CSIRO PUBLISHING
The Rangeland Journal, 2014, **36**, 25–33
http://dx.doi.org/10.1071/RJ13035

Review

Incorporating farmed goats into sustainable rangeland grazing systems in southern Australia: a review

Ronald B. Hacker[A] *and Yohannes Alemseged*[A,B]

[A]NSW Department of Primary Industries, PMB 19, Trangie, NSW 2823, Australia.
[B]Corresponding author. Email: yohannes.alemseged@dpi.nsw.gov.au

Abstract. The recent trend to farming or re-domestication of feral goats poses serious questions for the ecological sustainability of the semiarid and arid rangelands of southern Australia. This paper reviews aspects of the biology and grazing habits of goats, and aspects of the Australian goat industry, relevant to their sustainable management in livestock enterprises. Key factors identified include high fertility and fecundity even under low seasonal rainfall conditions and a generalist feeding strategy. Adverse consequences for rangeland condition can be expected if seasonal or market conditions result in an imbalance between population growth and turnoff, resulting in high grazing pressures. Given the limited control of the reproductive process at the current stage of the development of goat farming, strategies aimed at ensuring continuity of sale of goats (e.g. on-property feed lots or supply chain and market development) will be important in ensuring that imbalances are avoided. Conservative stocking rates and use of seasonal risk management tools are also particularly relevant. The major research and development needs identified by this review, from a resource management perspective, concern the appropriate dry sheep equivalent rating for goat classes based on age, sex and reproductive status, the extent and consequences of heterogeneity of grazing in space, time, and across forage species, and development of means of establishing sustainable stocking rates based on the use of all available forage sources, including browse.

Additional keywords: diet selection, grazing behaviour, growth, reproduction, shrubs.

Received 16 April 2013, accepted 31 October 2013, published online 6 December 2013

Introduction

Feral goats are ubiquitous in the semiarid rangelands of southern Australia. These feral flocks originated as escapees from dairy herds and from Angora flocks disbanded around the turn of the 20th century (Mason 1981). Holst *et al*. (1976) refer also to deliberate releases by railway gangs, possibly to ensure a future supply of meat, a motivation for release of goats on some islands and in other coastal locations by explorers.

Feral goats – called 'bush goats' by Holst *et al*. (1976) and today more generally marketed as 'rangeland goats' – have been harvested in Australia for export of meat since the early 1950s (Restall 1982), either by conventional mustering or, increasingly, by use of trapping yards or self-mustering facilities at watering points. The majority of goats sold from the Western Division of New South Wales (NSW) are still opportunistically harvested rather than commercially farmed (Pople and Froese 2012).

It is increasingly common, however, for landholders to fence a portion of their property into a 'goat paddock' that may be used to hold small goats until they reach a marketable liveweight, or to act as a depot for mustered goat so that larger, more uniform groups can be selected for sale. This represents an intermediate stage in the development of a rangeland goat enterprise.

The final stage of development – a farmed goat enterprise – usually involves retention of selected feral does which are subject to 'commercial' standards of management, including infusion of exotic breeds (e.g. the South African Boer goat) to increase productivity. Reproduction, however, is not usually controlled and, therefore, the current practices fail to meet the definition of a managed enterprise. The motivation for development of farmed goat enterprises, particularly for meat production, has been to take advantage of the perceived capacity of goats to thrive in areas in which sheep and cattle perform poorly (e.g. Fletcher 1995), to exploit their browsing habit to control or utilise invasive native scrub (e.g. Harrington 1979; Muir 1995), and to reduce the labour requirements of conventional sheep enterprises under extensive conditions. Nevertheless, few pastoral businesses in Australia's southern rangelands are currently based solely on a goat enterprise.

Most research on goats in this region has focussed on their capacity to reduce invasive native scrub (e.g. Harrington 1979; Muir 1995; Hacker *et al*. 2005) or on means to reduce them as a feral pest (e.g. Freudenberger and Hacker 1997; Thompson *et al*. 2002; Russell *et al*. 2011). Little attention has been directed to their management as livestock.

This review, necessarily based mainly on non-Australian literature, aims to identify key issues relevant to their use in this changed role, particularly in relation to sustainable management of natural resources, and associated research and development needs.

Biological characteristics

Reproduction

The capacity of goats to rear their offspring under challenging tropical conditions where only the most hardy and adapted females are able to perform using a low- or medium-quality pasture has been identified as a key attribute in improving meat production in the tropics (Devendra and McLeroy 1982; Chemineau *et al*. 1983). The same capacity is highly relevant to the production and management of farmed goats in the southern rangelands of Australia. Wilson and Mulham (1980) recorded a kidding rate of 120% by feral does compared with a lambing rate of 57% by Merino ewes in a belah-rosewood community near Ivanhoe in western NSW although the growth rate of kids was lower than that of lambs. Liveweight of kids was only ~60% of that of lambs at weaning and at 1.5 years of age whereas the liveweight of does was ~75% of the liveweight of ewes. Similar relativity between the reproductive performance of feral does and Merino ewes has been recorded in mulga shrub lands in the arid winter-rainfall zone of Western Australia (Fletcher 1995). The highest kidding rate recorded by Hacker *et al*. (2005) in a mulga range type near Tilpa in western NSW was 137% under high seasonal rainfall conditions, and a rate of 125% was recorded under low seasonal rainfall conditions when stocking rate was appropriately adjusted. Atkinson *et al*. (2007) recorded kidding percentages of 141 and 135% from feral does mated to Boer bucks under 'managed' (small paddock) or 'unmanaged' (large paddock) conditions, respectively, in a belah-bluebush range type near Wilcannia in western NSW.

The breeding season of goats differs between breeds (Ricordeau 1981). Some, such as the Maradi in Niger, are sexually active throughout the year although the interval between kiddings is nearly a year (Haumesser 1975). Others, such as the Angora goat of South Africa, have a short breeding season of 94 days between April and July (Pretorius 1973). The interval between kiddings also varies between breeds. Sengar (1976), for example, reported 92% of goats of the Jamnapari breed kidded once a year while 54% of the Black Bengal breed kidded twice a year. The reported length of gestation also varies, between 145 days for the Black Bengal breed (Ali *et al*. 1973) and 162 days for the Alpine breed of France (Ricordeau 1981). Observations in western NSW suggest a peak of kidding in spring (C. Bright, pers. comm.).

Under extensive conditions in the southern rangelands, management of reproduction is difficult due to the incursion of feral males. Atkinson *et al*. (2007) found that under 'managed' and 'unmanaged' conditions in western NSW only 88 and 39% of kids, respectively, were sired by males of the Boer breed to which non-pregnant feral does had been joined, even at a joining ratio (feral does to Boer males) of 20 : 1.

Growth

Birthweight of kids varies with breed and environmental conditions (Morand-Fehr 1981), with males slightly heavier than females. Liveweight gain during the first month is positively related to birthweight and liveweight gain during the first week (Morand-Fehr 1981).

Growth in meat animals is defined as an increase in tissue mass (Owens *et al*. 1993) and availability of energy is the main limiting factor (Lachica and Aguilera 2005*a*). AFRC (1998) indicate that the energy requirements for maintenance and growth in castrate males range from 3.7 MJ ME day^{-1} for kids of 15 kg liveweight to 14.6 MJ ME day^{-1} for kids of 30 kg liveweight, depending on metabolisability of the diet and liveweight gain (kg day^{-1}). However, Lachica and Aguilera (2005*b*) have argued that the literature contains limited information on the energy requirement of goats which has largely been inferred by extrapolation of data from other ruminants, ignoring differences in physiological or anatomical features. Molina Alcaide *et al*. (2000) compared the digestive physiology of sheep and goats and found no difference in digestibility (e.g. dry matter digestibility of 0.634 *v.* 0.635 for goats and sheep, respectively, when fed Alfalfa hay), degradation rate (22.8 *v.* 25.6%), or fractional rate of passage of the digesta out of the rumen when medium- or high-digestibility forages were offered. However, when grazing shrub- and tree-dominated vegetation in a semiarid environment goats were able to select forage of higher digestibility and with a lower proportion of unavailable nitrogen (N) than sheep (Molina Alcaide *et al*. 1997). Sheridan *et al*. (2003) also found higher digestive efficiencies (for dry matter, crude protein and energy) for goat kids of the Boer breed than for South African Mutton Merino lambs on a low-energy diet but not on a high-energy diet.

The capacity of goats to perform better than other ruminants in harsh environments has been variously attributed to their smaller body size and higher efficiency of utilisation of ingested nutrients (Silanikove 1997), low metabolic rates (Munn *et al*. 2012), ability to reduce metabolism (Silanikove 1997), efficient N economy (Muscher *et al*. 2010), efficient use of water (Silanikove 2000), and their ability to select a relatively high-quality diet from the variety of forage available (Ramirez 1999; see below). The extent to which these traits enable them to maintain growth under poor seasonal conditions is highly relevant to their use as livestock in the southern rangelands. No relevant data are available from Australian investigations but data from South Africa, summarised in Table 1, suggest that, while liveweight gains of goats, both pre- and post-weaning, are sensitive to diet quality (measured as metabolisable energy), the sensitivity appears somewhat muted relative to sheep. The higher liveweight gains of sheep in this table are consistent with the findings of several authors (e.g. Larbi *et al*. 1993; Kaitho *et al*. 1998; Mahgoub and Lodge 1998; although see Abidi *et al*. 2009; for a null finding) and are associated with larger mature liveweight.

Table 1. Liveweight gain (g day^{-1}) of Boer and indigenous (South African) goat kids and South African Mutton Merino (SAMM) lambs in relation to diet quality

n.a., Not applicable

Diet type and energy level	Boer	Indigenous	SAMM
Native pasture	90[A]	56[A]	n.a.
Pelleted ration (8.9 MJ ME kg^{-1} DM)	158[A]	76[A]	n.a.
Pelleted ration (9.9 MJ ME kg^{-1} DM)	168[B]	n.a.	220[B]
Pelleted ration (12.1 MJ ME kg^{-1} DM)	189[B]	n.a.	306[B]

[A]Derived from Greyling *et al*. (2004); pre-weaning growth rates to 12 weeks.
[B]Derived from Sheridan *et al*. (2003); post-weaning growth rates; averages of 28- and 56-day feeding periods.

Joining Boer males with farmed does of feral origin has the potential to increase meat production in pastoral areas. At 'Winderie' in Western Australia first-cross Boer goats had heavier liveweights at weaning than goats of feral origin (Elliott and Woodford 1998) and reached the target market liveweight of 35 kg substantially earlier. Being able to market goats earlier reduces stocking rates over a 12-month period, and provides a greater opportunity for the does to regain condition and conceive again.

Diet selection

Lemus and Brown (2008) present a useful generalised view of the diet preferences of the major livestock species (Fig. 1). While this representation highlights the predominance of browse in the diet of goats, a finding reported by many authors (e.g. Squires 1980; Teague 1989; Bartolome *et al*. 1998; Ramirez 1999), the literature also reflects considerable variation on this theme and points to goats as highly selective, or 'fastidious', grazers while willing to accept a wide variety of forages (Devendra and Burns 1983).

Compared with sheep, in particular, goats are 'top-down' grazers selecting readily from the upper layers of the canopy or sward, while sheep are 'bottom-up' grazers, selecting preferentially from the ground storey or bottom of the sward (Norton *et al*. 1990; Du Plessis *et al*. 2004). This fundamental distinction, if able to be expressed, will largely drive the difference in the selection patterns of the species in a given situation. Norton *et al*. (1990) concluded that in their study of grazing preferences in tropical grass-legume pastures, goats were more like cattle than sheep as both grazed from the top of the sward downwards, while sheep grazed from the bottom of the sward.

While differences in diet selection between sheep and goats are greater than the difference between breeds of either species (Du Plessis *et al*. 2004), numerous differences in diet selection between goat breeds have been reported (e.g. Merrill and Taylor 1981; Mellado *et al*. 2004*a*; Aharon *et al*. 2007; Celaya *et al*. 2010). These may be related to differences in oral morphology, which lead to different selection patterns among plant species without altering the quality of the diet selected (Mellado *et al*. 2007). Such differences have not been studied in the southern rangelands of Australia but it would be reasonable to expect that they might occur among herds bred or selected for particular production traits without greatly affecting the principles that should guide the management of their grazing.

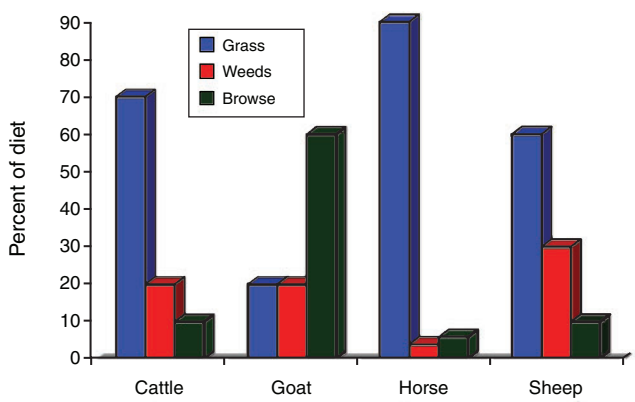

Fig. 1. Generalised diet preferences of major livestock species (Lemus and Brown 2008).

Other factors reported to have influenced the diet selected by goats include:

- season (e.g. Ricardi and Shimada 1992; Dziba *et al*. 2003);
- age and body condition (more shrub consumed by adults compared with juveniles in the rainy season, and by goats in lower body condition; Mellado *et al*. 2004*b*);
- grazing management system (more shrub consumed under rotational than continuous grazing; Mellado *et al*. 2004*c*); and
- reproductive status (more forbs and grasses consumed by pregnant or lactating does, according to nutritional requirements; Mellado *et al*. 2005).

While a preference for shrubs has generally been found, several exceptions have been reported. Grünwaldt *et al*. (1994) reported that goats grazing the arid piedmont of Argentina were not primarily browsers, favouring grasses over herbs and shrubs, but had the capacity to maintain diet digestibility under declining range condition resulting from heavy grazing. Guevara *et al*. (2009) also reported from Argentina that their studies provided 'no unanimity as to the fact that goats are strictly browsers'. Rafiq *et al*. (2010) reported, somewhat paradoxically, that the largest component of the diet of free-ranging goats in the Pubbi Hills of Pakistan was the grass, *Cymbopogon jwarancusa*, while pods of the shrub, *Acacia modesta*, were the major component of the diet of sheep under these conditions. In a rosewood-belah community in western NSW, Wilson and Mulham (1980) found that goats browsed trees but did not obtain the majority of their forage from them and were thus competitive with sheep for the herbaceous layer.

Goats have a notable capacity to select a diet with the highest nutrient concentration (Alexandre and Mandonnet 2005). Morand-Fehr (1981) noted that, whether on range, pasture or at the trough, goats seem to be very careful in choosing among plant species, varieties or morphological fractions and that, while selective feeding behaviour exists in other ruminants, it seems particularly well developed in goats. Lemus and Brown (2008) noted the capacity of goats to select plants when they are at their most nutritious stage. Merchant and Riach (1994), studying cashmere goats on sown pasture, observed that all classes of goats (females, castrates and kids) selected green leafy material of high digestibility. Wilson *et al*. (1975) found that the N content of the diet of goats was generally higher than those of sheep or cattle, while digestibility values were comparable among the species, in a rosewood-belah community in western NSW. In contrast, Squires (1980) found that sheep selected diets higher in both N and digestibility than either goats or cattle in poplar box woodland, also in western NSW, probably because they made better use of the short herbage layer that was present for much of the study while cattle, and particularly goats, consumed more browse.

Several authors have observed that goats are flexible grazers and continually adapt their grazing behaviour to changing herbage conditions (Teague 1989; Grünwaldt *et al*. 1994; McGregor 2010). More specifically, Dziba *et al*. (2003) observed

that goats selected species that offered the highest rate of nutrient intake. This well developed capacity for selective grazing is probably an important component of their ability to maintain body condition and production under a wider range of seasonal conditions than is feasible for sheep or cattle.

Role of goats in natural resource management

Goats have long been regarded as a major cause of rangeland degradation since they are often associated with environments that are considered 'overgrazed' or 'degraded', and with poverty and subsistence production systems in developing countries. A widespread cultural bias against goats has been identified among other livestock producers, bureaucrats and policy makers in developing countries (see Perevolotsky 1991; and authors quoted therein), and to some extent this bias probably prevails in Australia as well. However, the reputation of the goat is by no means well deserved and some authors have highlighted the ecological, as well as economic and social, benefits of goat grazing in landscapes often popularly considered to have been desertified by them (e.g. Perevolotsky 1991; Perevolotsky and Seligman 1998; de Rancourt *et al*. 2006).

Impact on shrubs

The browsing habit of goats has frequently resulted in attempts to use them for shrub control. Several studies have demonstrated that they can be effective in restricting the increase in shrub cover (particularly of small plants <2 m in height) or limiting regrowth after mechanical clearing or fire (e.g. Du Toit 1972; Radcliffe 1982; Wood 1987; Downing and Evans 1989; Hacker *et al*. 2005; Hester *et al*. 2006). Mills *et al*. (2005) recorded their effectiveness in converting extensive areas of semiarid thicket to open grassland. However, in western NSW, Harrington (1979), in poplar box (*Eucalyptus populnea*) woodland, and Wilson *et al*. (1975, 1976) and Wilson and Mulham (1980), in belah (*Casuarina cristata*)-rosewood (*Heterodendrum oleofolium*) woodland, have concluded that overall they are not a satisfactory management tool for control of invasive native scrub. This is due to their inability to exert significant grazing pressure on some of the most invasive species such as turpentine (*Eremophila sturtii*) and budda (*Eremophila mitchellii*), which are not preferred by them. Noble *et al*. (1980) found that goats did not graze the regrowth of mallee (*Eucalyptus* spp.) and that they had no potential as a management tool for limiting the regrowth of mallee after fire.

Goats can exert heavy grazing pressure on shrub species they prefer, and eliminate them from the community, particularly when heavy grazing is exerted under drought conditions (Wilson *et al*. 1976; Fletcher 1995; Muir 1995; Hacker *et al*. 2005). Such grazing can also lead to an increase in non-preferred shrub species and severe impacts on the herbage layer (Sweet and Mphinyane 1986; Muir 1995; Hacker *et al*. 2005) although at the site of the study of Muir (1995), in a mulga rangeland type in western NSW, excellent regrowth of perennial grasses has been observed by one of the authors (R. B. Hacker) following destocking and favourable weather conditions.

When used for the control of preferred shrub species, continuous grazing is more effective than rotational or non-continuous grazing since constant pressure on the target species appears to be important in determining the level of control achieved (Du Toit 1972; Muir 1995).

Holst *et al*. (1976) listed common species (both woody and non-woody) in NSW in terms of their preference by goats (Table 2) while recognising that selection of these species can be influenced by the stage of maturity of the plants and that their preference will therefore show seasonal variation.

While reduction in the cover of shrubs may have several advantages in terms of livestock production, it may also result in a considerable reduction in carbon (C) storage (Mills *et al*. 2005). Alchin *et al*. (2010) demonstrated the major contribution of woody vegetation and coarse woody debris to total C pools in the northern rangelands of Western Australia but to date no comparable analysis has apparently been conducted for the southern rangelands. Both Alchin *et al*. (2010) and Hunt *et al*. (2012) have identified the potential tradeoffs between pastoral production and C sequestration achieved partially through increased cover of woody vegetation in northern Australia. This role of goats in the future may change should pastoralists in the southern rangelands be able to derive economic advantage from C sequestration.

Effects on botanical composition

Despite their reputation as destroyers of vegetation and landscapes, several studies have shown that goats can confer benefits in term of pasture composition and resource condition. In high-rainfall pastures, grazing by goats has been shown to increase the clover content of grass-clover pastures compared with sheep in both New Zealand (Radcliffe *et al*. 1991) and the UK (Penning *et al*. 1996), the latter authors suggesting that they could be used as a management tool for this purpose. In

Table 2. Preference by goats of some common plant species in western New South Wales (after Holst *et al*. 1976)

Highly preferred	Orange bush (*Capparis mitchelli*), supplejack (*Ventilago viminalis*), kurrajong (*Brachychiton populneum*), gruie (*Owenia acidula*), emu bush (*Eremophila longifolia*), belah (*Casuarina cristata*), warrior bush (*Apophyllum anomalum*), whitewood (*Atalaya hemiglauca*), lignun (*Muehlenbeckia cunninghamii*), blackberry (*Rubus* spp.), sweet briar (*Rosa rubignosa*), lucerne tree (*Chamaecytisus proliferus*), yellow flower lucerne (*Medicago folicata*), turnip weed (*Brassica tournefortii*), sucker leaves of boxes, gums, mallees[A]
Moderately preferred	Punty bush (*Senna artemisioides* subsp. *filifolia*), broad- and narrow-leaf hop bush (*Dodonea viscosa* subsp. *spatulata* and subsp. *angustissima*), pine (young) (*Callitris* spp.), mulga (young) (*Acacia aneura*), ironwood (*Acacia excelsa*), yarran (*Acacia homalophylla*), various other *Acacia* spp., canegrass (*Eragrostis australasica*), some box and gum trees
Eaten occasionally	Budda (*Eremophila mitchellii*), wilga (*Geijera parviflora*), mature poplar box (*Eucalyptus populnea*), horse nettle (*Solanum* sp.), tall nettle (*Urtica* sp.), kangaroo thorn (*Acacia* sp.), galvanised burr (*Sclerolaena birchii*)

[A]Note that this assessment, in relation to mallee, is contrary to the findings of Noble *et al*. (1980).

temperate pastures in the high-rainfall zone of south-eastern Australia, McGregor (2010) found that grazing by Angora goats at the same stocking rate as sheep (animals ha^{-1}) resulted in more subterranean clover in the pasture, less undesirable grasses, and less bare ground, and concluded that Angora goats on sheep farms could be used to speed up establishment of subterranean clover, manipulate pasture composition, reduce soil erosion and reduce weed invasion.

The role of goats in controlling regrowth of shrubs after fire or mechanical clearing in rangelands has been noted above. Most of these studies have not reported in detail the effect on the grass layer but, in South Africa, Du Toit (1972) found that the greater control of regrowth of *Acacia karoo* by goats compared with sheep was also associated with a marked increase in cover, composition and vigour of the grass sward.

In semiarid thornscrub in Mexico, Baraza and Valiente-Banuet (2008) found that goats were able to disperse viable seed of diverse species, sometimes depositing them in favourable micro-habitats for survival, e.g. under the canopies of perennial plants. This study did not extend to examining the role of this process in rangeland regeneration but the authors called attention to its potential, contrary to the general assumption that goats cause only degradation.

Experiences of some pastoralists in western NSW have also supported the idea that well managed goats have less impact on rangeland condition than sheep, and can facilitate rangeland regeneration, due to their highly flexible diet (K. Francisco, pers. comm.). However, no documentary evidence to this effect is available. Experience in the Western Australian rangelands has also shown that the condition of some habitats (e.g. mulga shrub land) can improve under grazing by goats alone, without competition from other animals (Fletcher 1995; WADAF 2011).

Stocking rate estimation

Establishing appropriate stocking rates for new enterprises in which goats are substituted for traditional livestock is obviously fundamental to their sustainability. Species exchange based on the estimated dry sheep equivalent (DSE) rating for various classes of goats (Table 3) will provide a starting point for management of grazing pressure and pasture utilisation. In addition to the relativities described in Table 3, forage consumption will also vary with quality and quantity of feed on offer, water quality and season of year (WADAF 2011). Furthermore, the rate at which sheep can be exchanged for goats in practice will depend heavily on the amount of browse available to goats, with DSE ratings considerably reduced in vegetation types that contain browse that is eaten by goats but not by sheep. Muya *et al*. (2013) used utilisation-based methods (grazing unit and browsing unit) along with rainfall regime to determine the number of animals that can be stocked in a given area in managing wildlife in Kenya.

Table 3. Estimated dry sheep equivalents (DSE) ratings for classes of goats based on forage consumption (adapted from WADAF 2011)

Class	DSE	Liveweight range (kg)
Dry doe	0.75	30–40
Breeding doe[A]	1.5	40–60
Weaner	0.7	20–40
Entire male	1.5	60–80

[A]In a herd producing 150% kids.

Goat behaviour

Pastoralists frequently observe that feral goats removed by mustering or trapping are rapidly replaced by new individuals from the surrounding country. Feral goats normally have a high proportion of males in the herd and appear to be highly mobile although their movement is not nomadic. They appear to occupy defined home ranges for considerable periods of time (e.g. Holt and Pickles 1996), albeit ones that are not restricted by normal pastoral infrastructure developed for sheep. When captured they do not exhibit wild behaviour, or appear to fret (Holst *et al*. 1976), and so are readily domesticated.

Under commercial management, herds of does running as a single species, and with a low proportion of males (~0.05 is considered satisfactory for extensive pastoral situations), are much less mobile and have stable, well defined home ranges, to the extent that the need for internal fencing may be reduced in uniform landscapes (WADAF 2011).

Incursion of feral goats into managed herds may be a serious issue unless fencing is secure. Where managed herds are enclosed by electric fences, feral animals commonly breech the barrier to enter a paddock but receive an electric shock in the process and tend not to challenge it again to leave the paddock. Such paddocks can thus act as feral goat 'accumulators' with serious implications for stocking rate and breeding management.

Some observations in western NSW indicate that managed goats do not walk as far from water as sheep unless conditions are dry (C. Bight and A. McLeod, pers. comm.), perhaps reflecting their ability to select from a wider range of forages on offer.

Incorporating goats into sustainable grazing systems in the southern rangelands of Australia

Regardless of the species of livestock involved, sustainable grazing systems seek to maintain or, where necessary, improve the condition of rangeland resources. This implies at least the maintenance or improvement of landscape function (*sensu* Ludwig *et al*. 1997) and the maintenance of extant biodiversity at landscape scales. Fundamental to the achievement of these objectives is the matching of forage demand from all herbivores to forage supply with sufficient precision to ensure that utilisation levels are consistent with the resource management objective established for individual management units (see Campbell and Hacker 2000). Despite both anecdotal- and research-based evidence that goats may confer positive benefits in terms of natural resource management, contrary to their popular image, their incorporation into sustainable systems of rangeland use will be dependent on management which satisfies this criterion.

Sustainability of grazing systems (as defined above) is also influenced in practice by the economic conditions prevailing in the industry. The Australian goat industry involves two main supply chains, one for farmed goats and the other for rangeland goats although some movement occurs between them (MLA 2012). At this stage of the industry's development, these supply chains are not well understood and no economic models are available. Maintaining an adequate supply of meat of appropriate

quality has been identified as the major issue confronting both these sectors of the industry (MLA 2012).

The preceding review suggests that the salient features of goat biology relevant to their management as livestock in the southern rangelands are:

- high fertility and fecundity, even under low seasonal rainfall conditions; and
- a generalist feeding strategy and a marked capacity to select the best available diet from the forage on offer, resulting in a capacity to utilise a greater range of plant species, particularly browse, than those utilised by Merino sheep in current management systems.

It seems likely that these traits would also result in post-weaning liveweight gains of kids that are less sensitive to seasonal variation than is the case for Merino lambs (see Table 1) although few if any field data are available from the southern rangelands to support this suggestion. In any event, low seasonal rainfall conditions will reduce liveweight gains and increase the time to marketable liveweight.

These traits imply:

- the potential for a high rate of population growth, which can be maintained over a wide range of seasonal conditions;
- a potentially reduced selection pressure on individual species of plants but also potentially restricted distribution of grazing if forage demand can be met by utilisation of a wider variety of species; and
- potential for adverse impacts on natural resources should seasonal conditions results in an imbalance between population growth and turnoff.

While the last point applies to all livestock production systems, the capacity of goats to reproduce successfully under a wide range of seasonal conditions makes the issue potentially more serious for goat enterprises than for traditional sheep enterprises. This situation is exacerbated by the limited control over reproduction generally exercised by rangeland goat producers given the current state of development of the industry, and the continuing existence of a substantial population of feral males.

Management strategies to address these issues could include (a) stocking at a lower rate (in terms of DSE) than would be expected for a traditional Merino enterprise (b) use of seasonal risk management tools and (c) establishment of facilities (e.g. feed lots) or collaborative arrangements (e.g. off-property finishing) to ensure that the sale of animals can be maintained under low seasonal rainfall conditions.

Given that continuity of supply of meat of appropriate quality has been identified as a major issue for goat industry development, initiatives that facilitate market development and the operation of integrated supply chains should be beneficial to both the economic and ecological sustainability of the industry.

Research and development needs

The research and development needs relevant to the sustainable management of goats, from a natural resource perspective, include:

- establishment of the appropriate DSE ratings for goat classes based on age, sex and reproductive status;
- clarification of the heterogeneity of grazing – temporally, spatially and among species;
- development of practical means of determining sustainable stocking rates based on all sources of forage on offer, including browse; and
- elucidation of the response of key species, including shrubs, to the interaction of grazing and drought.

Some guidelines (Table 3) already exist in relation to DSE ratings. However, these are considerably higher than those thought appropriate by graziers participating in focus group discussions of goat management in western NSW (S. A. Khairo and R. B. Hacker, unpubl. data), differences relating particularly to the capacity of goats to utilise browse not utilised by Merinos.

Elucidation of the response of key species, including shrubs, to the interaction of drought and grazing is on ongoing issue which is an essential, and still largely incomplete, component of the development of strategies for sustainable grazing in the southern rangelands.

Conclusions

Goats possess physiological and behavioural traits which, taken together, indicate that under commercial management they may pose a threat to natural resource condition in the southern rangelands unless a high standard of management is applied. Their capacity to maintain high reproductive rates under low seasonal rainfall conditions could result in forage demand rapidly exceeding forage supply, with adverse impact on resource condition indicators such as ground cover, unless strategies are established to ensure continuity of the sale of goats. Facilitating continuity of sale (e.g. through on-property feed lots or greater vertical integration within the supply chain) would be enhanced by further development of the goat meat industry. Other management strategies, such as reduced stocking rate relative to traditional enterprises, will also be important in minimising the risk to natural resources but development of demand-side approaches to the sale of goats will be particularly important given that, at the current stage of industry development, the reproductive process is poorly controlled.

Acknowledgements

This review was part of a project jointly funded by the Lower Murray–Darling Catchment Management Authority (now Murray CMA) and the NSW Department of Primary Industries. We are grateful to Dr John Milne and an anonymous referee for constructive comments on the original manuscript.

References

Abidi, S., Ben Salem, H., Vastra, V., and Priolo, A. (2009). Supplementation with barley or spineless cactus (*Opuntia ficus indica* f. *inermis*) cladodes on digestion, growth and intramuscular fatty acid composition in sheep and goats receiving oaten hay. *Small Ruminant Research* **87**, 9–16. doi:10.1016/j.smallrumres.2009.09.004

AFRC (1998). 'The Nutrition of Goats.' Technical committee on response to nutrients, Report No. 10. (CAB International: Wallingford, UK.)

Aharon, H., Henkin, Z., Ungar, E. D., Kababya, D., Baram, H., and Perevolotsky, A. (2007). Foraging behaviour of the newly introduced Boer goat breed in a Mediterranean woodland: a research observation. *Small Ruminant Research* **69**, 144–153. doi:10.1016/j.smallrumres.2006.01.004

Alchin, M., Tiereney, E., and Chilcott, C. (2010). 'Carbon Capture Project Final Report. An Evaluation of the Opportunity and Risks of Carbon Offset based Enterprises in the Kimberley-Pilbara Region of Western Australia.' Bulletin 4801. (Department of Agriculture and Food WA: Perth.) Available at: www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/rpm/landup/carbonreport2010.pdf (accessed 5 August 2013)

Alexandre, G., and Mandonnet, N. (2005). Goat meat production in harsh environments. *Small Ruminant Research* **60**, 53–66. doi:10.1016/j.smallrumres.2005.06.005

Ali, S. Z., Hoque, M. M., and Hasnoth, M. A. (1973). A study on the growth and reproductive performance of black Bengal goats under farm conditions. *The Indian Veterinary Journal* **50**, 348–440.

Atkinson, T., Curran, G., and Church, G. (2007). ''Bushley' boer goat trial. Producer-initiated Research and Development.' Final Report. (Industry & Investment NSW: Sydney.)

Baraza, E., and Valiente-Banuet, A. (2008). Seed dispersal by domestic goats in a semiarid thornscrub of Mexico. *Journal of Arid Environments* **72**, 1973–1976. doi:10.1016/j.jaridenv.2008.04.004

Bartolome, J., Franch, J., Plaixats, J., and Seligman, N. G. (1998). Diet selection by sheep and goats on Mediterranean heath-woodland range. *Journal of Range Management* **51**, 383–391. doi:10.2307/4003322

Campbell, T., and Hacker, R. (2000). 'The Glove Box Guide to Tactical Grazing Management for the Semi-arid Woodlands.' (NSW Agriculture: Orange.)

Celaya, R., Jauregui, B. M., Garcia, R. R., Benavides, R., Garcia, U., and Osoro, K. (2010). Changes in heathland vegetation under goat grazing: effects of breed and stocking rate. *Applied Vegetation Science* **13**, 125–134. doi:10.1111/j.1654-109X.2009.01054.x

Chemineau, P., Gauthier, D., and Thimonier, J. (1983). Reproduction of ruminants in tropical areas. *Les Colloques de l'INRA* **20**,

de Rancourt, M., Fois, N., Lavin, M. P., Tchakérian, E., and Vallerand, F. (2006). Mediterranean sheep and goat production: uncertain future. *Small Ruminant Research* **62**, 167–179. doi:10.1016/j.smallrumres.2005.08.012

Devendra, C., and Burns, M. (1983). 'Goat Production in the Tropics.' (Commonwealth Agricultural Bureaux: Farnham House.)

Devendra, C., and McLeroy, G. B. (1982). Goat and sheep production in the tropics. *In*: 'Intermediate Tropical Agricultural Series'. (Longman: London/New York.)

Downing, B. H., and Evans, J. C. (1989). A survey approach to evaluating the effects of management on the semi-arid and arid lands in New South Wales. *Australian Rangeland Journal* **11**, 21–30. doi:10.1071/RJ9890021

Du Plessis, I., van der Waal, C., and Webb, E. C. (2004). A comparison of plant form and browsing height selection of four small stock breeds – preliminary results. *South African Journal of Animal Science* **34**, 31–34.

Du Toit, P. F. (1972). The goat in a bush-grass community. *Proceedings of the Grassland Society of Southern Africa* **7**, 44–50. doi:10.1080/00725560.1972.9648666

Dziba, L. E., Scogings, P. F., Gordon, I. J., and Raats, J. G. (2003). Effects of season and breed on browse species intake rates and diet selection by goats in the False Thornveld of the Eastern Cape, South Africa. *Small Ruminant Research* **47**, 17–30. doi:10.1016/S0921-4488(02)00235-3

Elliott, T. K., and Woodford, K. B. (1998). Industry opinions and development issues relating to feral goats. *Agribusiness Review*, Vol. 6. Available at: www.agrifood.info/review/1998/Elliot.html (accessed 8 March 2011).

Fletcher, W. (1995). 'Yerilla Goat Grazing Study.' Miscellaneous Publication No. 20/95. (Agriculture Western Australia: Perth.)

Freudenberger, D., and Hacker, R. B. (1997). The effect of temporary closure of watering points on grazing intensity of red and grey kangaroos with related observations on feral goats. *The Rangeland Journal* **19**, 157–165. doi:10.1071/RJ9970157

Greyling, J. P. C., Mmbengwa, V. M., Schwalbach, L. M. J., and Muller, T. (2004). Comparative milk production potential of Indigenous and Boer goats under two feeding systems in South Africa. *Small Ruminant Research* **55**, 97–105. doi:10.1016/j.smallrumres.2003.11.014

Grünwaldt, E. G., Pedrani, A. R., and Vich, A. I. (1994). Goat grazing in the arid piedmont of Argentina. *Small Ruminant Research* **13**, 211–216. doi:10.1016/0921-4488(94)90066-3

Guevara, J. C., Grunwaldt, E. G., Estevez, O. R., Bisigato, A. J., Blanco, L. J., Biurrun, F. N., Ferrando, C. A., Chirino, C. C., Morici, E., Fernandez, B., Allegretti, L. I., and Passera, C. B. (2009). Range and livestock production in the Monte Desert, Argentina. *Journal of Arid Environments* **73**, 228–237. doi:10.1016/j.jaridenv.2008.02.001

Hacker, R. B., Clipperton, S., and Melville, G. (2005). 'Role of Goat Production as a Range Restoring Alternative Enterprise.' Final Report to WEST 2000 Plus. (NSW Department of Primary Industries: Orange.)

Harrington, G. (1979). The effects of feral goats and sheep on the shrub populations in a semi-arid woodland. *Australian Rangeland Journal* **1**, 334–345. doi:10.1071/RJ9790334

Haumesser, J. B. (1975). Some aspects of reproduction in the Red Sokoto goat. Comparison with other tropical and subtropical breeds. *Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux* **28**, 225–233.

Hester, A. J., Scogings, P. F., and Trollope, W. S. N. (2006). Long-term impacts of goat browsing on bush-clump dynamics in a semi-arid subtropical savanna. *Plant Ecology* **183**, 277–290. doi:10.1007/s11258-005-9039-6

Holst, P. J., Carberry, P. M., Mitchell, T. D., Trimmer, B. I., and Kajons, A. (1976). 'Husbandry of Bush Goats.' (Department of Agriculture New South Wales: Orange.)

Holt, C., and Pickles, G. (1996). Home range responses of feral goats. *The Rangeland Journal* **18**, 144–149. doi:10.1071/RJ9960144

Hunt, L. P., Leidloff, A. C., and Eager, R. W. (2012). Above- and below-ground carbon dynamics of different fire regimes in extensive grazing systems in northern Australia. *In*: '17th Biennial Conference of the Australian Rangeland Society'. Kununurra, W. Aust., 23–27 September 2012. Abstract available at: www.austrangesoc.com.au/userfiles/file/2012%20ARS%20Conference/ARS%20Proceedings%20v4.pdf (accessed 5 August 2013).

Kaitho, R. J., Tegegne, A., Umunna, N. N., Nsahlai, I. V., Tamminga, S., Van Bruchem, J., and Arts, J. M. (1998). Effect of *Leucaena* and *Sesbania* supplementation on body growth and scrotal circumference of Ethiopian highland sheep and goats fed teff straw basal diet. *Livestock Production Science* **54**, 173–181. doi:10.1016/S0301-6226(97)00152-8

Lachica, M., and Aguilera, J. F. (2005*a*). Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* **59**, 105–121. doi:10.1016/j.smallrumres.2005.05.002

Lachica, M., and Aguilera, J. F. (2005*b*). Energy needs of the free-ranging goat. *Small Ruminant Research* **60**, 111–125. doi:10.1016/j.smallrumres.2005.06.006

Larbi, A., Thomas, D., and Hanson, J. (1993). Forage potential of *Erhthrina abyssinica* – intake, digestibility and growth rates for stall-fed sheep and goats in southern Ethiopia. *Agroforestry Systems* **21**, 263–270. doi:10.1007/BF00705245

Lemus, R., and Brown, K. (2008). 'Feeding small ruminants: developing a grazing system for sheep and goats.' *Forage News*, July 2008. (Mississippi State University Extension Service: Mississippi, MS.)

Ludwig, J., Tongway, D., Freudenberger, D., Noble, J., and Hodgkinson, K. (Eds) (1997). 'Landscape Ecology, Function and Management: Principles from Australia's Rangelands.' (CSIRO: Canberra, ACT.)

Mahgoub, O., and Lodge, G. A. (1998). A comparative study on growth, body composition and carcass tissue distribution in Omani sheep and goats. *Journal of Agricultural Science, Cambridge* **131**, 329–339. doi:10.1017/S0021859698005887

Mason, I. L. (1981). Wild goats and their domestication. *In*: 'Goat Production'. (Ed. C. Gall.) pp. 34–55. (Academic Press: New York.)

McGregor, B. A. (2010). Influence of stocking rate and mixed grazing of Angora goats and Merino sheep on animal and pasture production in southern Australia. 1. Botanical composition, sward characteristics and availability of components of annual temperate pastures. *Animal Production Science* **50**, 138–148. doi:10.1071/AN09128

Mellado, M., Rodriguez, A., Olvera, A., Villarreal, J. A., and Lopez, R. (2004*a*). Diets of Nubian and Granadina goats grazing on arid rangeland. *Journal of Range Management* **57**, 630–634. doi:10.2307/4004020

Mellado, M., Rodriguez, A., Olvera, A., Villarreal, J. A., and Lopez, R. (2004*b*). Age and body condition score and diets of grazing goats. *Journal of Range Management* **57**, 517–523. doi:10.2307/4003982

Mellado, M., Olvera, A., Duenez, J., and Rodriguez, A. (2004*c*). Effects of continuous and rotational grazing on goat diets in a desert rangeland. *Journal of Applied Animal Research* **26**, 93–100. doi:10.1080/09712119.2004.9706515

Mellado, M., Rodriguez, A., Villarreal, J. A., and Olvera, A. (2005). The effect of pregnancy and lactation on the diet composition and dietary preference of goats in a desert rangeland. *Small Ruminant Research* **58**, 79–85. doi:10.1016/j.smallrumres.2004.07.014

Mellado, M., Olivares, L., Pittroff, W., Diaz, H., Lopez, R., and Villarreal, J. A. (2007). Oral morphology and dietary choices of goats on rangeland. *Small Ruminant Research* **71**, 194–199. doi:10.1016/j.smallrumres.2006.06.005

Merchant, M., and Riach, D. J. (1994). The intake and performance of cashmere goats grazing sown swards. *Grass and Forage Science* **49**, 429–437. doi:10.1111/j.1365-2494.1994.tb02020.x

Merrill, L. B., and Taylor, C. A. (1981). Diet selection, grazing habits, and the place of goats in range management. *In*: 'Goat Production'. (Ed. C. Gall.) pp. 233–252. (Academic Press: New York.)

Mills, A. J., Cowling, R. M., Fey, M. V., Kerley, G. I. H., Donaldson, J. S., Lechmere-Oertel, R. G., Sigwela, A. M., Skowno, A. L., and Rundel, P. (2005). Effects of goat pastoralism on ecosystem carbon storage in semiarid thicket, Eastern Cape, South Africa. *Austral Ecology* **30**, 797–804. doi:10.1111/j.1442-9993.2005.01523.x

MLA (2012). 'Australian Goat Industry RD&E Strategy – 2012.' (Meat and Livestock Australia Ltd: Sydney, NSW.)

Molina Alcaide, E., García, M. A., and Aguilera, J. F. (1997). The voluntary intake and rumen digestion by grazing goats and sheep of a low-quality pasture from a semi-arid land. *Livestock Production Science* **52**, 39–47. doi:10.1016/S0301-6226(97)00117-6

Molina Alcaide, E., García, M. A., and Aguilera, J. F. (2000). A comparative study of nutrient digestibility, kinetics of degradation and passage and rumen fermentation pattern in goats and sheep offered good quality diets. *Livestock Production Science* **64**, 215–223. doi:10.1016/S0301-6226(99)00149-9

Morand-Fehr, P. (1981). Nutrition and feeding of goats: application to temperate climatic conditions. *In*: 'Goat Production'. (Ed. C. Gall.) pp. 193–232. (Academic Press: London, UK.)

Muir, S. J. (1995). Vegetation responses under goat stocking strategies to control hopbush (*Dodonaea viscosa* subsp. *angustissima*) in the semi-arid woodlands of eastern Australia. PhD Thesis, New Mexico State University, USA.

Munn, A. J., Cooper, C. E., Russell, B., Dawson, T. J., McLeod, S. R., and Maloney, S. K. (2012). Energy and water use by invasive goats (*Capra hircus*) in an Australian rangeland, and a caution against using broad-scale allometry to predict species-specific requirements. *Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology* **161**, 216–229. doi:10.1016/j.cbpa.2011.10.027

Muscher, A. S., Schröder, B., Breves, G., and Huber, K. (2010). Dietary nitrogen reduction enhances urea transport across goat rumen epithelium. *Journal of Animal Science* **88**, 3390–3398. doi:10.2527/jas.2010-2949

Muya, S. M., Kamweya, A. M., Muigai, A. W. T., Kariuki, A., and Ngen, S. M. (2013). Using range condition assessment to optimize wildlife stocking in Tindress Wildlife Sanctuary, Nakuru District, Kenya. *Rangeland Ecology and Management*, in press. doi:10.2111/REM-D-12-00075.1

Noble, J. C., Smith, A. W., and Leslie, H. W. (1980). Fire in the mallee shrublands of western New South Wales. *Australian Rangeland Journal* **2**, 104–114. doi:10.1071/RJ9800104

Norton, B. W., Kennedy, P. J., and Hales, J. W. (1990). Grazing management studies with Australian cashmere goats 3. Effect of season on the selection of diet by cattle, sheep and goats from two tropical grass–legume pastures. *Australian Journal of Experimental Agriculture* **30**, 783–788. doi:10.1071/EA9900783

Owens, F. N., Dubeski, P., and Hanson, C. F. (1993). Factors that alter the growth and development of ruminants. Available at: www.journalofanimalscience.org/content/71/11/3138.full.pdf (accessed 10 December 2012).

Penning, P. D., Johnson, R. H., and Orr, R. J. (1996). Effects of continuous stocking with sheep or goats on sward composition and animal production from a grass and white clover pasture. *Small Ruminant Research* **21**, 19–29. doi:10.1016/0921-4488(95)00816-0

Perevolotsky, A. (1991). Goats or scapegoats – the overgrazing controversy in Piura, Peru. *Small Ruminant Research* **6**, 199–215. doi:10.1016/0921-4488(91)90156-K

Perevolotsky, A., and Seligman, N. G. (1998). Role of grazing in Mediterranean rangeland ecosystems. *Bioscience* **48**, 1007–1017. doi:10.2307/1313457

Pople, A., and Froese, J. (2012). 'Distribution, abundance and harvesting of feral goats in the Australian rangelands 1984–2011.' Final report to the ACRIS Management Committee. (Department of Employment, Economic Development & Innovation, Queensland: Brisbane.)

Pretorius, P. S. (1973). Fluctuations in pituitary FSH and LH in normally cycling Angora goat. *Journal of the South African Veterinary Association* **44**, 279–283.

Radcliffe, J. E. (1982). Gorse control with sheep and goats. *In*: 'Proceedings of the Thirty-Fifth New Zealand Weed and Pest Control Conference'. (Ed. M. J. Hartley.) pp. 130–134. (New Zealand Weed and Pest Control Society Inc.: Napier, New Zealand.)

Radcliffe, J. E., Townsend, R. J., and Baird, D. B. (1991). Mixed and separate grazing of sheep and goats at two stocking rates. *New Zealand Journal of Agricultural Research* **34**, 167–176. doi:10.1080/00288233.1991.10423356

Rafiq, M. K., Afzal, J., Jasra, A. W., Ahmad, I., Kahn, T. N., and Farooq, M. U. (2010). Foraging preferences of free-ranging sheep and goats on the native vegetation of rangelands of Pubbi Hills in Pakistan. *International Journal of Agriculture and Biology* **12**, 944–946.

Ramirez, R. G. (1999). Feed resources and feeding techniques of small ruminants under extensive management conditions. *Small Ruminant Research* **34**, 215–230. doi:10.1016/S0921-4488(99)00075-9

Restall, B. J. (1982). The Australian feral goat – basis for a new industry? *Proceedings of the Australian Society of Animal Production* **14**, 130.

Ricardi, C., and Shimada, A. (1992). A note on diet selection by goats on a semiarid temperate rangeland throughout the year. *Applied Animal Behaviour Science* **33**, 239–247. doi:10.1016/S0168-1591(05)80011-5

Ricordeau, G. (1981). Genetics: breeding plan. *In*: 'Goat Production'. (Ed. C. Gall.) pp. 111–169. (Academic Press: London.)

Russell, B. G., Letnic, M., and Fleming, P. J. S. (2011). Managing feral goat impacts by manipulating their access to water in the rangelands. *The Rangeland Journal* **33**, 143–152. doi:10.1071/RJ10070

Sengar, O. (1976). Sheep and goat production in India. *In*: 'The Role of Sheep and Goats in Agricultural Development. Proceedings of Workshop'. (Eds E. Oltenacu, A. Martinez, H. Glimp and H. Fitzhugh.) pp. 26–28. (Winrock International Livestock Research and Training Centre: Little Rock, AR.)

Sheridan, R., Ferreira, A. V., and Hoffman, L. C. (2003). Production efficiency of South African Mutton Merino lambs and Boer goat kids receiving either a low or a high energy feedlot diet. *Small Ruminant Research* **50**, 75–82. doi:10.1016/S0921-4488(03)00109-3

Silanikove, N. (1997). Why goats raised on harsh environments perform better than other domesticated animals. *In*: 'Recent Advances in Small Ruminant Nutrition'. (Eds J. Lindberg, H. L. Gonda and I. Lendin.) pp. 185–194. (FAO: Rome, Italy.)

Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science* **67**, 1–18. doi:10.1016/S0301-6226(00)00162-7

Squires, V. R. (1980). Chemical and botanical composition of the diets of oesophageally fistulated sheep, cattle and goats in a semi-arid *Eucalyptus populnea* woodland community. *Australian Rangeland Journal* **2**, 94–103. doi:10.1071/RJ9800094

Sweet, R. J., and Mphinyane, W. (1986). Preliminary observations on the ability of goats to control post-burning regrowth of *Acacia nigrescens*/*Combretum apiculatum* savanna in Botswana. *Journal of the Grassland Society of Southern Africa* **3**, 79–84. doi:10.1080/02566702.1986.9648040

Teague, W. R. (1989). The rate of consumption of bush and grass by goats in a representative *Acacia karoo* savanna community in the Eastern Cape. *Journal of the Grassland Society of South Africa* **6**, 8–13. doi:10.1080/02566702.1989.9648151

Thompson, J., Riethmuller, D., Kelly, D., Miller, E., and Scanlan, J. C. (2002). Feral goats in south-western Queensland: a permanent component of the grazing lands. *The Rangeland Journal* **24**, 268–287. doi:10.1071/RJ02015

WADAF (2011). 'The Grazing of Goats in the Pastoral Areas of Western Australia. Best Management Practice Guidelines.' (WA Department of Agriculture and Food: South Perth.) Available at: www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/regions/nrr/warangelandsbmpwelfaregoats.pdf (accessed 8 March 2011)

Wilson, A. D., and Mulham, W. E. (1980). Vegetation changes and animal productivity under sheep and goat grazing on an arid belah (*Casuarina cristata*)–rosewood (*Heterodendrum oleifolium*) woodland in western New South Wales. *Australian Rangeland Journal* **2**, 183–188. doi:10.1071/RJ9800183

Wilson, A. D., Leigh, J. H., Hindley, N. L., and Mulham, W. E. (1975). Comparison of the diets of goats and sheep on a *Casuarina cristata* – *Heterodendrum oleifolium* woodland community in western New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry* **15**, 45–53. doi:10.1071/EA9750045

Wilson, A. D., Mulham, W. E., and Leigh, J. H. (1976). A note on the effects of browsing by feral goats on a belah (*Casuarina cristata*)–rosewood (*Heterodendrum oleifolium*) woodland. *Australian Rangeland Journal* **1**, 7–12. doi:10.1071/RJ9760007

Wood, G. M. (1987). Animals for biological brush control. *Agronomy Journal* **79**, 319–321. doi:10.2134/agronj1987.00021962007900020028x