Feral Goat Population Trends in the Western New South Wales Rangelands
A report prepared for the Western Catchment Management Authority by:

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The information contained in this publication is based on knowledge and understanding at the time of writing (May 2011). However, because of advances in knowledge, users are reminded of the need to ensure that information on which they rely is up to date and to check the currency of the information with the appropriate officer of NSW Department of Primary Industries or the user’s independent advisor. This report has been prepared as part of the Feral Goat Management in the Western NSW Rangelands project. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of the Western Catchment Management Authority.
Executive Summary

This report benchmarks the current knowledge of the distribution and abundance of feral goats (*Capra hircus*) in the western rangelands of NSW, including the Western Catchment Authority, and places it in a recent historical context. This knowledge has been gleaned from a review of published and unpublished information and developed with new estimates of feral goat abundance over the past 19 years (1992-2010) permitted by newly calculated correction factors for aerial surveys of feral goats coincident with NSW Office of Environment and Heritage Kangaroo Management Program (KMP) counts of kangaroos.

Key findings of the investigation were:

1. Populations of feral goats across Australia, including the Western rangelands of NSW, have increased from the early 1970s, as has commercial harvesting. The Western rangelands of NSW constitute 25% of the national distribution but have the highest densities of goats.

2. "Best knowledge" maps of feral goat distribution and relative abundance derived from interviews with local experts were available from 1978, 1979, 1980, 1985, 2002/03, 2004/05 and 2009. Methods were inconsistent between surveys, allowing only the relative distribution to be contrasted between them.

3. Best knowledge maps showed that distributions had increased between 1978 and 2002, retracted in 2004 and increased again 2009.

4. Correction factors for goat counts were calculated at three sites using fixed wing aircraft flown at standard height and speed of aerial surveys undertaken by KMP.

5. An overall correction factor of 1.129 was applied to raw counts of goats from KMP aerial surveys, indicating that the counts by aerial observers were underestimates (i.e. negatively biased).

6. The mean annual density of feral goats in the western rangelands of NSW during the study period was 2.83 ± 0.06 goats per km² (range 1.14 – 5.61 goats per km²). The median annual density was 2.58 ± 0.25 goats per km².

7. Corrected feral goat abundance estimates in the western rangelands of NSW ranged from a low of 521,458 ± 45,523 in 1999 to a high of 2,573,562 ± 198,613 in 2009. The most recent abundance of feral goats (in 2010) was 2,533,090 ± 181,394. These are still underestimates for methodological reasons.

8. The average exponential rate of increase of the region was 0.065 (range -0.401 to 0.526). The population has been increasing since 1999 and this is despite high commercial off-take and culling on public lands.

9. Given calculated average rate of increase and similar conditions to the study period, the goat population in the western rangelands of NSW will double by 2021.

10. Insufficient data regarding goat ownership was available to enable subtraction from the aerial survey estimates.

11. The rate of removal of goats for human consumption likely contributed significantly to overall mortality from 1992 but rates of increase were mostly positive in that period.

12. Feral and rangeland goats are likely to remain abundant in the western rangelands of NSW under the current management.

13. Numbers in 2011 are likely to be high given the good seasonal conditions in the second half of 2010 and early 2011.

Given the economic importance of feral and rangeland goats to landholders in the western rangelands of NSW, and their capacity to rapidly increase in abundance, their management will be an ongoing activity. To ensure a positive triple bottom line outcome, measures of the environmental effects of different densities of goats and different mixes of co-grazing domestic, native and feral herbivores are required and this information is currently lacking.

An integrated approach to goat management, taking into consideration the different objectives of private and public land managers, is recommended. With sufficient planning and goodwill, this can be implemented immediately using the strategic approach.
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Introduction

Background

In the Australian context, goats (*Capra hircus*) are exotic herbivores. They were first introduced to the continent by Europeans in 1788 (Rolls 1969) but have since been introduced many times (Mitchell 1988; Evans 1980; Harrington 1982, Parkes et al. 1996, Henzell 2000). Typically brought to Australia as domesticated livestock, goats have become wild, unhusbanded and therefore feral (Fleming 2004) following repeated deliberate and accidental releases (Parkes et al. 1996).

Bioclimatic modelling has indicated that much of Australia has suitable climate and habitat for feral goats and that includes all of the Western rangelands of New South Wales (West 2008). Goats occur extensively throughout semi-arid rangeland environments (Parkes et al. 1996, West 2008), where a broad, generalist diet (Harrington 1986) and an ability to survive away from water for two to three days (Dawson et al. 1975, Freudenberger & Hume 1993) have been key to their success. Although goats in wet areas may obtain their water requirements from forage (Parkes et al. 1996, Fleming, Tracey and Jones unpublished data), in hot and dry areas, such as the western rangelands, they need daily access to drinking water when the ambient temperatures are over about 30°C (Norbury 1993).

Goats are capable of surviving on fibrous herbage with low levels of nutrients (Doyle et al. 1984) and they can browse shrubs and trees, graze forbs and grass, eat fallen fruit capsules, bark and other dead plant material (Dawson et al. 1975; Squires 1980; Dawson and Ellis 1996). As consumers of such a wide range of vegetation, feral goats contribute substantially to total grazing pressure in the woody rangelands of NSW and have been described as the species having the greatest potential for causing grazing impacts in the region (Landsberg and Stol 1996).

As well as the potential to impact directly on vegetation, goats may in turn negatively affect native fauna (e.g. Lim 1987; Murphy 1986) via habitat degradation (Parkes et al. 1996) or impact negatively on livestock production. With respect to the latter, feral goats are perceived by many graziers to compete with sheep and cattle enterprises in the Western Division of NSW (Hacker and McLeod 2003), while others regard them as a resource. In addition, “wild” goats are considered game animals under the *NSW Game and Feral Animal Control Act 2002*, which means they have potential value to recreational hunters.

In NSW, and nationally, competition and land degradation by feral goats is listed as a key threatening process (see *NSW Threatened Species Act 1995* and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*, respectively) and they are identified as a key threatening process for two iconic Western NSW species, mallee fowl (*Leipoa ocellata*) and yellow footed rock wallabies (*Petrogale xanthopus*). Feral goats themselves are not declared pests under the *NSW Rural Lands Protection Act 1998*, but could be declared so locally under the part 11 of the Act if nominated by the local Livestock Health and Pests Agency (LHPA).

The environmental and agricultural impacts of feral goats on Australian society have been valued at $7.7m annually (McLeod 2004). In contrast, the value of goat and goat meat exports from Australia, of which ~90% were likely free-ranging feral or rangeland types, was estimated at $46.1m in 2000/01 and $82.2m in 2005/06 (Schuster 2006). Approximately 90% of national production in 2005/06 (~1.282 million head) was derived from feral (~40%) and rangeland (55%) animals (Schuster 2006). About 50% of the national total was exported from NSW and Victorian abattoirs, but sourced mainly from the western rangelands of NSW where there are no meat processors that handle goats (Schuster 2006; Forsyth and Parkes 2004).

Hence, managing free-ranging goats can be problematic because their various perceived and/or real positive and negative impacts, which result in different values for different segments of the human community. Informed decision-making is therefore vital for setting appropriate policy and avoiding conflict. Managers, as a minimum, need information on the number of animals, their distribution, how those population parameters have changed over time and how they might be expected to behave. This report addresses these fundamental requirements for feral goats in Western NSW by bringing together data from existing, disparate sources.

Estimates of the number of feral goats in Australia range from 1.5 million (Popple et al 1996) to 5 million (DAFF 2005) and they occupy approximately 1.2 million km² of rangelands. The distribution of feral goats in Western NSW rangelands is approximately 25% of the national distribution and the average density there is higher than in other States (~3.6 goats per km², Parkes et al. 1996). Historical estimates of feral goat abundance and distribution for the Western Division of NSW generally indicate that both have increased since the 1970s, when the estimated likely abundance was 57,500.
head (maximum 553,900) in 1977 with density range of 0.01–12.0 goats per km² according to habitat (Harrington 1982). A distribution map in Harrington (1982) indicated that the north-west corner of the Western Division was outside the approximate limit of their distribution but later maps have shown goats in those areas and further east than they predicted. In 1992, aerial surveys of the western rangelands indicated an uncorrected density of 1.51 ± 0.23 goats km² (Southwell et al. 1993), which equates to a minimum population size of 699,800 ± 104,500 goats.

Aerial surveys provide a rapid and efficient means of surveying large mammals such as feral goats and many techniques have been developed to adjust for the inability to count all animals within transects. Without adjustment for detection probability, abundance estimated using aerial surveys are known to be biased (Caughley et al. 1974) and can influence the ability to detect changes in populations over time and between sites (Tracey et al. 2005).

Detection probabilities and related bias from aerial surveys are known to vary considerably with: human factors including individual observer skill and observer experience; vegetation structure and density; activity and behaviour of the target animal; group size, and gender and age composition of groups; varied lighting, weather conditions including cloud cover, and time of day; and survey variables such as aircraft altitude and speed, and transect width (Caughley et al. 1976, Caughley 1980; Mahood 1985, Bayliss and Giles 1985; Tracey et al. 2005; Fleming and Tracey 2008). However, revised survey protocols (e.g. Fleming and Tracey 2008) and analysis techniques allow corrections to be made for a range of these variables (e.g. Melville et al. 2008, Laake et al. 2008; Fewster and Pople 2008).

Published reports on feral goat population abundance and distribution in NSW (e.g. Southwell et al. 1993) and rates of increase have been sporadic over the past 20 years and some historical data are in theses and other unpublished reports (e.g. Mahood 1985, Maas 1997). However, during the period from 1992 until the present, systematic surveys of feral goats have been repeated annually for the Western Division as part of the State Kangaroo Management Program (Payne 2008). These data have not been used because correction factors for feral goats have not been available.

Aims and Objectives

The objectives of this project are to benchmark historical and current knowledge about free-ranging goat distribution and abundance in the Western NSW rangelands, and to use this information to forecast feral goat population trends. The specific aims are to determine:

- the historical distribution and relative abundance of feral goats in the western rangelands of NSW
- detection biases in estimates of goat abundance obtained from fixed wing aircraft and use these to calculate correction factors for fixed-wing aerial surveys of goats the western rangelands, 1992 to 2010
- goat population estimates and trends from aerial surveys of the western rangelands, 1992 to 2010
- the distribution of feral goats across the Western Division from aerial surveys and map changes over the period
- the relative numbers of goats harvested and numbers of domestic goats on holdings in the western rangelands, if data is available from third parties.

Given these analyses, predictions will be made on:

- goat population trends
- goat distribution trends
- the relative contribution of feral goat harvesting and domestication to population trends.

These forecasts assume that future climatic, domestication and harvesting conditions will be similar to the past 19 years when data has been collected.
Methods

Study area

The area examined in this report is necessarily delimited by the study areas of the sources of data. The ongoing annual aerial surveys of kangaroos and feral goats undertaken the Kangaroo Management Program (KMP), National Parks and Wildlife Division of the Office of Environment and Heritage cover the western rangelands (Fig. 1) and other areas included in the commercial kangaroo harvesting zone. The zone is divided into 1 degree blocks and two transects are flown across each block, along the 15 and 45 minute lines within each degree of latitude (Fig 1).

Figure 1. A map of NSW showing the Western Division, Western CMA area, and 1 degree aerial survey blocks.

The Western Division of NSW is the rangeland region to the east of the South Australian border, south of the Queensland border to the Murray River. It is delineated in the east by a line from the Queensland border near Mungindi in the north to Balranald near the Victorian border in the south. The line follows the Barwon River and Marra Creek, thence to Euabalong and along the Lachlan River to the junction with the Murrumbidgee River and on to its junction with the Murray. This area includes all of Western CMA (Fig. 1) in the north west of the Western Division, the Lower Murray CMA in the south west, and the western part of the Lachlan CMA.

The Western Division does not correspond directly with historical Australian Bureau of Statistics (ABS) Statistical Subdivisions, Statistical Local Areas, or Livestock Health and Pests Authority (LHPA) areas or the area that is aerially surveyed for kangaroo and goats by KMP. Boundaries of statistical divisions also underwent changes in 2001 and 2005 (Australian Bureau of Statistics 2008). This caused problems while attempting to account for the domesticated portion of the goats surveyed from the air. There is no way of differentiating feral from domestic free-ranging goats at the height and speed of aerial surveys (see below) and we have relied on census and questionnaire data collected by ABS, LHPA, Department of Fisheries and Forestry (DAFF) and Meat and Livestock Australia (MLA). Therefore, the reliability of the livestock goat data is restricted by the methods employed by the collecting agency and the non-correspondence of survey boundaries between data sources and collection periods.
Study period
Cartographic historical data was available from 1978, 1979, 1980 and 1985, but the period of the study is focused on the best data set: the KMP aerial surveys, which ran from 1993 to 2010. For completeness, data published for aerial surveys undertaken in 1992 (Southwell et al. 1993) was included, which allowed the calculation of rates of increase for an extra year. Domestic goat numbers on hand and sales from ABS were not available for all years and neither were harvested numbers from public lands, but were included where available.

Data sources
We used 11 sources of data:

1. NSW agriculture department Vertebrate Pest Research Unit has mapped expert estimates of relative abundance at intervals from 1978 to 2002, 2004, 2009 (West and Saunders 2003, West 2008 and West and Ayre unpublished data 2009), reported at a statewide scale or, recently, for 0.5 degree grids.
2. Estimates of free-ranging goat density from broadscale aerial surveys in 1992 (Southwell et al. 1993) reported at a regional scale.
3. Broadscale fixed-wing aerial surveys undertaken by the Kangaroo Management Program of the KMP from 1993-2010, reported at a 1.0 degree block scale.
4. Correction factors from contemporaneous helicopter and fixed wing aerial surveys undertaken by Vertebrate Pest Research Unit (VPRU) and National Parks and Wildlife Service (NPWS) from 2005 to 2010 (calculated from observations of individual groups of goats, i.e. finest scale)
5. Goat National Vendor Declaration (NVD) applications from MLA 2009-2010 (property scale)
6. Shot, trapped and mustered goats out of Western Division Parks and Reserves from the Pest Management Unit of NSW Office of Environment and Heritage (property scale).
7. National Livestock Identification System (NLIS) summaries from Livestock Health and Pest Authority (LHPA) State Management Council (Catchment Management Authority scale).
8. Australian Bureau of Statistics (ABS) agricultural surveys and censuses and DAFF (varied scales)
9. Published and unpublished density, population and rate of increase research (varied scales, e.g. Parkes et al. 1996, Pople et al. 1998b)
10. Published and unpublished reports of goat slaughterings and meat exports (national and statewide scale)
11. Spatial data on goat-proof fencing and trap points within Western CMA (line and polygon data, Catchment Management Authority scale).

Data collection and analysis methods
Historical and best knowledge surveys
“Best knowledge” maps of feral goat distribution and relative abundance derived from interviews with local experts were available from 1978 (NSW Department of Agriculture 1978), 1979 and 1980 (Mahood 1985), and 1985 (NSW Agriculture1985 unpublished map) and on three other occasions during the study period. The methods between these surveys and the abundance categories varied, allowing only presence/absence contrasts between them, i.e. changes to coarse-scale distribution.

For the NSW agriculture department surveys and those in 1979 and 1980, Pastures Protection Board (precursor organisation to current LHPAs) rangers were asked to draw on maps of their area the distribution and relative abundance of all feral animals. These maps were then merged to make the NSW maps.

Three standardised surveys of local and regional experts were undertaken by the Vertebrate Pest Research Unit of NSW DPI and other agencies in 2002, 2004 and 2009 (West and Saunders 2003, West 2008, West and Ayre unpublished data 2009; the methods are outlined in detail in West 2008). Field operatives and rangers familiar with feral animal management in public lands (including National Parks and Wildlife Service personnel) and Livestock Health and Pest Authority regions (previously Rural Land Protection Boards) were asked to draw the distribution of feral animals on maps of their region at 0.5 degree blocks. These distributions were according to relative abundance criteria, which were held consistent across regions, but were still subjective because they relied on the individuals’ knowledge and experience and assumed homogenous visitation and reporting rates across their regions.
**Aerial surveys**

Annual aerial surveys of red kangaroos, eastern and western grey kangaroos and goats have been undertaken in the western rangelands since the mid-1970s (Payne 2008). From 1984 to 2000 surveys were conducted in a consistent manner in a similar aircraft (always a Cessna 206) flying at average height of 76m and at average speed of 185 km hr\(^{-2}\). Strip transects of 200m on each side of the aircraft were flown until 2000 since when the strip width was reduced to 100m in response to studies by Cairns & Gilroy (2001). The region is divided into 1.0 degree blocks (Fig. 1) and two transects are flown at across each block at 15 and 45 minute lines. The same lines are used every year to allow comparison of results between years. This very large area takes 12-15 days of flying time to survey, depending on weather conditions.

Surveys are conducted in June and July when kangaroos are more visible than they are in the hotter months (Bayliss and Giles 1985). Along each transect, trained observers count the kangaroos and goats seen within the strip, which is identified by a tape on the wing strut, for 90 second (i.e. 5km) intervals, then have a seven second break in which they record the information before beginning the next interval.

**Correction factors for fixed-wing aircraft**

Raw counts from aerial surveys represent underestimates, for reasons outlined above and in Fleming and Tracey (2008), and require correction. Correction factors have been calculated for kangaroos in the KMP surveys (Pople et al. 1998a; Cairns & Gilroy 2001; Pople 2004; Payne 2008), but these are species specific and do not apply to goats. Parkes et al. (1996) give a range of correction factors for goats variously calculated for Western Australian and South Australian terrains and vegetation communities (Table 1). However, these correction factors could not be used here because they varied widely between regions of Australia, none were undertaken in the western rangelands of NSW and that estimated for the mulga lands in Queensland (Lee et al. c.1995; Pople et al. 1998b), which are contiguous with the Western Division, were for different aircraft and survey protocols. Hence correction factors were required that were representative of the Western rangelands of NSW.

<table>
<thead>
<tr>
<th>Environment</th>
<th>Correction factor</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flinders Ranges, South Australia</td>
<td>1.33</td>
<td>R. Henzell in Parkes et al. (1996)</td>
</tr>
<tr>
<td>Yerilla, Western Australia</td>
<td>1.89</td>
<td>D. King in Parkes et al. (1996)</td>
</tr>
<tr>
<td>Semi arid low vegetation cover, Western Australia</td>
<td>1.00</td>
<td>Smith (1994) in Parkes et al. (1996)</td>
</tr>
<tr>
<td>Semi arid medium vegetation cover, Western Australia</td>
<td>1.55</td>
<td>Smith (1994) in Parkes et al. (1996)</td>
</tr>
<tr>
<td>Semi arid high vegetation cover, Western Australia</td>
<td>1.95</td>
<td>Smith (1994) in Parkes et al. (1996)</td>
</tr>
<tr>
<td>Average semi-arid Western Australia</td>
<td>1.68</td>
<td>Smith (1994) in Parkes et al. (1996)</td>
</tr>
<tr>
<td>Semi-arid Queensland</td>
<td>~1.00</td>
<td>Lee et al. (c.1995)</td>
</tr>
<tr>
<td>Semi-arid Queensland</td>
<td>1.00-2.00</td>
<td>Pople et al. (1998b)</td>
</tr>
<tr>
<td>Semi-arid Western NSW and Queensland</td>
<td>0.00</td>
<td>Southwell et al. (1993)</td>
</tr>
</tbody>
</table>

To obtain correction factors for fixed wing aerial surveys to apply post hoc to the KMP data, detection probability data was taken from three separate aerial surveys in Western NSW (Fleming and Tracey, 2008; Melville, Tracey, Fleming and Lukins, 2008). Fixed wing and helicopter surveys were flown over 3 large sites (Gundabooka, 30° 36’ S, 145° 41’ E, ~950 km\(^2\); Toorale 30° 10’ S, 145° 42’ E, ~900 km\(^2\); and Yathong 145° 30’ E; 32° 35’ S ~1070 km\(^2\)) with vegetation and terrain representative of much of the Western NSW rangelands. These surveys were flown at the standard height and speed of KMP surveys but with the search area delineated into four 50m strips, out to 200m (Fig. 2). This enabled the calculation of detection probabilities and correction factors that could be applied to both stripwidths used in previous KMP surveys (100m and 200m) and the use of distance (Buckland et al. 1993), tandem-count (e.g. Tracey et al. 2005) and combination analysis methods (e.g. Laake et al. 2008). Sighting, recording and other methods were as used in Fleming and Tracey (2008). It should be noted that due to methodological limitations within KMP surveys arising from human factors (e.g. fatigue and counting rather than the more accurate subtising: where groups are enumerated in ones, twos, threes and fours as animals are seen by observers; Fleming and Tracey 2008), these corrected counts are still negatively biased.
Figure 2. Distance class delineators used during fixed wing aerial surveys in western rangelands of NSW. Yellow zone= 0–50m, green= 50–100m, blue= 100–150, black= 150–200m; red tape delineated the area visible to the observers in their normal seated position.

Detection functions were obtained using a conditional likelihood approach (Ahlo, 1990; Huggins, 1991). Factors initially included in the models were observer position (front or rear), observer pair, observed group size, Distance class (0-50m, 50-100m, 100-150m, 150-200m), vegetation type in which the observation was made and the observation session (morning or afternoon). Only significant variables were used in the final models for each species and aircraft.

Relative numbers of goats behind wire
An estimate of the number of goats that were owned was subtracted from the aerial survey estimates to obtain a breakdown of feral and husbanded goats (rangeland, dairy, meat and fibre goats). A variety of sources were required to obtain the numbers of goats that were owned: ABS (Table 2), DAFF, NVD and NLIS Schuster (2006) and unpublished data held by MLA. Some spatial information was available to examine the relationship of interest in goat management, through construction of infrastructure, and the relative density of goats from KMP surveys.
Table 2. Aggregations of ABS statistical subdivisions used as sources of data for owned goats in Western rangelands of NSW. Goat data was not collected on all ABS censuses and surveys. SLA= Statistical Local Area, which were shire districts; SD= Statistical sub-district.

<table>
<thead>
<tr>
<th>Year</th>
<th>Statistical subdivision data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>Western Division SLAs in Far West, Upper Darling, Macquarie-Barwon (pt), Murray-Darling, Lower Murrumbidgee (pt) SDs,</td>
</tr>
<tr>
<td>1993</td>
<td>Western Division SLAs in Far West, Upper Darling, Macquarie-Barwon (pt), Murray-Darling, Lower Murrumbidgee (pt) SDs,</td>
</tr>
<tr>
<td>1994</td>
<td>Western Division SLAs in Far West, Upper Darling, Macquarie-Barwon (pt), Murray-Darling, Lower Murrumbidgee (pt) SDs,</td>
</tr>
<tr>
<td>1995</td>
<td>Not collected</td>
</tr>
<tr>
<td>1996</td>
<td>Not collected</td>
</tr>
<tr>
<td>1997</td>
<td>Far West, Murray, North Western and Northern SDs (greater area than previously and post 1999)</td>
</tr>
<tr>
<td>1998</td>
<td>Far West, Murray, North Western and Northern SDs (greater area than previously and post 1999)</td>
</tr>
<tr>
<td>1999</td>
<td>Far West, Murray, North Western and Northern SDs (greater area than previously and post 1999)</td>
</tr>
<tr>
<td>2000</td>
<td>Not collected</td>
</tr>
<tr>
<td>2001</td>
<td>Not collected</td>
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<tr>
<td>2002</td>
<td>Not collected</td>
</tr>
<tr>
<td>2003</td>
<td>Not collected</td>
</tr>
<tr>
<td>2004</td>
<td>Far Western only CoV range from 10% to 50%</td>
</tr>
<tr>
<td>2005</td>
<td>Not collected</td>
</tr>
<tr>
<td>2006</td>
<td>Not collected</td>
</tr>
<tr>
<td>2007</td>
<td>Not collected</td>
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<tr>
<td>2008</td>
<td>Not collected</td>
</tr>
<tr>
<td>2009</td>
<td>Not collected</td>
</tr>
<tr>
<td>2010</td>
<td>Western and Darling LHPAs Land &amp; Stock returns</td>
</tr>
</tbody>
</table>
Relative numbers of goats harvested
To estimate the number of goats that were removed annually to contrast with the aerial survey estimates data was obtained from Harrington (1982), ABS, DAFF, Schuster (2006) and unpublished data held by MLA. To fill in years where data was absent, regressions were drawn from the known data for 1974 to 1979 and 1997 and interpolated for 1980 to 1996.
Results and discussion

Historical distribution and relative abundance
Although methods varied between surveys, these have resulted in maps (Figures 3, 4, 5 and 6) that are useful for observing broad scale changes. For example, the general distribution of feral goats would appear to have expanded in the Western Division between 1978 and 1985.

The distribution of medium densities expanded between surveys and that of high densities contracted, but may have reflected differences in methods, and the experience and opinions of respondents rather than real changes.

Figure 3. Distribution and relative abundance of feral goats in NSW in 1978 from a survey of experts conducted by John Waithman and David Croft, Vertebrate Pest Unit, NSW Department of Agriculture. Density categories are High = larger herds above 50 goats, Medium = number of smaller herds 20-50, Low = few small herds and Nil = no sign reported.
Figures 4 and 5. Distribution and relative abundance of feral goats in NSW in 1979 and 1980 from a survey of experts conducted by John Waithman and David Croft, Vertebrate Pest Unit, NSW Department of Agriculture (from Mahood 1985). Density categories are High = abundant goats, Medium = common, Low = occasional small herds and Nil = no sign reported.
Figure 6. Distribution and relative abundance of feral goats in NSW in 1985 from a survey of experts conducted by Hedy Bryant and Glen Saunders, Vertebrate Pest Research Unit, NSW Department of Agriculture. Density categories are High = abundant goats, Medium = number of smaller herds 20-50, Low = few small herds and Nil = no sign reported.

Review of the “best knowledge” maps showed that distributions had increased to the north-west between 1978 and 1985. The historical core distribution to the east of the Darling River, north from the Murray River, persisted throughout.

More recent surveys (Fig. 7, after West & Saunders 2003; West 2008 and West and Ayre unpublished data 2009) have followed a common data collection process and are therefore more comparable between years. These maps show overall consistency of distribution and relative abundance between surveys, and that some expansion into the north-west occurred in 2009 (Fig. 7). The historical distribution between the Darling and Lachlan Rivers remained, although perceived density generally increased there. The distribution to the north-west of the Darling has become well established and wider than in the 1970s maps.
Figure 7. Distribution and relative abundance density of feral goats in 2002/03, 2004/05 and 2009 (after West and Saunders 2003, West 2008 and from West and Ayre 2009 unpublished data).
Goat population estimates from aerial surveys, 1992–2009

Correction factors for fixed-wing aircraft
The detection functions for goats were derived after pooling the data from all sites. The best model was used and for goat sightings was:

\[ \text{Detection} = \text{Position} + \text{Group Size} + \text{Distance class} \]

Just under 90% of available goats were counted (Table 3) during the three surveys undertaken to estimate detection probabilities.

Table 3. Sighting details for feral goats used to calculate detection and correction factors for fixed wing surveys of three sites in the western rangelands of NSW.

<table>
<thead>
<tr>
<th></th>
<th>Number of groups seen</th>
<th>Count</th>
<th>Corrected count</th>
<th>Overall detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sites</td>
<td>144</td>
<td>1107</td>
<td>1249</td>
<td>0.886 (range 0.81–0.888)</td>
</tr>
</tbody>
</table>

Average correction factors for feral goats at the three sites (where correction factor = 1/Overall detection, Table 3) were then applied to goat counts from KMP annual surveys and Southwell et al. (1993) estimate.

Goat density estimates
Based on equal-sized sampling units within annual surveys, corrected counts of goats were used to generate goat densities, estimates of population size and standard errors (for sampling without replacement) using the 'simple' model outlined in Caughley & Sinclair (1994). These values were generated for each 1.0 degree block and for the entire KMP aerial survey area.

Overall goat density, for the area covered by KMP aerial surveys (Fig. 1), ranged from a minimum of 1.14 goats per km² in 1999 to a maximum of 5.61 goats per km² in 2009. At a block scale, densities ranged from 0.00 to 24.14 goats per km² although most blocks, in most years, had densities from 0 – 6.03 goats per km² (Figures 8, 9 and 10, see also Spatial trends across the western rangelands). From 2004 onwards, the proportion of blocks with densities above 6.03 goats per km² increased markedly. Throughout the entire study period, only block 83, a partial block in the south west of the study area, had no goats recorded in it.
Figure 8. Goat density estimates for 1-degree survey blocks in Western NSW; 1993 to 1998 inclusive.
Figure 9. Goat density estimates for 1-degree survey blocks in Western NSW; 1999 to 2004 inclusive.
Figure 10. Goat density estimates for 1-degree survey blocks in Western NSW; 2005 to 2010 inclusive.
Goat abundance estimates

Goat abundance, as a function of density (above), also varied considerably throughout the study period (Fig. 11). The total goat population within the aerial survey area was estimated to be at its lowest in 1999, with 521,458 ± 45,523 goats. This climbed to a maximum of 2,573,562 ± 198,613 goats in 2009. Most recently, (in 2010) goat abundance was estimated to be 2,533,090 ± 181,394. As aerial surveys within 1 degree blocks did not always record goats, abundance estimates at block-scale (Figures 12, 13 and 14) ranged from a minimum of zero goats upwards to a maximum of 253,971, for Block 45, in 2010.

Figure 11. Goat abundance estimates for the KMP kangaroo survey area, 1992 to 2010, inclusive. Standard errors bars are for sampling without replacement. 1992 estimate is corrected from Southwell et al. (1993).
Figure 12. Goat abundance estimates for 1-degree survey blocks in Western NSW; 1993 to 1998 inclusive.
Figure 13. Goat abundance estimates for 1-degree survey blocks in Western NSW; 1999 to 2004 inclusive.


Goat Population Estimates: 2004

Estimated Goat Population

- Green: 0
- Light Green: 1 - 63493
- Yellow: 63494 - 126985
- Orange: 126986 - 190478
- Red: 190479 - 253971
Figure 14. Goat abundance estimates for 1-degree survey blocks in Western NSW; 2005 to 2010 inclusive.
Spatial trends across the western rangelands

Goat density, and therefore abundance, tended to be lowest in the periphery of the survey area. With the exception of blocks 23 to 26 in the central north of the survey area, and block 42, in the central west, higher densities of goats tended to occur in the central portion of the survey area (blocks 33 – 35, 43 – 45 and 53 – 55, inclusive). This area was also highlighted in several expert surveys, e.g. 1978, 1979, 1980 as well as in 1993 by Southwell et al. (see Historical distribution and relative abundance) supporting the notion of a long term trend.

From year-to-year, blocks south of the 34th degree of latitude line (72 to 85 inclusive) and east of the 148th degree of longitude (19, 28, 29, 38, 39 and 48) were relatively stable (Fig. 15). Elsewhere, blocks tended to experience annual increases more frequently than decreases, in accordance with overall population growth (see Goat population estimates).

Figure 15. Trends in goat abundance in each 1-degree block, between 1993 and 2010.

Despite this, no observed overall increases or decreases occurred uniformly (Figures 16, 17 and 18). Even when the overall population experienced its greatest rate of increase (i.e. from 2000 to 2001, see rates of increase) or decrease (1993 to 1994), the population of some blocks either remained stable or showed a reverse trend.
Figure 16. Changes in goat abundance, per 1-degree block, between subsequent years; 1993 to 1998.
Figure 17. Changes in goat abundance, per 1-degree block, between subsequent years; 1998 to 2004.
Figure 18. Changes in goat abundance, per 1-degree block, between subsequent years; 2004 to 2010.

![Feral Goat Population Status: 2004-2005](image1)

![Feral Goat Population Status: 2005-2006](image2)

![Feral Goat Population Status: 2006-2007](image3)

![Feral Goat Population Status: 2007-2008](image4)

![Feral Goat Population Status: 2008-2009](image5)

![Feral Goat Population Status: 2009-2010](image6)

**Population Status**

- RED: INCREASED
- GREY: STABLE
- GREEN: DECREASED
Relative numbers of goats behind wire

This data (Fig. 19) proved most difficult to obtain because of differences in collection methods through the period of the study, and changes to ABS statistical divisions and subdivisions (Table 2) and survey questions between survey and census periods. Hence the data should be viewed with great caution. The data for 2004 was only for the Far Western Statistical Sub-district, which approximately coincides with the Western CMA. The data was of insufficient accuracy or consistency for use to determine the proportion of feral and husbanded goats among those aerially surveyed.

![Graph showing total goats and number sold from 1992 to 2010](image)

**Figure 19.** Goats recorded as domestic on hand (solid bars) and sold (pale bars) for the period 1992 to 2010 from Australian Bureau of Statistics Censuses and Surveys. Different coloured bars cannot be compared directly because of different data collection methods. See text and Table 2 for details of methods and changes in these between years - no data was collected in blank years.

Goats are not constrained by most sheep or cattle fencing. Incorporating them into an ongoing enterprise as one of the livestock mix requires landholders investing in fencing and handling infrastructure. To encourage a more enterprise-based approach to managing goats, the Western CMA has promoted the use of goat-proof fencing and trapyards since 2005 (Fig. 20).
Figure 20. Locations of goat fences, goat trap yards and national parks within the Western CMA area. Relative goat density is from the 2010 aerial survey in Fig.10.

Latest information from the Western CMA indicates high uptake of fencing and trap yards, with 254 trapyards and 3,450 km of goat-proof fencing funded by the Western CMA and additional fencing erected by landholders without Western CMA assistance. Locations of this goat management infrastructure correspond with areas of recent high density (Fig. 20) or ongoing harvesting effort.

In addition to private infrastructure, NPWS has commenced a program of strategic fencing on reserves, coupled with one-way gates and water closures, to protect specific vegetation communities and targeted populations of threatened flora and fauna (Russell et al. In Press). For example, three goat-proof fences totalling 16 km have been erected at Gundabooka National Park (in block 35 Fig. 1 and Fig. 20) to direct goats onto neighbouring land for neighbours to incorporate in their rangeland goat enterprise or to harvest.

If the uptake of better technologies for managing goat numbers and dispersion becomes dominant and widespread, the reliance on harvesting feral goats within enterprises will diminish. Landholders will need to adjust their enterprise mix to incorporate rangeland goats as part of their total grazing pressure. Reciprocally, if harvesting goats is important to landholders, other stakeholders in goat management may need to accept that strategic planning for goat management will necessarily involve consideration of potential negative impacts on livestock enterprises.
Relative numbers of goats harvested

This data also proved difficult to obtain because of differences in collection methods through the period of the study and between agencies collecting the data. The total numbers of goats removed slaughtered annually from Australia and the area of the KMP aerial surveys were estimated from combined datasets for private and public landholders and are shown below.

Removal of domestic goats by private landholders

There were 1748 identified properties in the Western Division in 2010 (Udai Pradhan, NSW DPI, unpublished records 2011) and nearly a quarter (430) have applied for and received National Vendor Declaration forms from Meat and Livestock Australia (MLA) from 2004 to 2010 (Bruce Gormley, MLA personal comm. 2011). NVD forms are required for the transport of live goats from one property identification code (PIC) to another, or to saleyards or abattoirs. This does not mean that all of these property owners used any of the forms or removed goats from their holding but does indicate a level of interest in harvesting of feral goats or selling domesticated goats.

During the KMP survey period, numbers slaughtered nationally (Fig. 21) varied between years, likely reflecting price stimuli and seasonal availability, but have generally increased more than fivefold since 1990. Because of data collection differences, regressions were fitted separately to data from 1974 to 1996 and from 1997 to 2010. The trend (Fig. 21) from 1974 to 1996 was linear increasing \( y = 349.12x - 600.77, r^2 = 0.996, n = 6 \) years, but in the second period the rate of off-take increased, dramatically so after 2001 \( y = 1345.5x - 5584.9, r^2 = 0.822, n = 14 \) years.

Figure 21. Reported goat meat exports (tonnes) from Australia 1991–2010, including domestic stock but not live exports. Brown bars are estimates calculated as per text, green bar is 1997 ABS estimate, black bars are from Schuster (2006), and 2007 to 2010 from DAFF unpublished data. Data for 2007 and 2008 is incomplete.
Removal of feral goats by public land managers
The numbers of feral goats removed from public lands managed by NSW Office of Environment and Heritage varied between years (Fig. 22) reflecting funding availability and reporting rates by different staff. The data, while accurate for some parks and reserves for some years, are likely underestimates of the total numbers removed from western rangelands parks and reserves.

Figure 22. Total reported numbers of goats removed from 17 National Parks and reserves by mustering, trapping and aerial culling, 1992 –2010 inclusive.

Predicted goat population trends
Rates of increase
Feral goats have a high reproductive potential. Females attain sexual maturity at around six months of age and produce one to three kids every eight months (Henzell 2000), or twice every 12 months under favourable conditions (Menkhorst 1995). In the absence of control, feral goat populations can increase by up to 75% per year (Henzell 2000). To calculate maximum observed rate of increase in semi-arid Western NSW, Maas (1997) surveyed feral goat populations at Mt Gundabooka (30° 36’ S, 145° 41’ E) and Mt Deerina (30° 44’ S, 145° 09’ E) before, immediately after and 12 months after intensive culling programs and found a maximum rate of increase of 1.513. This means that rangeland populations can increase by more than 50% in one year when resources are super abundant relative to goat numbers.

In accordance with Caughley (1980), the finite rate of increase (the ratio of numbers in two successive years) and the exponential rate of increase ($r_m =$ intrinsic rate of increase and is the exponential rate at which a population with stable age distribution grows when resources are unlimited) were calculated for the goat population within the study area (Table 4).
Table 4. Finite and exponential rates of increase of goat populations within the study area; 1992 to 2010 inclusive.

<table>
<thead>
<tr>
<th>Year</th>
<th>Finite rate of increase (e^r)</th>
<th>Exponential rate of increase (r_m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992-1993</td>
<td>1.547</td>
<td>0.436</td>
</tr>
<tr>
<td>1993-1994</td>
<td>0.669</td>
<td>-0.401</td>
</tr>
<tr>
<td>1994-1995</td>
<td>1.065</td>
<td>0.063</td>
</tr>
<tr>
<td>1995-1996</td>
<td>0.782</td>
<td>-0.246</td>
</tr>
<tr>
<td>1996-1997</td>
<td>0.980</td>
<td>-0.020</td>
</tr>
<tr>
<td>1997-1998</td>
<td>0.990</td>
<td>-0.010</td>
</tr>
<tr>
<td>1998-1999</td>
<td>0.788</td>
<td>-0.238</td>
</tr>
<tr>
<td>1999-2000</td>
<td>1.675</td>
<td>0.516</td>
</tr>
<tr>
<td>2000-2001</td>
<td>1.692</td>
<td>0.526</td>
</tr>
<tr>
<td>2001-2002</td>
<td>0.802</td>
<td>-0.221</td>
</tr>
<tr>
<td>2002-2003</td>
<td>0.939</td>
<td>-0.063</td>
</tr>
<tr>
<td>2003-2004</td>
<td>1.417</td>
<td>0.348</td>
</tr>
<tr>
<td>2004-2005</td>
<td>1.108</td>
<td>0.102</td>
</tr>
<tr>
<td>2005-2006</td>
<td>0.814</td>
<td>-0.206</td>
</tr>
<tr>
<td>2006-2007</td>
<td>1.296</td>
<td>0.259</td>
</tr>
<tr>
<td>2007-2008</td>
<td>1.398</td>
<td>0.335</td>
</tr>
<tr>
<td>2008-2009</td>
<td>0.861</td>
<td>-0.149</td>
</tr>
<tr>
<td>2009-2010</td>
<td>1.143</td>
<td>0.133</td>
</tr>
</tbody>
</table>

Between 1999 and 2000, the goat population within the study area increased at an exponential rate of 0.526; the maximum rate for this study. In contrast, from 1993 to 1994 the population experienced maximum decrease, at an exponential rate of -0.401. If sustained, these rates would equate to the population doubling in 1.32 years, or halving in 1.73 years, respectively. Overall, the average exponential rate of increase observed between 1992 and 2010 was 0.065. At this rate, the population would be expected to double in size in 10.7 years.

It is worth noting that the maximum exponential rate of increase observed in this study was higher than those reported by previous studies from NSW, e.g. 0.395 (Mahood 1985) and 0.414 (Maas, 1997) for rangelands and 0.112 for central eastern NSW (Fleming 2004).

Simple population trend predictions

Observed exponential rates of increase from this, and previous relevant studies (Fleming 2004) were applied to an average of population estimates from 2008 to 2010 to make simple population trend predictions until 2020. They assume the mortality, survival and recruitment factors over the next 10 years will be similar to those observed in the previous 19 years. No attempt has been made to use productivity of rangeland systems under different total grazing pressures, rainfall regimes and drought incidence to develop numerical response models.

Assuming a starting point equal to the average of population estimates for 2008 to 2010, and an exponential rate of increase equal to the average of 0.065 observed in this study the goat population would reach 4,675,986 in 2020 (Fig. 23). If, however, the population were to increase at a higher exponential rate of 0.112, as recorded from a monitored population of goats near Coolah, in central eastern NSW (Fleming 2004) the population could be expected to reach 7,481,550.
Figure 23. Simple goat population trend predictions for the average exponential rate of increase observed in this study and the maximum exponential rate of increase reported by Fleming (2004). For context, a stable population, based on the most recent 3 years' estimates is also shown.

Predicted relative contribution of feral goat harvesting and domestication to population trends

Unless harvest rates dramatically increase, feral goat numbers are unlikely to diminish into the future. This is probably a desirable outcome for landholders who obtain financial gain from feral goats. However, if it is desirable to lower goat abundance to achieve environmental targets across the region, control and management efforts must increase substantially. Although environmental damage (e.g. Fig. 24) has been reported and valued (e.g. Landsberg and Stol 1996; Mcleod 2004), density/damage or density/yield functions have not been estimated for feral goats in any of the rangeland ecosystems and optimum goat density targets are therefore impossible to set.

Figure 24. Feral goat damage to Acacia sp. showing distinctive browseline to mature shrubs and dead saplings, near White Cliffs NSW, 2009.

Simplistically, and assuming the average exponential rate of increase ($r_m=0.065$), more-or-less continuous births and constant harvesting rates throughout the year, the number of goats that need to be removed to retain stable population at 2010 level is 164,650 ±11,790 goats. However, better estimates of necessary offtake for retaining the population at a particular level or to cause the population to decline will require more complex modelling and additional information to that provided here.
Conclusions and recommendations

Record rainfalls across much of the region, and consequent abundant forage, mean that feral and rangeland goat numbers are likely to increase at maximum rate in 2011. In addition, the distribution of waters after the rains has resulted in restricted access to goats for harvesting and greater dispersion of goats throughout the landscape, resulting in reduced off-take until Autumn 2011 (pers. comm. Blair Brice, Meat and Livestock Australia, Manager Goat Industry Development and Agribusiness). It would be fruitful to revisit the data after the 2011 KMP aerial survey has been conducted and following the 2011 Agricultural Census.

Given the economic importance of feral and rangeland goats to landholders in the western rangelands of NSW, and the capacity of goats to rapidly increase in abundance, their management will be an ongoing activity. In any planning or debate about goats in the rangelands, their multiple values (i.e. livestock, weed controller, harvest resource, game animal, threatening process for soils, vegetation and fauna) must be adequately addressed. Acknowledgement of their value to livestock enterprises will become increasingly important if the population and markets for their sale persist and continue to grow.

To ensure an acceptable triple bottom line outcome, knowledge of the environmental effects of different densities of goats and different mixes of co-grazing domestic, native and feral herbivores are required but this information is lacking. Managers must seek an answer to the question: “What density of goats and livestock mix is sustainable, both economically and environmentally?”

Density/damage and density/yield functions are the first requirements of any economic analysis of feral goat management and these require experimentation for their development. This research is a priority and is required for the major agro-ecosystems within the western rangelands; one size is unlikely to fit all.

An integrated approach to goat management, taking into consideration the different objectives of private and public land managers, is recommended. With sufficient planning, goodwill and stakeholder capacity building, integrated management can be implemented immediately using the strategic approach (Braysher 1993, Parkes et al. 1996). True strategic management is adaptive and has the advantage of allowing actions to occur now, on the basis of current best knowledge. As knowledge advances, it is incorporated into strategic actions that, via monitoring, generate more knowledge and opportunity for refining management actions. Although a relatively young approach in Australia, there are experts in adaptive management who could assist western rangeland land managers to implement such an approach at regional and local scales.

To better explain and predict likely abundances and distributions of goats and the effects of different harvesting rates in the western rangelands of NSW, a modelling approach is recommended, using the density and rate of increase data from this report, as well as rainfall, water points, habitat, annual instantaneous primary productivity, densities of other large herbivores gleaned from other sources and seasonal birth, offtake and other mortality rates. A collaborative approach between CMAs and with other states, particularly Queensland and South Australia, would be beneficial.
References


Appendix 3 in *The proposed use of 1080 to control feral goats in Western Australia. Public Environmental Review EPA Assessment No. 752. Agricultural Protection Board of Western Australia.*


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