FERAL GOATS IN SOUTH-WESTERN QUEENSLAND: A PERMANENT COMPONENT OF THE GRAZING LANDS.

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Abstract

Feral goats were harvested in south-western Queensland at four sites under two regimes (opportunistic harvesting and sustained control). We assessed how this impacted on their contribution to total grazing pressure, on soil and pasture conditions and on the economics of goat management. The population impact was not consistent across sites with the same treatment, with 62% and 84% reductions in numbers in the two northern sites (one opportunistic harvesting site and one sustained control site) while numbers in the southern sites essentially remained the same. The contribution of goats to grazing pressure ranged from 3 to 30%; kangaroos contributed 16-36%; and livestock contributed 37-72%. Harvest rates of feral goats calculated for each of the sites ranged from 17 to 41%. There was no consistent relationship between population changes and the harvest rates. Seasonal conditions had greater influence on pasture and soil conditions than did changes in feral goat populations. The average cost of mustering goats (based on 34 operations) was \$1.93 per head. Mustering costs increased markedly when goat density was lower than 10/km^2. Average trapping costs (based on 7 trapping programs) were \$2.08 per head. This compared with on-farm prices of \$16-\$25 per head in 1997. Personal circumstances and preferences of individual landholders were the key determinant of the level of control undertaken. Variability in price contributed to landholders being apprehensive about the viability of the goat industry. There are few simple tools available for landholders to estimate feral goat numbers and this makes effective management of total grazing pressure difficult.

Key words: Feral goats, total grazing pressure, monitoring, economic returns, grazing impact, landholder participation

Introduction

Land use studies have revealed extensive land degradation in the rangelands of south-western Queensland, particularly in the mulga lands. Excessive total grazing pressure was highlighted as a significant issue with domestic, native and feral herbivores all contributing to the problem (Williams 1995). The focus of domestic livestock management has been the determination of safe long-term stocking rates (Johnston *et al.* 1996a,b). However, the focus of feral goat management has been eradication with little or no emphasis on longer-term strategies.

There are an estimated 2.6 million feral goats in Australia (Parkes *et al.* 1996). The majority live in the pastoral areas of Queensland, New South Wales, Western Australia and South Australia. Feral goats are pests as they compete with stock for pasture, and their grazing, browsing and trampling contributes to soil erosion and land degradation. Conversely, feral goats are regarded as a resource in areas where they can be mustered or trapped for slaughter and processed to meet the food, fibre and skin demands of overseas and domestic markets (Wilson *et al.* 1992, Ramsay 1994). As a consequence of this "pest versus resource" status, the approach to management has been inconsistent.

There are between 240,000 (Southwell *et al.* 1993) and 400,000 (Parkes *et al.* 1996) feral goats in Queensland (Allen *et al.* 1995). These are widely distributed with the major populations found in the central and south-western areas of the State. Feral goats have expanded their distribution and density in Queensland since the mid 1980s (Allen *et al.* 1995). Goats have a wide dietary tolerance which gives them greater drought resistance than sheep (Parkes *et al.* 1996). This makes goats effective competitors with domestic stock, and with native species such as the yellow-footed rock wallaby *Petrogale xanthopus* and the brush tailed rock wallaby *Petrogale penicillata* (Short and Milkovits 1990) which inhabit similar areas to feral goats.

The study was conducted in the mulga lands of south-western Queensland to assess the impact of managing feral goats under two different regimes, sustained control and opportunistic harvesting. Additional information is provided on the numbers of goats and their contribution to total grazing pressure, and assessments made on the short-term environmental impact of reducing goat populations (as recommended by Sharp *et al.* 1999) and on the economics of feral goat management. We report on landholders' views concerning feral goats and discuss the concept of managing feral goats as a permanent component of the grazing lands.

Methods

General

Four sites were selected with both treatments being assessed at a northern location and a southern location (See Fig. 1 and Table 1). These sites were selected on the basis of a history of feral goat reports and harvesting programs in the areas. Thus, the sites represented good goat habitat and immigration into these areas was likely to occur. The management sites had 4-10 properties with overall size of 109,400 to 117,300 ha (Table 1). All properties are used for sheep and/or cattle grazing.

Table 1. Details of the feral goat management sites studied in south-western Queensland during 1994 to 1997.

	S1 Mt Edinburgh	**S2 Jobs Gate**	**O1 Ward River**	**O2 Mt Alfred**
Treatment	Sustained control	Sustained control	Opportunistic harvesting	Opportunistic harvesting
Dominant vegetation	*Acacia aneura* *Acacia cambagei* *Astrebla* grassland	*Acacia aneura* *Eucalyptus populnea*	*Acacia cambagei* *Acacia harpophylla* *Acacia aneura* *Astrebla grassland*	*Acacia aneura* *Acacia cambagei*
Landforms	plains; undulating downs; range country	alluvial plains; sandhills; hard mulga	soft mulga; hard mulga; alluvial plains;	soft mulga; hard mulga; residuals
Property sizes	6000-30,000 ha	12,000-45,000 ha	4000- 0,000 ha	8000-25,000 ha
Number of properties	7	4	10	6
Mean annual rainfall (mm) (S.E.)	525 (204) (Blackall)	392 (158) (Noorama)	524 (188) (Augathella)	362 (173) (Charleville)
Total area (ha)	115,500	117,300	109,400	110,500
No. of population estimates	11	14	6	5
No. of trappings and musterings	11	17	8	5
No. of monitoring sites	10	10	16	12

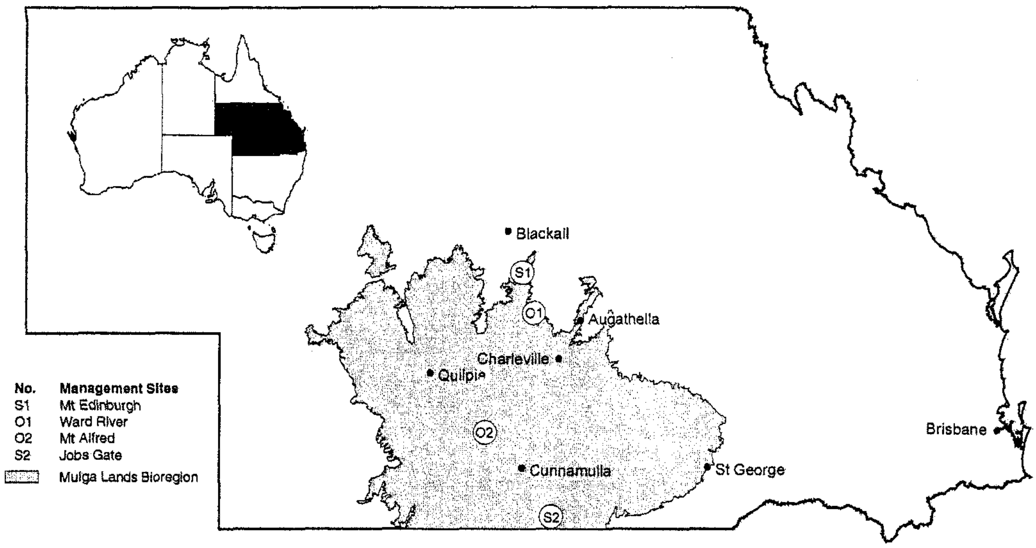

Fig. 1. Location of the four management sites for feral goat study in south-western Queensland.

Goat numbers and environmental conditions were monitored over the three years of the project (1994-1997). Management groups were set up for each of the four sites and were made up of landholders in the study area. Government officers provided technical information and collected data (e.g. carried out aerial population estimates). Landholders made management decisions, for example, timing and method of harvesting goats, sometimes after consultation with government officers. Thus, the project was participatory, with landholders involved in decision-making, planning and implementation of almost all aspects of the project.

Treatments

The two treatments assessed were:

1. *Sustained Control.* The principal objective at these sites was to reduce goat density as low as economically feasible, using a combination of mustering and trapping. This effort was coordinated across all properties at the sites. Control activities were undertaken regularly throughout each year. These sites are S1 and S2.

2. *Opportunistic Harvesting.* This involved the sporadic muster of easily accessible goats when commercially viable. An annual muster at individual properties was the maximum level of control undertaken. The opportunistic harvesting sites were selected to represent the level of management practised on most south-western Queensland properties during 1994–97. No coordinated activities were undertaken. These sites are O1 and O2.

Goat management

Forty-one mustering or trapping programs were conducted at the four study sites from 1995 to 1997 (see Table 1 for the number of mustering/trapping operations in total and Table 4 for the seasonal distribution of these at each site). At the two sustained control sites, an integrated mustering and trapping program was developed in collaboration with the landholders. The aims for mustering and trapping were essentially the same at all sites, but the methods used differed slightly between sites.

While mustering was the most common method of goat management in the trial, trapping was also used as means of harvesting goats. Trap design was based on recommendations from the

Queensland Department of Primary Industries (QDPI) following trials of self-mustering gates (O'Dempsey 1993), and on trap designs trialed by NSW Agriculture (T. Brill, pers. comm.). Bettini trap gates or ramps were used on all traps built.

Assessing goat numbers

Counting goats from the air is regarded as the most practical, rapid and cost-effective survey method for large areas (Parkes *et al.* 1996). A total of 36 surveys were conducted at the four sites over 3 years. Surveys were conducted prior to, and following, major control operations at sustained control sites and at least annually at opportunistic harvesting sites. Additional surveys were conducted at S1 and S2 to monitor changes in goat density throughout the year. All surveys were conducted prior to 10.00 a.m. or after 2.30 p.m. from a Cessna 182 fixed-wing aircraft. The aircraft was flown at a height of 75 m and a ground speed of 185 km/h. A radar altimeter was used to monitor height above ground and a global positioning system used for navigation.

The survey methods used are similar to those used throughout rangeland Australia for feral goat and kangaroo surveys (Caughley and Grigg 1981, Southwell 1989). We used a 100-metre strip compared with the more commonly used 200 metres. The 100-metre strip width has been successfully used for other feral goat surveys (Pople *et al.* 1996, Edwards *et al.* 1997, Pople *et al.* 1998). Transect lines were systematically spaced 2.5 km apart, representing a sampling intensity over each management site of between 6.6 and 7.2%.

Differences in visibility produce bias in aerial counts of feral goats and these counts must be corrected. Pople *et al.* (1998) calculated visibility bias using the data collected in this study and the results of similar double count surveys conducted in the same region. Correction factors were calculated using the double count technique which is based on the Peterson mark-recapture model (Caughley and Sinclair 1994). The correction factor for sightability used was 1/P where $P= 1-0.47e^{-0.061*\text{group size}}$.

Kangaroos (red kangaroos, *Macropus rufus;* eastern grey kangaroos, *Macropus giganteus;* and the common wallaroo, *Macropus robustus*) were simultaneously counted during each aerial survey. Correction factors applied to counts for this study were: 1.87± 0.4 for red kangaroos; 3.27± 0.4 for eastern grey kangaroos; and 3.81± 1.1 for common wallaroos (Pople *et al.* 1996).

The calculation of harvesting rates enables assessments to be made regarding appropriate levels of harvesting for different populations. In this study instantaneous harvest rates were calculated for all sites. The instantaneous harvest rate (H) is the rate at which the population was harvested throughout the project. It is calculated by dividing the harvest offtake per year by the average population size for the period (Caughley 1977). Harvesting programs were conducted regularly during this project which is consistent with the assumptions for calculating instantaneous harvest rates.

Changes in population size were assessed by taking natural logarithms of all population estimates and fitting a linear regression to the data points using time on the x-axis (Caughley and Sinclair 1994).

Estimating total grazing pressure

Domestic livestock, feral goats and kangaroos were present at all sites. The total grazing pressure being exerted on each of the management sites in September 1996 was estimated through aerial surveys and the collation of property stocking records. The livestock, kangaroo and feral goat population estimates from each of the sites were converted to dry sheep equivalents (DSEs) (Table 2) and combined with property records of domestic stock numbers to calculate the total grazing pressure.

Table 2. Conversion factors for livestock, kangaroos and feral goats to dry sheep equivalents (DSE) used for determining total grazing pressure in the feral goat study (from Crichton 1995).

Animal	Dry Sheep Equivalents
1 goat	1.0
1 kangaroo	0.7
1 steer	8
1 cow + calf	12
1 bull	16
1 weaner beast	6
1 ram	2
1 weaner sheep	0.8
1 ewe+lamb	1.5

The long-term safe carrying capacity was assessed for each management site by a QDPI team using methods outlined by Johnston *et al.* (1996a). The assessments involved the preparation of detailed land system and paddock maps of the property. The current land condition was then assessed and the average annual forage production estimated. This model utilises pasture rainfall use efficiency, annual rainfall and land system information to calculate a long-term safe carrying capacity for that property. The model was implemented on several properties on each of the management sites and the information generated was used to estimate the long-term safe carrying capacity of each site.

Pasture changes

The Mulga Assessment Program (MAP) was developed by the Charleville QDPI and south-western Queensland graziers to assist landholders to manage their pastures more efficiently (Evenson 1992). The basis of MAP is a photographic record at fixed sites to show pasture changes over time. Two sites per major land system were established on each management site to record pasture levels before control of feral goats began, and at six-month intervals for the life of the project (see Table 1 for numbers per site).

Two samplings for pasture biomass and species composition was undertaken in 1996 (April and September) using the BOTANAL sampling technique (Tothill *et al.* 1978). At two locations within each management site, 20 quadrats (0.5 m x 0.5 m) were recorded on each of three transects radiating from a central point with 10 m between sampling points along each transect. These data were supported by photographs taken at the MAP locations mentioned above and yield estimates at these being made by using standard photographs of yields in mulga communities (Partridge 1996).

Soil changes

Changes in soil condition were assessed using field methods outlined in the Rangeland Soil Condition Assessment manual (Tongway 1994). A minimum of two monitoring sites was placed in each major land system on S1, O1 and O2 (logistical problems prevented any sites being established on S2). To avoid possible bias, monitoring sites were located away from: steep hills in areas with less than 3% slope; fence lines; roads; and watercourses.

Soil surface assessments were made on permanent transects, 100 m in length, with a 1 m^2 quadrat placed at 5 m intervals (after Tongway 1994). The results of the soil condition assessments were grouped into three categories: stability; nutrient cycling status; and infiltration/run-off. The ratings for each of these categories were subjected to analyses of variance to detect changes over time within a site.

Economics of goat management

Cost-benefit analysis is the appraisal of an investment project, which includes all social and financial costs and benefits accruing to the project (Bannock *et al.* 1992). A complete analysis is rarely achieved or attempted due to lack of knowledge or because it is impractical (Allen *et al.* 1995).

The cost-benefit of an animal control program requires information on the relationship between animal density and damage caused by that species (Braysher 1993). For feral goats this means an understanding of the impact of feral goats on the land resource and/or the effects of competition with domestic stock for feed. The descriptive costs and benefits of feral goats are summarised in Table 3. Only some of these factors could be valued and assessed. Participating landholders at the management sites provided details of the costs of mustering and trapping feral goats. Information was collected on vehicle, motorbike and aircraft usage, labour inputs, and trap construction and maintenance costs. All costs were valued in 1997 dollars for ease of comparison. For the 34 musters and 7 trapping programs that landholders undertook, cost-benefit data were collected and analyses undertaken. Goat prices were collected from landholders and/or from a local goat buyer.

Table 3. The costs and benefits of feral goats in grazing lands of south-western Queensland.

Costs of feral goats	Benefits of feral goats
Mustering and trapping costs	Revenue from sale of feral goats
Competition with domestic stock	Diversification of income
Damage to fences	Breeding stock for domestic herd
Environmental damage(e.g. erosion, changes in species composition)	Potential for weed control
Wool contamination	
Disease risk	

Assessing attitude and social aspects

Changes in landholder understanding and behaviour regarding feral goat management were assessed by comparing reports of landholders' situations written at the beginning of the project, during annual review meetings and at the end of the project. These comparisons were checked against landholders' and government officers' perceptions of the changes. While these techniques are obviously subjective, qualitative data about the same issues were collected from three sources (written reports; landholders' perceptions; government officers' perceptions). Where the data are consistent from the three sources, it has considerable validity.

Statistics

Analyses of variance, regression analyses and chi-squared analyses were done using SYSTAT 7 (Wilkinson 1977) and GENSTAT 5 (Lawes Agricultural Trust 1995). The probability level used to detect significance was $p<0.05$, unless otherwise stated.

Results

Rainfall data

S1 and O1, the two most northerly sites, recorded below average rainfall in 1994 and 1995 and marginally higher than average rainfall in 1996 (Table 4). This is in contrast to the two most southerly sites, S2 and O2 which recorded average or higher than average rainfall for all years of the project.

Table 4. Annual and long-term average rainfall (mm) for the four feral goat study sites in south-western Queensland (Source: Bureau of Meteorology).

	S1	S2	O1	O2
Average rainfall (mm)	525 ± 204	392 ± 158	524 ± 188	362 ± 173
Rainfall 1994	418	489	464	389
Rainfall 1995	346	552	375	362
Rainfall 1996	541	474	550	497

Population trends and the impact of control

Population estimates and numbers harvested for all four sites are presented in Table 5. Substantial population decreases were recorded at S1 and O1, while the other two sites remained relatively unchanged.

Densities of feral goats throughout the project varied from 6–20 goats/km^2 at S1, 1–10 goats/km^2 at O1, 5–11 goats/km^2 at O2 and 10-24 goats/km^2 at S2. These values represent goat densities over areas between 1094 km^2 and 1173 km^2, and are generally higher than the regional average of between 0 and 6 goats/km^2 as reported in Pople *et al.* (1996). The densities are similar to those reported by Pople *et al.* (1998) on their study sites (which were north of S1) of between 5 and 23 goats/km^2.

Feral goats were observed to breed at all times of the year although the major kidding period occurred in May–June. Larger goat group sizes, while variable during the year and between sites, occurred more frequently in the summer/autumn period (χ^2=153.84, 12 df, P<0.01)

A total of 32,762 feral goats were removed from the sites during this study. Of these, 26,809 or 82% of the goats were taken from S1 and S2, the sustained control sites. Some feral goats were removed from S1 and O1 during unreported trapping and mustering operations in 1996 and 1997.

Table 5. Population estimates and the number of goats removed in control operations for the 4 study sites during the study period.

Time		S1	S2	O1	O2
1994 Summer	Population	23100 ± 6670	12890 ± 2150	9280 ± 3090	10520 ± 2470
1995 Summer	Population	13770 ± 4530	18300 ± 4040	11730 ± 4170	7490 ± 2010
	Removed#			*283 (2)*	
Autumn	Population	15860 ± 4780	19350 ± 4100		
	Removed	*1971 (3)*	*2525 (3)*		*450 (1)*
Winter	Population	23510 ± 6930			
	Removed	*3977 (2)*		*1064 (2)*	*895 (2)*
Spring	Population	11340 ± 2210	25020 ± 4050		
	Removed		*2059 (2)*	*248 (2)*	*428 (1)*
1996 Summer	Population	12020 ± 3230		7650 ± 2890	5320 ± 950
	Removed	*3789 (2)*	*1105 (1)*	*702 (1)*	
Autumn	Population		12680 ± 2010	7658*	
	Removed	*860 (1)*	*1021 (2)*		
Winter	Population		28260 ± 5790		
	Removed		*4476 (4)*	*634 (1)*	
Spring	Population	7280 ± 3040	14510 ± 3270	2516*	12440 ± 2730
	Removed	*1722 (2)*	*864 (2)*		*1249 (1)*
Summer	Population		17040 ± 4220		
	Removed	*657 (1)*	*1362 (1)*		
1997 Summer	Population				9480 ± 3010
	Removed		*149 (1)*		
Autumn	Population			1460 ± 640	
	Removed		*272 (1)*		

number of musterings/trappings shown in parentheses
* results provided from DPI surveys. No SE available

There were reductions in feral goat density at S1 and O1 (the two northern sites), yet little change at O2 and S2 (the two southern sites) regardless of control methods used (Table 6).

A significant decrease in population size was recorded at two sites, S1 and O1 (see Fig. 2 for regression equations). At S1 a significant decline in population size was recorded over the two years of the project ($F_{1,9}$= 11.47, $p<0.01$) with the exponential rate of decrease over 1 year for the population being 0.60. A significant population decline was also recorded at O1 ($F_{1,4}$= 13.46, $p<0.05$). The exponential rate of decrease over 1 year was 0.85. No significant population trends were recorded for S2 ($p>0.8$).

Instantaneous harvest rates ranged from 17% to 41% (Table 6).

Table 6. Change in population of feral goats and the harvest rate for the sustained control and opportunistic harvesting sites in south-western Queensland from December 1994 to late 1996/early 1997 (see Table 5 for actual dates).

	S1	S2	O1	O2
Change in population	62% decrease	No change	84% decrease	No change
Instantaneous harvest rate	41%	37%	27%	17%

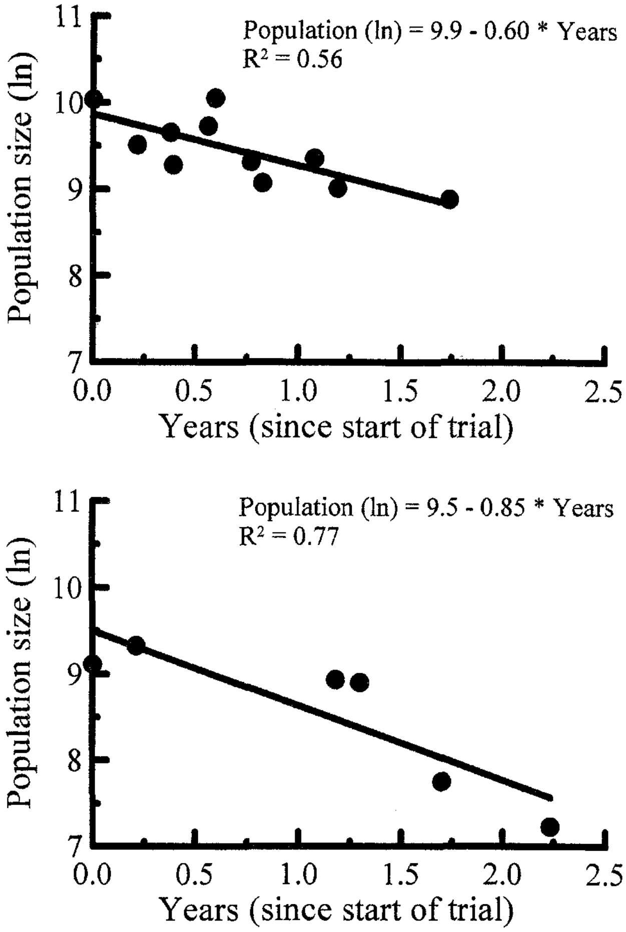

Fig. 2. Population change for (a) site S1 and for (b) site O1, where significant population declines were observed over the study period. [Sites O2 and S2 showed no significant change in population – data not shown].

Relative contributions to grazing pressure

The estimated safe carrying capacities for the management sites varied between 17 and 54 DSE/km^2 (Table 7). On all of the management sites, the total grazing pressure in September 1996 exceeded the estimate of the long-term safe carrying capacity.

Feral goats contributed between 3% and 30% of the total grazing pressure. This contribution was smaller than that made by the domestic stock (37–72%) and similar to that made by kangaroos (16–36%) across the management sites (Table 7).

Table 7. Relative contribution by feral goats, domestic stock and kangaroos to the total grazing pressure on feral goat management sites at September 1996.

	S1	S2	O1	O2
Domestic stock	72%	37%	61%	54%
Kangaroos	19%	34%	36%	16%
Feral goats	9%	29%	3%	30%
Total grazing pressure (DSE/km^2)	74	42	79	38
Safe carrying capacity (DSE/km^2)	54	35	48	17

Pasture changes

The monitoring sites showed large fluctuations in ground cover and pasture biomass at all locations on the four management sites. Measured pasture biomass ranged from 150 to 1470 kg/ha during 1996. Between the first record (March 1995) and the last record (January 1997), there was an increase in ground cover and pasture biomass at 68% of the monitoring sites. The remainder of the monitoring sites showed little change between the first and the last record.

Pasture yield estimates showed an increase in pasture biomass at all management sites over the trial period (Fig. 3) with no obvious differences among sites. Species composition data were available for 1996 only. There were some changes in composition but these were not related to goat management. The fluctuations in both biomass and species composition reflected differences in the amount and timing of rainfall at the monitoring sites.

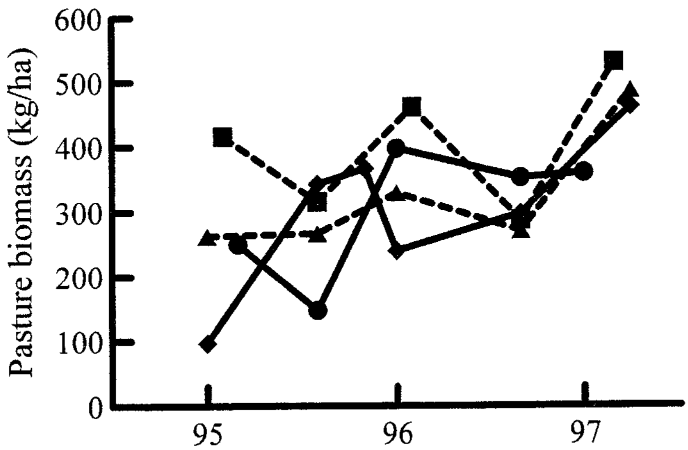

Fig. 3. Change in estimated pasture biomass at each management sites during the feral goat study (Site S1 ●; Site S2 ◆ ;Site O1 ■; Site O2 ▲).

Soil changes

The pattern of soil stability changes was consistent at the three sites monitored (Fig. 4). Significant changes in the means of the soil stability data occurred between the 1996 and 1997 samples on both the S1 and O2 sites, i.e. soil became more stable. No significant change was detected in the means of the soil stability data collected from the O1 management site during the project. The soil infiltration results and the soil nutrient cycling results from the S1 and O2 sites showed similar changes between 1995 and 1997 samples (Fig. 4).

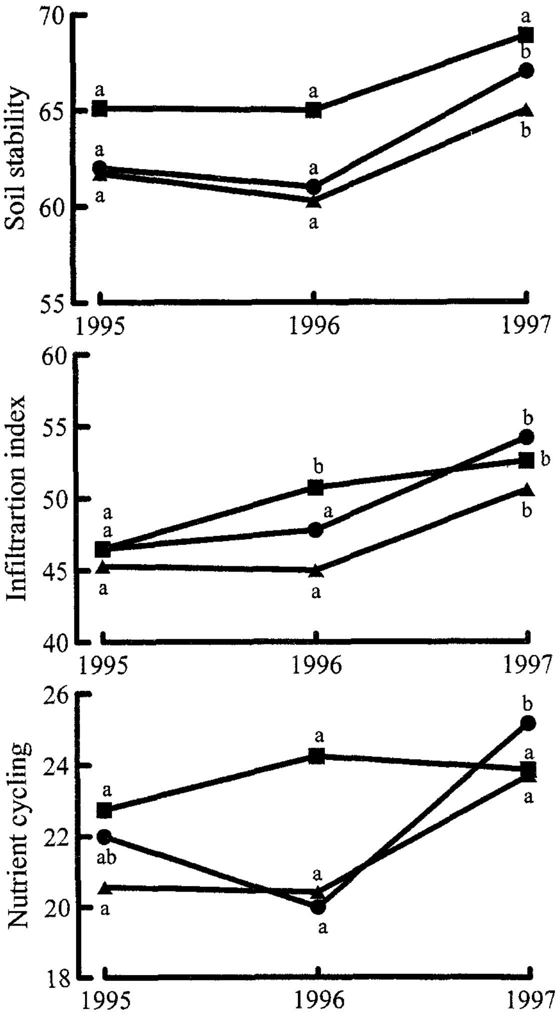

Fig. 4. Changes in indices of (a) soil stability, (b) soil infiltration, and (c) nutrient cycling during the feral goat study in south-western Queensland (Site S1 ●; Site O1 ■; Site O2 ▲). [Within a site, indices are not significantly different if followed by the same letter].

Economic aspects

The average mustering cost of all goats captured over the life of the project was \$1.93 (S.D. = \$1.30) per head (range \$0.42 to \$7.40). Factors influencing mustering costs include: feral goat density; ruggedness of terrain; experience of operator; and capital equipment used to muster goats. Feral goat density is perhaps the most important of these. There is an inverse relationship between mustering costs and goat density (Fig. 5). Goats are often found in rugged terrain and under these circumstances, the cost of mustering is relatively high. Landholders with greater experience with feral goat mustering tended to have lower mustering costs. The labour component dominated total mustering costs, ranging from 42-53% across the four management sites. Landholders spent between 2-4% of their available working time per year on feral goat management. This is a small amount of time relative to that spent on domestic stock and other management activities.

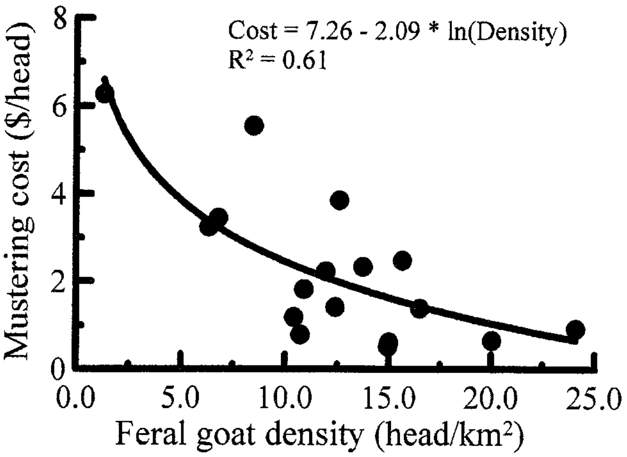

Fig. 5. Relationship between mustering cost and feral goat density in south-western Queensland.

Trap construction costs ranged from $2,000 to $5,000 per trap. The variable cost of operating the trap was $0.58 per head (S.D. = $0.35). Total average trapping costs (which includes construction and maintenance) was $2.08 per head, with a range of $1.15 and $3.87 per head. Fixed costs were annualised over a 10-year loan (the estimated life of a trap) and divided by the average number of goats caught per trap per year over the life of the project. The number of animals caught has a major influence on trapping costs per head. It should also be noted that traps are multipurpose and can be used as self-mustering yards for sheep as well.

Estimates of damage to fences in the management sites were made by landholders based on the total amount of fence maintenance required each year and the approximate proportion of damage attributable to feral goats. The range of costs was from about $800 to $1300 per property per year (average of $1000). These estimates should be considered as conservative because landholders generally repair fences to a level sufficient to hold domestic stock rather than to return them to original condition.

Social aspects

Most landholders admitted that they did not have a good idea of goat numbers on their properties. During the project, their interest in estimating numbers intensified and they became far more observant.

In 1994 most people were adamant that there were few benefits from feral goats and all said that the ideal situation was to have no goats at all. At the end of the study, some landholders thought that feral goats were a resource because of the high prices being paid at the time. Other landholders still thought goats were pests, despite the high prices.

Landholders' personal circumstances and preferences seemed to be the key determinant for the level of control considered necessary. Economics were significant but not the only factor for many landholders. For example, the incentive to harvest goats rose during the drought when people needed cash. In 1994 landholders on three sites wanted to eradicate feral goats completely, and all landholders wanted to reduce their numbers. By 1997 numbers were lower on three sites and most landholders said current numbers were manageable with some landholders stating that 200 to 300 goats would be acceptable on their property.

In 1994 market price was mentioned as a significant trigger for control to be undertaken with people indicating that if goats were worth more money they would do more harvesting. However, in 1997, only one group mentioned market price as a significant trigger, probably because low price was no longer a major issue. Landholders at three sites said they would remove goats if populations were building up to what they regarded as unacceptable levels, regardless of market price.

At the beginning of the project, all landholders undertook some goat control but the level of control and the techniques used differed among them. Landholders at only one site (a sustained control site) regularly used aircraft in conjunction with motorbikes and dogs to muster. At the end of the project, all sites recognised the value of mustering with aircraft even though not everyone used them.

On the two sustained control sites where trapping was trialed, best practice was considered to be a combination of trapping and mustering. Weather conditions influenced which technique was used at which time, for example, the availability of temporary surface waters means that trapping would not be successful. On one site, the best combination of methods was considered to be a muster followed by trapping to clean up the goats that remain after the muster.

When asked about what they had learned from the project, most landholders mentioned that the significant lessons were:

- The many improvements to mustering and trapping practices. The lessons people learned varied, and depended on the different situations within which they worked, and the different levels of understanding at the beginning of the project. More lessons were reported on the sustained control sites where landholders undertook more control activities and had closer interaction with government staff. A key difference is that people at the sustained sites were involved in structured reflection and evaluation sessions about their own activities
- A large profit can be made from feral goat control while market prices are high. However, some landholders still asserted that in the long-term they could make more money out of sheep than goats.
- A greater understanding of feral goat behaviour which enabled landholders to manage and muster feral goats more effectively.

Discussion

Feral goat populations

Feral goat populations averaged about 10/km^2 in this study (range 1–24 goats/km^2) and are similar to those reported from other studies related to feral goats in western Queensland (e.g. Pople *et al.* 1998). However, they are markedly higher than the regional average of 0-6 goats/km^2 calculated from annual counts from kangaroo surveys conducted by the Queensland Parks and Wildlife Service (Pople *et al.* 1996), reflecting that the sites were indeed good goat habitat. It also supports the perception that feral goats aggregate in particular areas and highlights the importance of conducting species-specific surveys.

The results obtained here show that feral goats contributed between 3 and 30% of total grazing pressure, and are consistent with data from Western Australia where feral goats represent 20% of the total grazing pressure (Pickles 1992). In north-western New South Wales, Landsberg and

Stol (1996) reported that goats represented 17-80% of total grazing pressure over three paddocks during an 18-month period, with a mean of approximately 40%. At average densities (1.9–5 goats/km^2), feral goats in South Australia consume up to 25% of food eaten by large and medium sized herbivores (Parkes *et al.* 1996). Feral goats in some rangeland areas in South Australia reach densities of 40 goats/km^2 in the absence of domestic livestock (Parkes *et al.* 1996).

In this study, the short-term total grazing pressure was high compared with estimated safe carrying capacity. The safe carrying capacity is an estimate of what livestock could be carried for the long-term, given the rainfall, soil fertility and woody plant composition of an area and is based on safe level of utilisation (Johnston *et al.* 1996a). During periods of high pasture production, grazing at a safe level of utilisation will enable more stock to be carried (i.e. a higher total grazing pressure) than indicated by the safe carrying capacity. Thus care must be taken when interpreting such data, as the two concepts are not directly comparable.

Control

Henzell (1984) reported that, in a localised area, up to 80% of a feral goat population could be removed by mustering. In western Queensland, Pople *et al.* (1998) used helicopter-based shooting to reduce populations at 3 sites by 49%, 75% and 100%. Edwards *et al.* (1997) reduced a feral goat population by 60% using a combined mustering/aerial shooting operation in south-western Queensland. Results from our study also indicate that a high level of control can be achieved in localised areas with up to 81% reductions being achieved over some transects within the surveyed region.

Edwards *et al.* (1997) alluded to difficulties in achieving regional control and stated that control programs had no impact on the populations on properties fringing the control area. At S2 (a sustained control site), no significant change in density occurred despite the removal of 13,833 feral goats over 2 years. However, at the other sustained control site, the feral goat population did decline over the period of the project. Based on a similar trend being exhibited at O1, we conclude that the reduction at S1 was not due to control activities alone, but was the combined effect of sustained control and below average rainfall in the area. The failure of sustained control activities to reduce feral goat populations has also been reported from western New South Wales (Sharp *et al.* 1999).

The emigration and immigration of feral goats during a survey period can confound the results obtained. The pre- and post-control survey results did not always correspond with the number of goats removed. It is possible that the act of mustering itself drove some goats away from the area being surveyed, or the change may have been part of 'normal' goat movements. However, Holt and Pickles (1996) found that aerial control activities had little effect on home ranges of resident feral goats. Where goat movement and habitat use has been studied in relatively flat terrain, feral goats have a strong fidelity to a relatively small core area (Freudenberger and Barber 1999). This contrasts with Sharp *et al.* (1999) who reported that annual removal of substantial numbers of goats had relatively little effect in rocky and hilly reserves, presumably due to reinvasion from surrounding pastoral properties. Thus, movement of feral goats may be influenced by topography, habitat quality, harvesting pressure and feed availability (Freudenberger and Barber 1999).

Recommendations of target harvest rates are difficult to make. At S1 and O1, we observed a 62% and an 85% reduction in feral goat numbers with instantaneous harvest rate of 41% and 27%, respectively. It is likely that this reduction was a combined effect of extensive harvesting and the effects of low rainfall in 1994 and 1995. No such changes were observed at the other sites. We suggest that instantaneous harvest rates greater than 20-30% would be needed to achieve substantial long-term reductions in population size. Freudenberger and Barber (1999) suggest that removal of 80% of the feral goat population would result in the maintenance of low feral goat numbers on a property.

Control programs would be best targeted prior to major kidding periods in May-June to avoid the difficulties associated with the movement or trapping of young animals. Larger groups were more common in summer and autumn. If larger group sizes improve the effectiveness of control operations then control would best be undertaken in autumn. Control operations in summer are not favoured due to the heat and the difficulty in moving goats long distances. Difficulties may also arise if trapping is an integral part of the control program as this region has a summer dominant rainfall pattern that can cause major disruptions to trapping operations due to temporary surface water.

Mustering and trapping programs conducted in this study removed a maximum of 3977 goats in what could be classified as one control operation. To achieve this, high density feral goat populations were targeted and efficient mustering programs conducted. Edwards *et al.* (1997) found that contract mustering followed by aerial culling was an effective method of control in the mulga woodlands of south-western Queensland. Ground based shooting was shown to be ineffective but Pople *et al.* (1996, 1998) reported that substantial reductions in goat numbers were achievable by shooting goats from helicopters. At low goat densities ($<1/km^2$) the majority of goats were shot whereas at high densities ($>5/km^2$) reductions between 49% and 75% were achieved.

Based on initial population estimates, the specific control program mentioned above removed a maximum of 32% of the regional population over an area of approximately 100,000 ha. To achieve substantial reductions in the total population size, the control effort must be maintained. However, as feral goat densities reduce, mustering efficiency decreases due to increased search time (Fig. 5) and mustering becomes uneconomic when goat densities are reduced to less than 1 goat per km^2 (Henzell 1984). Consequently, long-term control requires the integration of two or more control techniques.

Sustained control as practised in this study represents a more coordinated and planned level of control than usually occurs but may fall short of the level necessary to have a long-term significant impact on the population. If control is to be effective, it must be conducted over a large area. Given the independence of many landholders and the relative isolation of many properties, this requires a fundamental change in approach by many landholders if they wish to effectively reduce feral goat populations.

Impact

Despite several years of ongoing control, feral goats were still contributing up to 30% of total grazing pressure. If domestic stock and kangaroo numbers alone exceed the sustainable carrying capacity of the country, then feral goat control will achieve little improvement of land condition in the long-term.

On the northern sites, feral goats contributed less than 10% of the total grazing pressure. In this situation, further feral goat removal will only achieve a minor reduction in the overall grazing pressure for that area; kangaroo and domestic stock management would achieve a greater gain than further intensive goat control. On sites with excessive grazing pressure, any reduction in herbivore numbers (feral, domestic or native) must be welcomed, as it allows better control of grazing in an effort to operate within sustainable limits.

Accurate estimates of feral goat and kangaroo populations are very difficult for landholders without aerial surveys available to them. Researchers have used dung counts as an indirect method of estimating populations (Landsberg and Stol 1996), but this technique has not been developed for landholders. In the absence of data on feral goat and kangaroo numbers, estimates of total grazing pressure for a property is practically impossible for the landholder. More effective pasture-based indicators of grazing pressure need to be developed to allow landholders to judge when to manipulate grazing pressure and by how much it should be reduced.

Good seasonal conditions led to increased pasture biomass and improved soil condition changes at some of the sites. The sustained control and opportunistic control sites behaved similarly. The fact that the assessed condition of the pasture and soil did not differ between treatments is not surprising. Monitoring and feral goat control would have to be continued for a considerably longer period before substantial improvements in pasture and soil condition would be detected and before seasonal influences could be separated from the effects of reduced grazing pressure. Improvements may be expected first in areas of better soil in marginal grazing areas where goat removal would substantially reduce grazing pressure. Examples would include areas a long distance from permanent water points, and away from feral goat and kangaroo refuge areas such as 'jump-up' ranges and dense timber. Near refuge areas and in degraded areas with poor soil, any improvements will take much longer.

Economic considerations

This study provides a snapshot of some of the costs and benefits of feral goat management. It was not possible to undertake a full cost benefit analysis of feral goats due to a lack of data.

Prices for feral goats during 1997 ranged from $16 to $25 per head on-farm, making it quite profitable to muster and trap feral goats. However, the rate of feral goat capture in mustering programs is low (about 30-40% in Parkes *et al.* 1996; 17-41% in this study). Feral goats compete with domestic stock for pasture because of dietary overlap, and for other resources such as water and shelter (Henzell 1989). The degree of competition will depend on pasture productivity and the actual dietary overlap. These factors must be considered when comparing returns from feral goats with domestic stock. Using a hypothetical case study, Thompson *et al.* (1999) found that competition with domestic stock reduced the apparent windfall gain from the sale of feral goats by 38%. Factors which influenced this reduction included: feral goat price; cost of capture; domestic stock gross margin; dietary overlap; range overlap; and the proportion of goats removed.

The main benefit from feral goats is the income received from their sale. Historically, feral goat prices have been quite volatile. The yearly average price was relatively stable through the 1980s and bottomed in 1993 at under $5 per head. However, after 1993 there was a rapid increase in prices, for example, about $34 per head on-farm in November 1998. Since then, prices have been around $25-$35 per head. The continued high prices for feral goats is attributable to strong demand from overseas, greater competition between goat buyers and between abattoirs, and reduced supply of feral goats as a result of prolonged harvesting in response to good prices.

Feral goat densities were not reduced to low levels during the project. Landholders only spent a relatively small amount of time managing feral goats (2–4%) compared to other activities. Landholders should be encouraged to spend more time and effort catching feral goats while it is highly profitable to do so.

Feral goat management is becoming increasingly important as grazing as an enterprise becomes more difficult due to decreasing farmer's terms of trade, and an increased environmental responsibility being placed on landholders by the broader community.

Between 150,000 and 160,000 feral goats per year have been harvested from south-western Queensland in recent years (with some estimates as high as 200,000 in some years). Given the above estimates, feral goat harvesting in south-western Queensland provides between $3m and $5m directly to graziers each year. While relatively small in comparison to the wool and beef industries, this is significant considering the poor seasonal conditions and reduced financial performance of wool and beef over the life of the project. The benefits to the local community are even greater from the jobs created at the local abattoirs, actions of the local feral goat buyers and associated flow-on effects.

Social aspects

Few landholders recognised the *terms* 'total grazing pressure' and 'safe carrying capacity' at the commencement of the study. However, the *concepts* were well understood by most landholders. Many were particularly concerned about the presence of feral goats and the impact these have on the number of domestic stock the land can carry. However, opinions varied widely about the extent of the feral goat problem. Some landholders wanted to eradicate all goats and considered them a pest, others saw them as a financial resource, and still others dismissed them as not posing any problems.

While landholders have accurate estimates of the domestic stock on their property, they have no tools available to enable them to accurately estimate the populations of feral goats and kangaroos on their land. They tend to underestimate the numbers of feral goats on their properties. This makes effective management of grazing pressure extremely difficult. Practical indicators of grazing pressure are needed to allow landholders to judge when to manipulate the feral and native herbivores, and domestic stock populations on their property.

Variability in price, coupled with traditional attitudes to grazing enterprises, contributed to landholders being apprehensive about the viability of the feral goat industry compared with existing enterprises. Increasing prices and a more reliable market in the 1990s encouraged landholders to see the profits to be made from feral goats. However, many landholders view the commercial return from feral goats as a simple bonus and do not try to balance overall animal numbers by reducing domestic stock numbers (Pickles 1992).

Personal circumstances and preferences were a key determinant for the level of feral goat control and in many cases the opportunity to make money was not fully realised because of those preferences. Examples included taking holidays instead of mustering goats, shooting rather than selling goats, and people liking cattle and sheep more than goats.

All participants agreed that reducing numbers and reducing problems caused by feral goats should be the overall objective of feral goat management. A key understanding gained by landholders during the project was that more-intensive management was needed to maintain numbers at the existing level than was previously believed necessary.

As landholder opinions vary considerably, they will only adopt management strategies and options if these are flexible enough to meet a range of situations. The initial step is joint definition of the problem by all parties, before considering options for management in that situation. Therefore, a statewide prescription for managing feral goats is unlikely to be effective. The suite of options would need to allow for unexpected or divergent factors, such as variable markets or weather conditions as highlighted in other situations (e.g. Jiggins 1993).

Conclusion

Feral goats are likely to remain a permanent component of the total grazing pressure of the pastoral rangelands of south-western Queensland. On the basis of this and other studies, opportunistic harvesting of feral goats will not result in regional or local eradication of feral goats. The sustained control effort conducted in this project was also unsuccessful in reducing feral goat populations on a regional scale. Local, short-term reductions were achieved via intensive harvesting, but these would have to be replicated in time and space to achieve a greater degree and extent of control. This project has highlighted the problems associated with attempting to achieve that goal. In particular, it is difficult to coordinate control activities between landholders over an area of 100,000 ha, particularly when feral goat control is assigned a low priority activity compared with other property management.

The failure to significantly reduce feral goat populations even under sustained control effort has implications for land managers and government. The responsibility of government is to work with industry to provide appropriate management advice and a practical policy framework. The starting point for this is for feral goats to be regarded as a component of the total grazing system that must be managed rather than a pest that can be eradicated.

Landholders in the area now have better knowledge of the effectiveness of control techniques and the impact of control operations on a local and regional scale. However, they lack the resources to regularly monitor populations and only have circumstantial evidence of the movement patterns of feral goats. The tools for control are known. The next major hurdle to overcome is to develop ways to utilise these tools efficiently and effectively, to reduce regional populations. Accompanying this, the impact of feral goats on the land resource and the effects of competition with domestic stock should be calculated in financial terms. Landholder participation is essential in establishing a process to improve feral goat management.

Degraded areas require the opportunity to regenerate. Grazing pressure must be managed, as domestic stock, kangaroos and feral goats will be attracted to areas of young plant growth. Areas which are solely grazed by one of these groups are extremely rare, so any grazing pressure management must be approached in an integrated manner.

Sustainable feral goat management is not a system that can be exactly described for any particular property. The goals for feral goat management on individual properties also change with changing circumstances. Cox *et al.* (1997) argue that sustainability cannot be described as a system or a goal, and they highlight the importance of processes by which people learn how to improve the situation. This is quite appropriate for feral goat management in south-western Queensland.

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