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Managing feral goat impacts by manipulating their access to water in the rangelands

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Abstract. Feral goats are a significant threat to biodiversity in Australia. However, goats are also harvested by some landholders for commercial benefit and this can lead to disagreements regarding control techniques. In the rangelands of New South Wales, feral goat distribution is closely linked to artificial watering points (AWP) such as tanks and bores. Previous surveys indicated that goat activity was rare more than 4 km from water. We hypothesised that constructing sections of goat-proof fencing in areas where goats were feeding on National Parks but watering on neighbouring properties, such that they had to travel more than 4 km from the AWP to access the park, would result in a significant decrease in goat abundance in these areas. We tested this hypothesis in Paroo-Darling National Park, Gundabooka State Conservation Area and Gundabooka National Park using changes in index (fresh goat dung groups per 100-m transect). We also measured kangaroo dung and ground cover index changes. Twelve months after the fences were constructed, goat dung significantly declined compared with non-treatment areas and the relationship between distance to water and goat dung broke down at the treatment sites. Kangaroo indices were not affected by the fences. The results for bare ground were the same as for goat dung, with significantly less bare ground and a breakdown in the relationship with distance to water at the treatment sites after the fences were constructed, but this was due to a corresponding increase in litter rather than live vegetation. This technique can be a significant tool for protecting biodiversity from feral goats, without removing the potential for neighbouring landholders to harvest the goats. If strategically used to create zones free of resident goats around the boundaries of conservation reserves, it should increase the effectiveness of other techniques such as trapping, mustering and shooting, by reducing post-control reinvasion. Recognition of access to water as an important management tool should substantially improve our management of feral goats in the rangelands.

Additional keywords: exclusion fencing, invasive species, pest animal management.

Introduction

Feral goats *Capra hircus* are a major threat to biodiversity in Australia and are listed as a key threatening process under the commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (E. P. B. C. Act 1999). They are also listed as a key threatening process in New South Wales under the *Threatened Species Conservation Act 1995* (T. S. C. Act 1995) and are thought to impact 94 entities (species, populations and endangered ecological communities) listed under this legislation (Coutts-Smith *et al*. 2007).

Grazing and browsing by feral goats has significant impacts on native vegetation in the rangelands (Harrington 1976, 1986; Greene *et al*. 1998). This is because of the relatively high densities of feral goats in the environment (West and Saunders 2007) and because feral goats feed differently to native herbivores such as kangaroos, which have evolved with native plant species over millions of years, both in terms of the species they consume and the way they feed upon them (Parkes *et al*. 1996). This can lead to changes in species composition as more palatable species are eaten and removed, as well as changes in vegetation structure (Wilson *et al*. 1976; Harrington 1976, 1986; Henzell 1992; Landsberg and Stol 1996). Areas with a high density of goats have a conspicuous browse line, as all foliage within their reach is consumed (Henzell 1990, 1992). Provided sufficient water is available, feral goats can survive on highly fibrous, low nutrient herbage, and will consume litter, fruit fall, bark and sticks (Harrington 1976, 1986; Squires 1980, 1982). This can lead to a decrease in overall cover and an increase in bare ground, which, combined with trampling and soil surface damage caused by their hooves, may result in significant increases in soil erosion

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(Eldridge and Greene 1994; Bayne *et al*. 2004). These habitat changes in turn affect native fauna, which may also be impacted by feral goats through competition for food and shelter (Dawson and Ellis 1979, 1996; Lim and Giles 1987; Henzell 1990; Short and Milkovits 1990; Murphy 1996).

Despite these negative aspects of feral goats, they are seen as a resource by some landholders, who harvest them for commercial benefit (Allen *et al*. 1995; Chapman 2003; Bellchambers 2004; Forsyth and Parkes 2004; Forsyth *et al*. 2009). While this practice has led to a reduction in feral goat numbers in many areas, the aim is typically to maintain goats at a level where they continue to contribute to the economic prosperity of the landholder (Elliott and Woodford 1995; Forsyth and Parkes 2004; Forsyth *et al*. 2009). This is in contrast to conservation reserves and other environmentally sensitive areas, where eradication or suppression at very low levels is the goal. This dichotomy in the aims and outcomes of goat management strategies can lead to disagreement regarding the development of regional programs to manage goat populations, particularly when the use of lethal control techniques such as ground shooting and aerial shooting are suggested (Choquenot *et al*. 1995; Parkes *et al*. 1996).

Feral goats are widespread across New South Wales, but their distribution and ecology changes from east to west (West and Saunders 2007). In eastern New South Wales where rainfall is higher, they live in isolated high density populations with small home ranges and can acquire their water requirements from forage (Fleming 2004; West and Saunders 2007). In contrast, in the arid and semiarid rangelands of western New South Wales their populations are contiguous (West and Saunders 2007) although lower in density with larger home ranges (Freudenberger and Barber 1999) and they must drink regularly to meet their water requirements (Sarawaswat and Sengar 2000). The proliferation of artificial watering points (AWP) such as ground tanks and bores for watering stock in western New South Wales has allowed feral goats to expand further than would otherwise be the case (Fensham and Fairfax 2008). AWP function as invasion hubs for invasive animals that require access to drinking water (Florance *et al*. 2011). Focusing control efforts such as trapping, mustering and shooting around AWP can rapidly remove large numbers of goats (Edwards *et al*. 1997; Fleming *et al*. 2005). However, the effectiveness of these programs tends to be short term because the contiguous dispersion of the western New South Wales goat populations allows rapid reinvasion (Sharp *et al*. 1999).

Surveys conducted in Nocoleche Nature Reserve and Mutawintji National Park in 2006 indicated goat activity decreased as distance to water increased and was rare more than 4 km from water (M. Letnic, B. G. Russell, P. J. S. Fleming, and J. Tracey, unpubl. data). This was in contrast to native species of kangaroos, where no such pattern was evident. Montague-Drake and Croft (2004) similarly did not detect any relationship between kangaroos and AWP. Based on these results, we hypothesised that localised goat distribution could be altered by manipulating their access to water, without impacting upon kangaroo dispersion. To test this hypothesis, we erected discrete sections of goat-proof boundary fencing in National Parks where AWP were situated close by on adjacent pastoral land predominantly used for sheep grazing. Feral goats feeding on-park were suspected of drinking from these off-park AWP. Once the fences were erected, the goats would have to travel more than 4 km to access the National Park after drinking from the AWP, and if our hypothesis was correct, would be unlikely to return to these areas. We used changes in indices, calculated from goat dung, to evaluate the effectiveness of this strategic boundary fencing in manipulating feral goat distribution. We also looked at dung indices for kangaroos to see if they were affected by the fences and at ground cover indices to determine if there were any flow-on effects from the expected decrease in goat grazing activity.

Methods

Study sites

The study was conducted at the Peery section of Paroo-Darling National Park, Gundabooka National Park and Gundabooka State Conservation Area. All three conservation reserves are located in the rangelands of north-western New South Wales.

The Peery section of Paroo-Darling National Park covers 92 144 ha and is located ~30 km east of White Cliffs and 80 km north of Wilcannia 32°18′–32°40′S, 142°10′–142°25′E (NPWS 2009). The climate is arid with average annual rainfall of 250 mm (Bureau of Meteorology 2010). During the course of the study, the annual rainfall at nearby White Cliffs was 251 mm in 2008 and 148 mm in 2009 (Bureau of Meteorology 2010). Temperatures are high in summer and mild in winter with average daily maxima of 35°C in January and 17°C in July and average daily minima of 21°C in January and 4°C in July (NPWS 2009). Located in the Mulga Lands Bioregion, the vegetation is predominantly open and shrubby woodlands dominated by mulga *Acacia aneura*, red box *Eucalyptus intertexta*, leopardwood *Flindersia maculosa*, black oak *Casuarina pauper*, whitewood *Atalaya hemiglauca* and beefwood *Grevillea striata*, with gallery woodlands along creeklines and around Peery and Poloka lakes dominated by river red gum *Eucalyptus camaldulensis*, black box *Eucalyptus largiflorens*, bimble box *Eucalyptus populnea* spp. *bimble*, Yapunyah *Eucalyptus ochrophloia* and river cooba *Acacia stenophylla* (Westbrooke *et al*. 2003).

Gundabooka State Conservation Area and Gundabooka National Park are adjoining conservation reserves covering 89 103 ha (NPWS 2005). They are located ~50 km south-west of Bourke, 110 km north-west of Cobar and 60 km east of Louth (30°35′–31°2′S, 143°17′–143°40′E) (NPWS 2005). The climate is semiarid with average annual rainfall of 350 mm (Bureau of Meteorology 2010). During the course of the study the annual rainfall was 262 mm in 2008 and 410 mm in 2009 (Bureau of Meteorology 2010). Temperatures are high in summer and mild in winter with average daily maxima of 34°C in January and 16°C in July and average daily minima of 21°C in January and 5°C in July (NPWS 2005). Located in the Cobar Peneplain Bioregion, the vegetation of the reserves consists of intergrading open woodland communities. Dominant species include mulga, bimble box, red box, ironwood *Acacia excelsa*, white cypress pine *Callitris columellaris*, belah *Casuarina cristata*, leopardwood, western bloodwood *Corymbia terminalis*, and grey mallee *Eucalyptus morrisii* in various associations (NPWS 2005).

Feral goats are common in all three conservation reserves (NPWS 2005, 2009; West and Saunders 2007). Traditionally, mustering by external contractors has been the main form of goat control on all three reserves. These mustering programs continued unchanged throughout the course of the project.

Fences

Eight-kilometre goat-proof fences (see below for specifications) were erected along the boundaries of Paroo-Darling National Park (Fig. 1*a*) and Gundabooka National Park (Fig. 1*b*), such that the goats had to travel more than 4 km from water to access the park. An additional 15-km fence was erected, starting along the boundary of Gundabooka State Conservation Area and continuing along the boundary of Gundabooka National Park, where several AWP were close together on the neighbouring property, such that each end of the fence was ~4 km from the nearest AWP (Fig. 1*b*). As feral goats readily pass through the normal plain-wire stock fencing commonly used in these areas, the fences were constructed using 8–90–30 hingejoint with a barbed wire strung 20 cm above the top of the hingejoint, with a maximum of 10 m between the supporting steel star pickets.

Data collection

The effectiveness of the boundary fences was evaluated through dung and ground cover indices undertaken along 100-m transects. Dung counts are frequently used as an index of abundance and grazing activity by herbivores including goats and have been shown to correlate with actual densities (Landsberg *et al*. 1994; Landsberg and Stol 1996). Transects were spaced every 500 m along both sides of the fence (on-park and off-park). The transects were roughly perpendicular to the fence and the start and end of each transect was marked with an aluminium fence dropper and the location recorded with a GPS. For each survey, a rope was extended along the length of the transect and all fresh black dung within 1 m either side of the rope was identified to species according to Landsberg *et al*. (1994) and Triggs (1984), and the number of dung groups and the total number of pellets per 100-m transect were recorded. A dung group was defined as a single depositional event, where pellets of the same size, species and freshness occurred within a distinct group. Red kangaroo *Macropus rufus*, eastern grey kangaroo *M. giganteus*, western grey kangaroo *M. fuliginosus* and euro *M. robustus* dung could not be reliably differentiated and so the results for these four species were pooled. The rope was marked at 5-m intervals and the ground cover directly beneath each mark was recorded as either bare ground, grass, forb, litter, log, shrub or tree.

Dung and ground cover surveys were conducted in spring 2008, before the fences were erected, and again in spring 2009 after the fences were erected. For comparison, non-treatment transects were also established along equivalent sections of boundary fence with AWP on the adjacent property where goat-proof fencing was not erected (Figs 1 and 2).

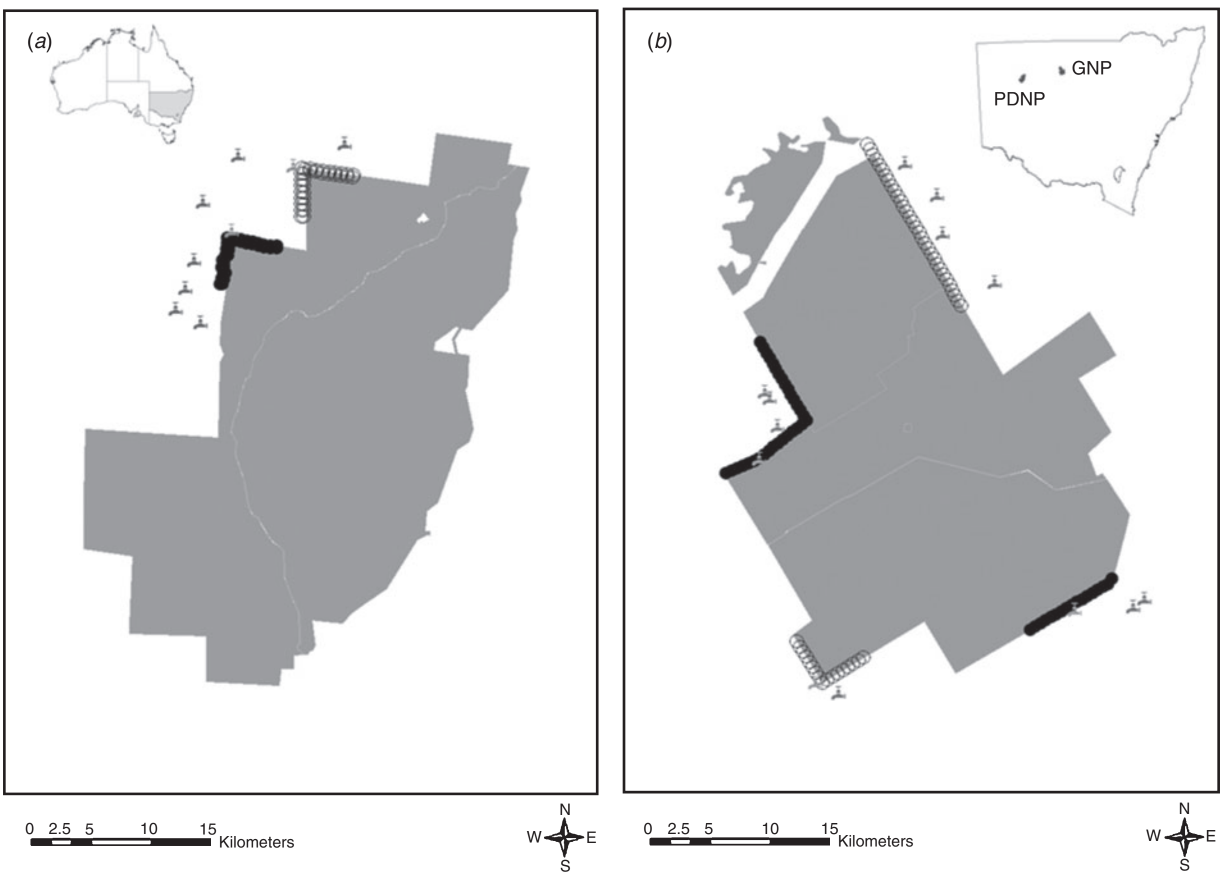

Fig. 1. Location of goat-proof fences (black) and comparison areas (open) relative to relevant neighbouring artificial watering points (taps) within (*a*) the Peery section of Paroo-Darling National Park and (*b*) Gundabooka State Conservation Area and Gundabooka National Park. Location of reserves within New South Wales inset right, location of New South Wales within Australia inset left.

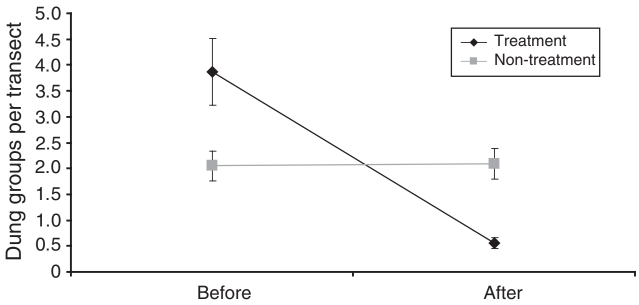

Fig. 2. Mean ± s.e. number of fresh goat dung groups per transect in the treatment and non-treatment sites before (spring 2008) and after (spring 2009) the goat-proof fences were erected at the treatment sites.

Treatment and non-treatment sites were paired in the analysis. At Gundabooka, the two sets of paired sites (northern and southern) were treated as independent. This was based on local differences in rainfall caused by Mount Gunderbooka arising between the two sites and differences in vegetation, with the southern sites being entirely covered by red soil woodlands, while the northern sites intergraded between red soil woodlands and alluvial black soil woodlands.

Data analysis

The data were analysed using a mixed-model ANOVA in SAS Enterprise Guide. There were four fixed factors and all interaction terms between the four factors; distance to water as calculated using ArcGIS 9.3 (ESRI 2008), on- or off-park, before or after the fences were built and treatment or non-treatment. Site (Peery, north Gundabooka and south Gundabooka) was included in the analysis as a random factor.

Results

Dung indices

Only the results for dung groups are presented, as analyses of dung groups and total dung revealed the same significant results for both goats and kangaroos.

The analysis of the goat dung groups revealed four significant results; distance to water, before/after, a before/after × treatment interaction, and a before/after × treatment × distance to water interaction (Table 1). Figure 2 illustrates the before/after × treatment interaction, showing that the number of goat dung groups per transect significantly decreased at the sites where the fences were built, but did not change at the non-treatment sites. Overall, there was a negative relationship between goat dung and distance from water, such that the number of dung groups per transect were higher closer to water and lower further from water. However, this relationship broke down at the treatment sites after the fences were built (Fig. 3).

The only significant variable from the analysis of kangaroo dung groups was treatment (Table 2), as there were more kangaroo dung groups at the treatment sites than the non-treatment sites, however there was no before/after × treatment interaction, i.e. the goat-proof fences did not affect kangaroo numbers.

Table 1. Mixed-model ANOVA of effects of fixed variables on indices of goat abundance and activity (number of goat dung groups per transect)
Variables were: distance to water; location on- or off-park; time – before or after the treatment was applied; treatment (goat-proof fencing) or non-treatment (standard stock fence); and all interactions between these four factors. Num DF, Numerator degrees of freedom; Den DF, denominator degrees of freedom. Numbers in bold indicate significant results at the $P = 0.05$ level

Effect	Num DF	Den DF	*F*-value	Pr > *F*
Distance to water (dtw)	1	508	9.04	**0.0028**
On or off (oo)	1	508	0.06	0.8023
Before or after (ba)	1	508	7.42	**0.0067**
Treatment	1	508	2.21	0.1381
dtw*oo	1	508	0.11	0.7453
dtw*ba	1	508	1.35	0.2461
dtw*treatment	1	508	2.56	0.1106
oo*ba	1	508	1.58	0.2098
oo*treatment	1	508	0.27	0.6013
ba*treatment	1	508	14.32	**0.0002**
dtw*oo*ba	1	508	0.56	0.4557
dtw*oo*treatment	1	508	0.78	0.3784
dtw*ba*treatment	1	508	5.00	**0.0257**
oo*ba*treatment	1	508	0.00	0.9562
dtw*oo*ba*treatment	1	508	0.00	0.9828

Ground cover

There was a mean of ~5% more bare ground off-park than on-park both before and after the fences were erected (Table 3). Apart from this, the results for bare ground mirrored those for goat dung, with distance to water, before/after and the before/after × treatment × distance to water interaction being significant (Table 3). As with goat dung, there was a negative relationship with distance to water, which broke down at the treatment sites after the fences were built (Fig. 4).

Although there was a significant positive relationship between the amount of grass and distance to water, there was not a before/after × treatment interaction (Table 4), i.e. the distribution of grass was not affected by the fences within the 12 months following fence construction. However, for litter there was both a before/after × treatment interaction and before/after × treatment × distance to water interaction (Table 5). After the fences were built, the amount of litter increased at the treatment sites, but remained the same at the non-treatment sites and the positive relationship between distance to water and the amount of litter broke down at the treatment sites (Fig. 5).

Discussion

These results clearly show that feral goat dispersion and distribution in the rangelands are affected by their proximity to water and that feral goat numbers can be significantly reduced at a local scale by manipulating their access to AWP. This technique was successful in reducing goat numbers both in an arid area during a period of below-average rainfall (Peery), and in a semiarid area during a period of above-average rainfall (Gundabooka). We contend that this technique can be a significant tool for protecting biodiversity from the impacts of feral goats.

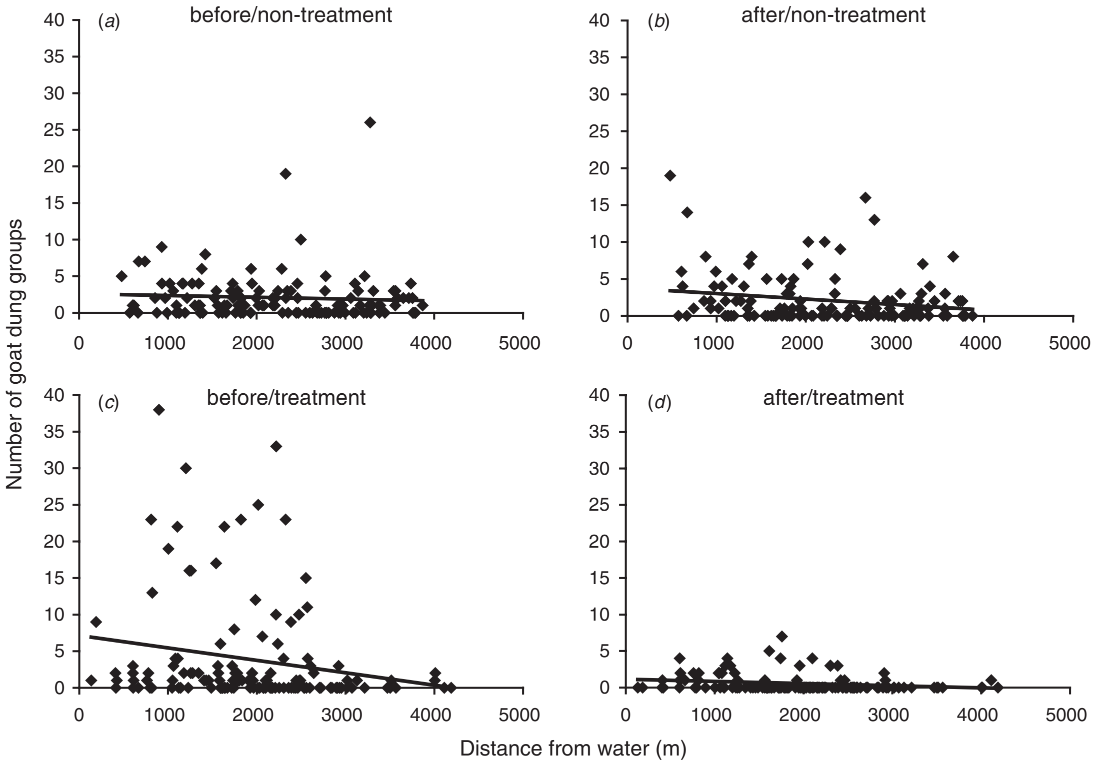

Fig. 3. Scatterplots and linear trendlines for the effects of distance to water on indices of goat activity and abundance (number of fresh goat dung groups per transect) at; (*a*) the non-treatment sites before the goat-proof fences were erected, (*b*) the non-treatment sites after the goat-proof fences were erected, (*c*) the treatment sites before the goat-proof fences were erected, and (*d*) the treatment sites after the goat-proof fences were erected.

Table 2. Mixed-model ANOVA of effects of fixed variables on indices of kangaroo abundance and activity (number of kangaroo dung groups per transect)

Variables were: distance to water; location on- or off-park; time – before or after the treatment was applied; treatment (goat-proof fencing) or non-treatment (standard stock fence); and all interactions between these four factors. Num DF, Numerator degrees of freedom; Den DF, denominator degrees of freedom. Numbers in bold indicate significant results at the $P = 0.05$ level

Effect	Num DF	Den DF	*F*-value	Pr > *F*
Distance to water (dtw)	1	508	3.21	0.0739
On or off (oo)	1	508	0.00	0.9468
Before or after (ba)	1	508	0.07	0.7921
Treatment	1	508	3.87	**0.0498**
dtw*oo	1	508	0.31	0.5784
dtw*ba	1	508	2.62	0.1064
dtw*treatment	1	508	1.38	0.2398
oo*ba	1	508	0.20	0.6578
oo*treatment	1	508	0.00	0.9930
ba*treatment	1	508	3.35	0.0678
dtw*oo*ba	1	508	0.08	0.7781
dtw*oo*treatment	1	508	0.08	0.7740
dtw*ba*treatment	1	508	1.43	0.2321
oo*ba*treatment	1	508	0.03	0.8593
dtw*oo*ba*treatment	1	508	0.10	0.7533

Table 3. Mixed-model ANOVA of effects of fixed variables on the amount of bare ground (number of bare ground points per transect)

Variables were: distance to water; location on- or off-park; time – before or after the treatment was applied; treatment (goat-proof fencing) or non-treatment (standard stock fence); and all interactions between these four factors. Num DF, Numerator degrees of freedom; Den DF, denominator degrees of freedom. Numbers in bold indicate significant results at the $P = 0.05$ level

Effect	Num DF	Den DF	*F*-value	Pr > *F*
Distance to water (dtw)	1	508	9.50	**0.0022**
On or off (oo)	1	508	5.64	**0.0179**
Before or after (ba)	1	508	15.00	**0.0001**
Treatment	1	508	0.40	0.5283
dtw*oo	1	508	1.49	0.2226
dtw*ba	1	508	1.17	0.2809
dtw*treatment	1	508	0.33	0.5677
oo*ba	1	508	1.80	0.1802
oo*treatment	1	508	0.40	0.5269
ba*treatment	1	508	1.94	0.1646
dtw*oo*ba	1	508	2.47	0.1168
dtw*oo*treatment	1	508	0.19	0.6590
dtw*ba*treatment	1	508	5.58	**0.0186**
oo*ba*treatment	1	508	0.12	0.7281
dtw*oo*ba*treatment	1	508	0.43	0.5120

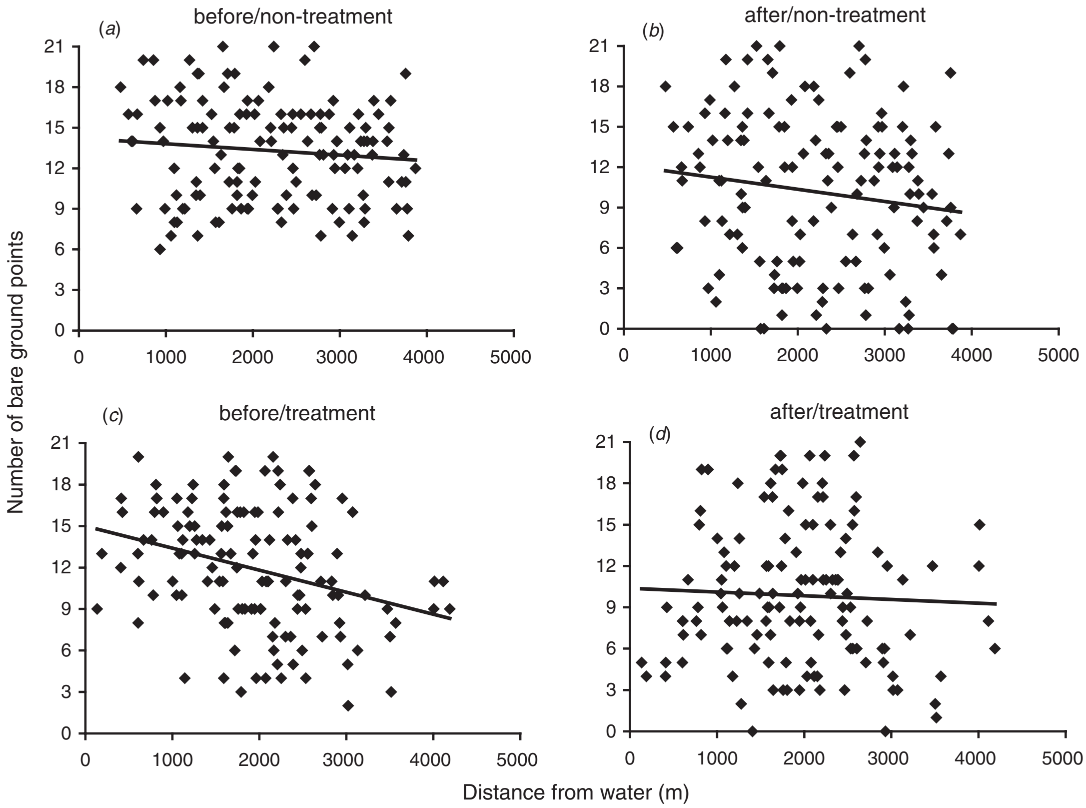

Fig. 4. Scatterplots and linear trendlines for the effects of distance to water on the amount of bare ground (number of bare ground points per transect) at; (*a*) the non-treatment sites before the goat-proof fences were erected, (*b*) the non-treatment sites after the goat-proof fences were erected, (*c*) the treatment sites before the goat-proof fences were erected, and (*d*) the treatment sites after the goat-proof fences were erected.

Table 4. Mixed-model ANOVA of effects of fixed variables on grass cover (number of grass points per transect)

Variables were: distance to water; location on- or off-park; time – before or after the treatment was applied; treatment (goat-proof fencing) or non-treatment (standard stock fence); and all interactions between these four factors. Num DF, Numerator degrees of freedom; Den DF, denominator degrees of freedom. Numbers in bold indicate significant results at the $P = 0.05$ level

Effect	Num DF	Den DF	*F*-value	Pr > *F*
Distance to water (dtw)	1	508	15.38	**<0.0001**
On or off (oo)	1	508	0.06	0.8106
Before or after (ba)	1	508	2.47	0.1166
Treatment	1	508	3.36	0.0673
dtw*oo	1	508	0.01	0.9214
dtw*ba	1	508	0.37	0.5457
dtw*treatment	1	508	34.51	**<0.0001**
oo*ba	1	508	0.00	0.9985
oo*treatment	1	508	0.78	0.3764
ba*treatment	1	508	0.84	0.3608
dtw*oo*ba	1	508	0.07	0.7954
dtw*oo*treatment	1	508	0.72	0.3955
dtw*ba*treatment	1	508	1.01	0.3147
oo*ba*treatment	1	508	0.34	0.5625
dtw*oo*ba*treatment	1	508	0.52	0.4703

Table 5. Mixed-model ANOVA of effects of fixed variables on the amount of litter (number of litter points per transect)

Variables were: distance to water; location on- or off-park; time – before or after the treatment was applied; treatment (goat-proof fencing) or non-treatment (standard stock fence); and all interactions between these four factors. Num DF, Numerator degrees of freedom; Den DF, denominator degrees of freedom. Numbers in bold indicate significant results at the $P = 0.05$ level

Effect	Num DF	Den DF	*F*-value	Pr > *F*
Distance to water (dtw)	1	508	2.27	0.1324
On or off (oo)	1	508	3.23	0.0731
Before or after (ba)	1	508	0.99	0.3203
Treatment	1	508	2.97	0.0853
dtw*oo	1	508	1.92	0.1669
dtw*ba	1	508	0.21	0.6438
dtw*treatment	1	508	8.06	**0.0047**
oo*ba	1	508	0.19	0.6665
oo*treatment	1	508	0.05	0.8247
ba*treatment	1	508	12.60	**0.0004**
dtw*oo*ba	1	508	0.06	0.8108
dtw*oo*treatment	1	508	0.15	0.7028
dtw*ba*treatment	1	508	7.87	**0.0052**
oo*ba*treatment	1	508	0.64	0.4224
dtw*oo*ba*treatment	1	508	2.30	0.1297

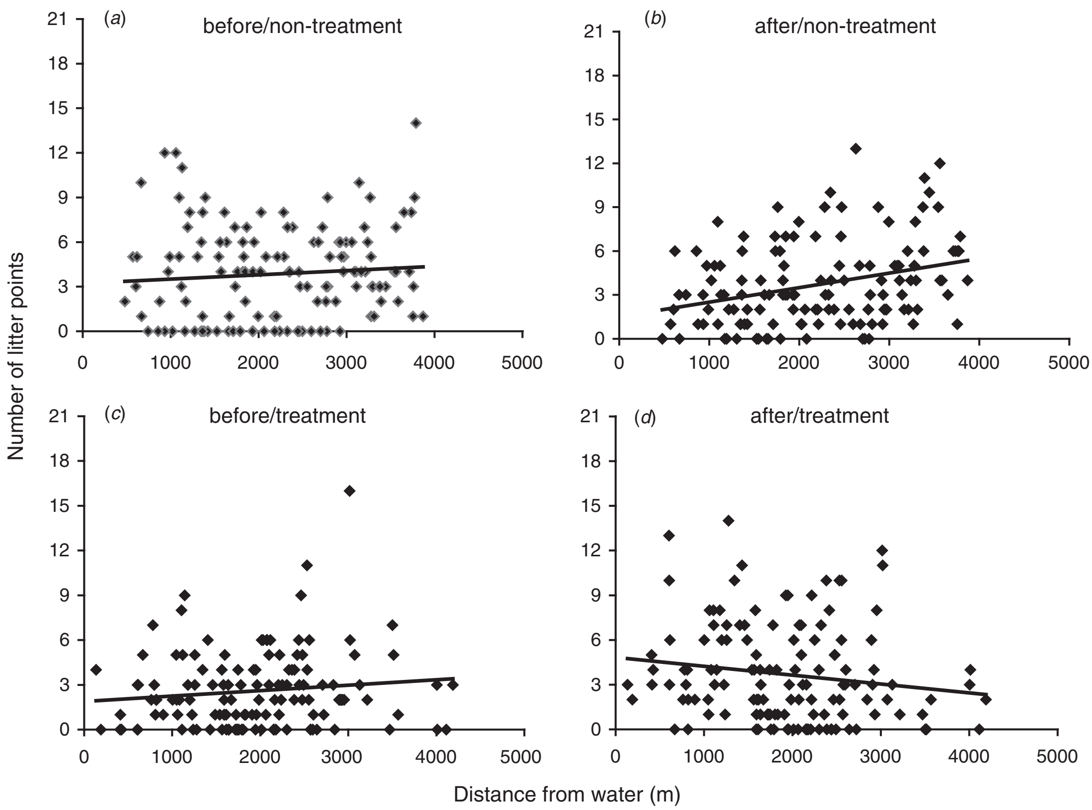

Fig. 5. Scatterplots and linear trendlines for the effects of distance to water on the amount of litter (number of litter points per transect) at; (*a*) the non-treatment sites before the goat-proof fences were erected, (*b*) the non-treatment sites after the goat-proof fences were erected, (*c*) the treatment sites before the goat-proof fences were erected, and (*d*) the treatment sites after the goat-proof fences were erected.

The ground cover surveys showed that within 12 months, the environment was already responding to the reduction in goat numbers. Relationships between distance to water and ground cover have been observed in past studies (James *et al*. 1999; Friedel *et al*. 2003; Landsberg *et al*. 2003). The relationship between distance to water and grass cover follows the same pattern as for goat dung, suggesting that goats (and possibly other introduced ungulates) are responsible, rather than kangaroos that did not exhibit this pattern. However, the lack of response from grass after only a 12-month reduction in goat density was unsurprising, considering some authors have suggested that recovery from ungulate grazing in these rangeland environments may take more than a decade (Meissner and Facelli 1999; Friedel *et al*. 2003; Montague-Drake and Croft 2004; Croft *et al*. 2007).

Despite no response in living vegetation (grasses, shrubs, herb/forbs or trees) being detected, there was an increase in litter and a corresponding decrease in bare ground. This was likely caused by reduced goat feeding on litter, as well as reduced feeding on living browse before it could fall and accumulate as litter (Dawson *et al*. 1975; Squires 1980; Harrington 1986; Dawson and Ellis 1996). Increased litter is the first stage in recovery from goat impacts. It should provide better seed germination conditions than bare ground and improved landscape function in terms of nutrient capture and retention (Facelli and Pickett 1991), leading to increased living vegetation cover in the future (Ludwig *et al*. 1997).

The close correspondence between the results of the goat dung surveys and the ground cover surveys strongly indicates that the two sets of results are complementary. In contrast, kangaroo density was not affected by the fences and showed no relationship with distance to water up to the 4 km considered in this study. Montague-Drake and Croft (2004) similarly found no relationship between proximity to water and kangaroo density. The most obvious reason for this dichotomy is that goats have a higher water requirement than kangaroos (Dawson *et al*. 1975). However, it may also be due to differences in the energetic costs associated with moving to and from water, with kangaroos able to move between their feeding-resting and watering sites with the high energy efficiency of moderate speed hopping relative to quadrupedal ungulates such as goats (Dawson and Taylor 1973; Priddle 1987; Montague-Drake and Croft 2004).

Management implications

This non-lethal technique reduces goat impacts on conservation reserves, without removing the potential for neighbouring landholders to harvest the goats. As such, it is likely to be viewed favourably by neighbours who view goats as a resource, when compared with lethal control techniques such as ground and aerial shooting, and reduce the level of conflict over conservation-based goat control programs (Choquenot *et al*. 1995; Parkes *et al*. 1996). However, consideration should be given to how feral goats are redistributed on these neighbouring properties. Although the fences reduced goat numbers along the boundary, there was not an increase in goat dung groups along the goat-proof fence on the side closest to the AWP. Rather, goat dung groups were reduced on either side of the fence equally. Although it is possible there was a reduction in goat activity either side of the goat-proof fence associated with the disturbance caused by their construction, it is unlikely this disturbance was responsible for the lower goat indices 8 months later, when the post-construction surveys were conducted. Within 2 weeks of their construction, each of the fences was checked to ensure quality before payment of the contractor. At this time, mobs of goats were seen immediately adjacent to the fence on the off-park side of the fence. Approximately 8 months later, when the transect surveys were conducted, the tracks from these goats were still visible, as they had worn a pad along the off-park side of the fence, but no goats were seen and significantly less fresh dung was found on the transects than before the fences were constructed. This would indicate that after this initial period when their regular pattern of feeding on-park but watering off-park was disrupted, they established a new pattern in a different direction relative to the AWP.

Presumably, feral goat foraging will move to the best available habitat on the off-park side of the fence that is close enough for them to utilise the AWP. It is possible that the reduction in goat activity directly adjacent to the fence on the off-park side could lead to an increase in the quality of this habitat for goats, and they could return to the off-park side of the fence in the future. However, in the short term it appeared that they had moved to other parts of the adjacent pastoral properties. Under such circumstances, neighbouring landholders may need to consider not only the potential increase in goats on their property, but also to where goats are likely to shift their feeding.

These lands are predominantly used for sheep grazing, so it is worth considering the impacts that these additional goats could have on enterprise operation. Although goats and sheep have different dietary preferences, when resources become limited, as during the 2001–10 drought in western New South Wales, the degree of overlap increases (Dawson *et al*. 1975; Harrington 1986; Dawson and Ellis 1996). Bare ground was greater off-park than on-park both before and after the fences were constructed, presumably caused by the additional grazing of sheep as well as goats and kangaroos on the neighbouring pastoral properties. The further pressure of an influx of extra goats could lead to loss of landscape condition and productivity (Harrington 1986; Elliott and Woodford 1995). Goats could potentially displace sheep from formerly productive grazing country as goats can remain in the landscape after it has become unsuitable for sheep (Harrington 1986; Parkes *et al*. 1996). Therefore, the level of harvesting of goats displaced from conservation reserves must be carefully considered in the context of protecting the productive value of the land and not just the direct financial benefit from their sale (Allen *et al*. 1995; Choquenot *et al*. 1995; Forsyth and Parkes 2004).

This study has shown that feral goat numbers can be significantly reduced at a local scale by using fences to manipulate their access to AWP. Assuming the fence is effective in lowering goat abundance in the longer term, this technique also has the potential to be used strategically to counter the larger problem for goat management in the rangelands of rapid reinvasion following other control programs (Edwards *et al*. 1997; Sharp *et al*. 1999). Immigration into conservation reserves will take place where watering points are close to the boundary. By closing on-park AWP within 4 km of the boundary and strategically fencing where off-park AWP are within 4 km, a boundary zone can be created without any resident goats. Subsequent on-park control programs using techniques such as trapping, mustering or shooting (Edwards *et al*. 1997; Fleming *et al*. 2002) should then achieve a longer-term reduction in goat numbers, as the area adjacent will be free of resident goats. Reinvasion will depend on the natural increase of the remaining goats and recruitment of occasional transients that pass through the boundary zone, rather than the sink created by the removal of the goats being filled from the high density of resident goats in the adjacent areas (Sharp *et al*. 1999).

The development of boundary zones should allow for significantly lower feral goat population levels to be achieved in conservation reserves throughout the rangelands. One of the advantages of this technique is that AWP inside the boundary zone can be retained where required for maintenance (e.g. roads) and infrastructure (e.g. residential water supply) (Croft *et al*. 2007). They can also be used in the construction of goat traps (Bellchambers 2004) to increase the initial effectiveness of the goat control program inside the boundary zone and capture any transient goats that do make their way into the centre of the reserve.

While manipulating access to AWP can be an effective tool in the suite of techniques used to manage feral goats in the rangelands, there will be situations where it is not entirely applicable. Under certain circumstances, the size and shape of the property may preclude the establishment of an effective boundary zone. This may also be the case where natural water sources such as lakes, lagoons and rivers lie close to the boundary or even run through the middle of the park. However, where the latter occur, manipulating access to AWP can be used to reduce the total area of the park available for residential mobs of goats, allowing control effort to be concentrated in a smaller area around the natural water source. Under these circumstances, we suggest that all AWP within 4 km should be closed, to prevent goats from spreading out from the river into the surrounding landscape. Exceptions to this general principle may apply however, where the AWP are less than 1 km from the river. Under such circumstances, it may be preferable to maintain the AWP, in order to reduce the pressure on the riverbank from the environmental degradation goats can cause, and also for construction of a trap to remove the goats from this vulnerable landscape.

Conclusion

There are several techniques that can be used to control feral goats (Edwards *et al*. 1997; Sharp *et al*. 1999; Fleming *et al*. 2002) and the combination of techniques to be used for each program needs to be considered in light of the characteristics of the area where the program is to be undertaken (Parkes *et al*. 1996). Recognition of the importance of proximity to water to goat distribution and the adoption of techniques to manipulate their access to water should lead to a substantial improvement in our ability to manage feral goats in the rangelands.

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