicopters or light aircraft to flush animals out of dense vegetation or inaccessible terrain, followed up by

a ground team on bikes that bring the animals into yards; and 2) ground mustering on motor bikes or horseback, usually with the help of dogs, that round up groups of goats and bring them into yards (Parkes et al. 1996).

Trapping

Trapping involves the construction of goat proof fences around a water hole with a number of one way entrances or ramps (Parkes et al. 1996). This technique is effective when goats are obliged to find water during drought and alternative water sources can be fenced off.

Aerial Shooting

In Australia aerial shooting has been successfully used to control a range of vertebrate pest species, including pigs (Saunders and Bryant 1988; Hone 1990), donkeys (Choquenot 1988), water buffalo (Bayliss and Yeomans 1989), and goats (Mahood 1985; Naismith 1992; Maas and Choquenot 1995; Pople et al. 1996). This technique is used to: 1) control inaccessible populations; 2) manage low density populations; and 3) remove survivors from other control campaigns (Parkes et al. 1996). It involves using a helicopter as a shooting platform with light aircraft occasionally acting as "spotters." It is can be an expensive control technique but allows difficult terrain to be covered quickly and gives culling rates far in excess of other methods (Lim et al. 1992).

AN AERIAL SHOOTING CAMPAIGN IN DETAIL

A goat population on Mt Gunderbooka in the semi-arid rangelands of NW New south Wales, Australia was reduced by shooting from a helicopter in September 1992. The outcrop was 75 km^2 in size. Shooting over five days in a Kawasaki/Bell 47 helicopter reduced goat density by 85%.

COST OF CONTROL USING AERIAL SHOOTING

Evaluating the cost of controlling vertebrate populations is essential to understanding the pests role in a production or conservation system (Hone 1994). When the benefits of control (reduced impacts) cannot be easily estimated cost effectiveness analysis is appropriate (Hone 1994). The lack of quantitative information describing the relationship between impacts and feral goat density in Australia make this the appropriate analysis here.

The relationship between cost per animal captured and prevailing animal density can be linear (O'Brien 1985; Brennan et al. 1993) or curvilinear (Bayliss 1986 [as cited in Bayliss and Yeomans 1989]; Choquenot 1988; Parkes 1993; Choquenot and Lukins 1995). In general, the lower the density of prey animals, the greater the cost per kill. This is because the efficiency of helicopter shooting decreases as density is lowered since more time is spent searching for and pursuing animals (Bayliss and Yeomans 1989). Due to this the cost of control increases exponentially with decreasing density (Caughley 1977; Choquenot 1987).

To estimate the cost of a control operation, three things must be determined: 1) the target density that achieves the objectives of the control operation;, 2) the cost of the initial reduction; and 3) the cost of maintaining the target density (Bayliss and Yeomans 1989).

METHODS

To construct a model predicting variation in the cost of removing feral goats as their density was reduced, the relationship between time per kill and density was examined. Time per kill (T) was estimated for each helicopter sortie by dividing the total number of goats killed by the duration of the sortie. Density (D) was taken as that at the beginning of each sortie and was calculated by subtracting the cumulative number of goats shot from previous sorties from the initial population density. This density was estimated from corrected helicopter counts of goat groups conducted prior to the shooting operation. Linear and curvilinear functions were fitted to the relationship between time per kill (T) and density (D).

A linear regression was fitted to examine the possibility that the rate of goat removal had not significantly decreased with declining density and is described by:

$$T = x - bD \qquad (1)$$

where: x = time taken to kill the last animal
b = slope of the line

An exponential function was fitted to determine if the rate of killing goats reduced significantly with decreasing density and is described by:

$$T = a + c(\exp(-dD)) \qquad (2)$$

where: a = handling time
$c+a$ = time taken to kill the last animal
d = coefficient that determines the efficiency of the relationship

To fit the exponential model the value of a was estimated by averaging T for densities before any appreciable rise in T was apparent. The values for c and d were then derived using an iterative non-linear estimation technique (Statsoft 1995).

Cost of control for both functions was then calculated by multiplying the amount of time (hours) per kill by A$300 for helicopter charter, A$20 for labor and then adding A$2 per kill for ammunition.

PRODUCTIVITY MODEL

A numerical response model (Figure 1) (Maas 1997) describing the population dynamics of the feral goats on the control site was used to develop a productivity model.

Annual recruitment or productivity is determined by multiplying the annual exponential rate of increase (r) predicted by the numerical response model by prevailing density (N) to give:

$$rN = N (-a + c(1 - \exp(-dV))) \qquad (3)$$

where: a = the rate of decrease in the absence of food
c = the rate at which a is ameliorated when food is abundant
d = the demographic efficiency of the animals
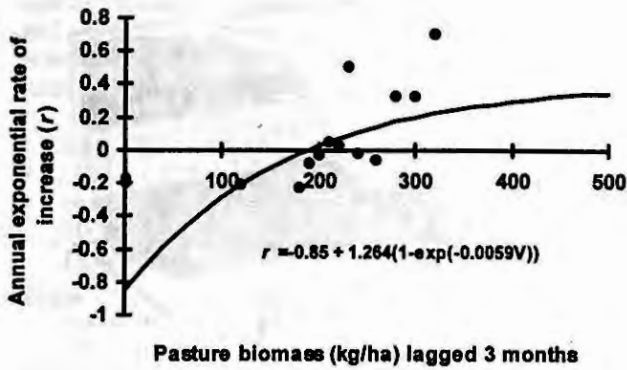V = pasture biomass

Figure 1. The numerical response of feral goats to pasture biomass lagged three months in a semi-arid environment.

ANALYSIS

The cost of initial reduction and the ongoing costs of control are needed to determine the cost of controlling a feral goat population. The models to predict these will be determined for a hypothetical site 100 km² in area with an initial goat density of 25 goats/km². This density is similar to the density of animals seen on the outcrop of the study site previous to the experimental reduction.

Cost of the Initial Reduction

The cost of the initial reduction involves determining the time taken to progressively remove each animal until the target density is achieved. This will be determined with the cost of control model which best predicts the time per kill from prevailing density and will, therefore, be described by one of the following functions following Choquenot's (1988) method:

$$\text{Time} = \sum_{i=1}^{F} x - b(D - Di) \qquad (4)$$

If the linear function is the best cost of control model or:

$$\text{Time} = \sum_{i=1}^{F} a + c(\exp(-d(D - Di))) \qquad (5)$$

If the exponential function best predicts time per kill from density.

For both these functions D is the original population density, F is the target density and Di is the density represented by the progressively reduced population where i is the change in population density equivalent to the number of animals removed. x, b, a, c and d are the same as in equations (1) and (2).

The cost is once again determined by multiplying the time taken per kill by A\$300 per hour for helicopter charter, A\$20 per hour for labor and then adding A\$2 per kill for ammunition.

Cost of Ongoing Control

To determine the cost of maintaining a target density a productivity model is used to predict annual recruitment (rN). These animals must then be removed each year to maintain the target density. The model used to calculate the cost of the initial reduction will be used to determine the cost of maintaining a target density, and so depending on which model was used to calculate the cost of the initial reduction, the cost of ongoing control will be either:

$$\text{Time} = \sum_{i=1}^{F} x - b([Dt + rN] - Di]) \qquad (6)$$

If the linear function best describes the cost of control or if the exponential function better predicts cost of control:

$$\text{Time} = \sum_{i=1}^{F} a + c(\exp(-d[(Dt+rN)-Di])) \qquad (7)$$

In both these functions Dt is the target density achieved by the initial reduction and rN is annual recruitment as calculated by equation (2). Di and F are the same as for equation (6.3), x,b a, c and d are as for equations (1) and (2). Once again, the cost is calculated by multiplying time by A\$300 per hour helicopter charter, A\$20 per hour labor and A\$2 for ammunition used per animal.

RESULTS
The Cost of Control Model

The exponential model was a better predictor of time per kill from prevailing density than the linear model (Table 1).

Table 1. A comparison of the fit (r^2) and prediction of time to kill the last animal for the two cost of control models fitted to the data.

Model	r^2	p	Time to Kill the Last Animal
Linear	0.24	0.102	2 minutes
Exponential	0.53	0.016	296 minutes

This function predicts that when goat densities are high, handling and search time combined was 0.013 hours per kill or 47 seconds per goat shot. The time taken to kill the last goat predicted by this model is 4 hours and 56 minutes.

The Productivity Model

Using the numerical response productivity can be determined using the function:

$$rN = N[-0.85 + 1.264(1-exp(-0.0059V))] \qquad (8)$$

where:
- rN = annual productivity of the goat population
- N = prevailing goat density
- V = pasture biomass (kg/ha)

Cost of the Initial Reduction

Using the exponential function, the cost of the initial reduction down to different densities can be calculated. Figure 2 shows the relationship between target density and the cost of achieving that density on a site 100 km^2 in area with a starting density of 25 goats per km^2. The predicted cost of removing the last goat according to this model is A$290 824.
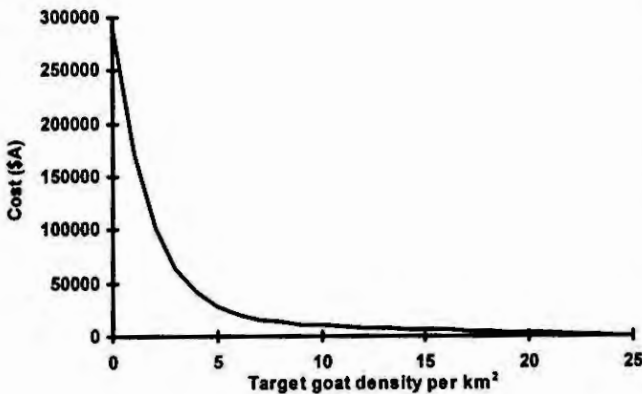
Figure 2. The modeled cost of reducing a population of goats from 25 goats/km^2 to various target densities using aerial shooting.

The Ongoing Cost of Control

Combining the productivity model and the cost of initial reduction model we get a 3-dimensional surface which allows us to predict the cost of maintaining a particular target density under a range of environmental conditions on a site 100 km^2 in area with a starting density of 25 goats/km^2 (Figure 3).
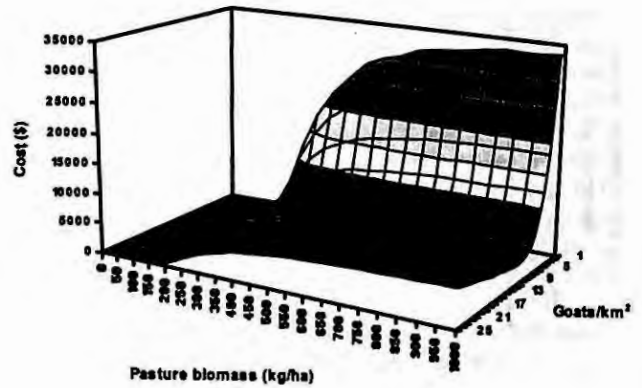
Figure 3. The ongoing costs of maintaining various target densities under different environmental conditions.

DISCUSSION
Cost of Control Models

Only the exponential function had a significant fit to the data with the linear model having a much poorer fit. This demonstrates that the helicopter shooting operation proceeded long enough for the time per kill to become progressively larger as density decreased. The reason for this study having a stronger curvilinear than linear effect of time may be related the change in group size over the course of the shooting campaign. Feral goats have a strong tendency to form groups. These groups may have been larger at the beginning of the control campaign since they had not been selectively culled and had not dispersed due to continued disturbance.

The time taken per kill, and therefore the cost per kill, was very low at high goat densities, but increased markedly when densities approached approximately half the initial density. Shooting became increasingly less cost efficient as goat densities fell below 11/km^2.

Managing Feral Goats in Australia

Feral goats in Australia are most abundant in semi-arid areas where they are both a pest and a resource. Land managers must optimize control in terms of production and/or conservation objectives while keeping in mind control costs and their resource value. Information needed to do this includes an understanding between goat damage and goat density as well as the relationship between goat density and cost of control. This paper presented a cost of control model that was based on the exponential relationship between goat density and costs. In the absence of any information on a relationship between density and damage it is the only tool available to help decide on the optimal level of control in this environment using aerial shooting. Since

eradication of feral goats is not possible on Australia's mainland control to a density that is financially sustainable and optimal is prudent until information describing the relationship between impacts and density can further inform the decision making process.

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