The impacts of pastoralism on the fauna of arid Australia

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ABSTRACT

Since European settlement there have been profound changes to the fauna of semi-arid and arid Australia. Some species have gone extinct, others have become rare or restricted in range and some have increased their range and abundance. Many, but not all, of these changes in species range and abundance have been linked to the direct and indirect impacts of pastoralism. Grazing by livestock is the main "direct" impact of pastoral activity and has resulted in widespread changes in habitat structure and a decrease in primary productivity. The loss in primary productivity may have reduced the capacity of the landscape to support some fauna species. Pastoral activities have also had indirect impacts on fauna through the establishment of pastoral infrastructure such as artificial waters and barrier fences, and pest control activities. These indirect activities have caused some species to increase in abundance and others to decrease. The widespread extinction of dingoes is likely to have exacerbated the impacts of foxes and overgrazing. Successful restoration of the arid zone fauna will require the restoration of ecological functions and species interactions, particularly nutrient cycling and predation.

Key words: grazing impact, arid, pastoralism, dingo, biodiversity, mammal, reptile, bird, fauna

Introduction

Just as you enter Bourke, in Western New South Wales, there is prominent mural that proclaims "welcome to the outback" (Fig. 1). To me, this mural tells a sombre story about Australians and their arid landscapes. It portrays two ghostly swag-men, walking along a road that crosses a parched and desolate gibber plain. Drought has set in and there's not a blade of grass for miles, the country has been skinned back to its bare bones, yet these two men appear unfazed. Somehow or other they make their living out there, in the "never never". They might be doggers, responsible for the barrier (dingo) fence or perhaps shearers looking for work. A broken fence serves as a reminder, as if the denuded landscape was not enough, of the constant battle our outback pioneers wage and revel in against the harsh Australian landscape.

The imagery contained within this sign is typical of the popular perception of the relationship that Australians have with our vast depopulated arid lands, which comprise 70% of the continent. Our outback pioneers, we are told, have been in a constant and at times life threatening battle against the biota, soil and climate which has forged steely characters whose endurance, propped up by mateship and dry wit, has shaped our nation. These characters have been incorporated into our national identity via icons, both real and fictitious, such as the Akubra hat, Captain Starlight and the Aussie stockman

Progress however has had its costs, our swaggies on the road at Bourke, are unlikely to see many native mammals smaller than a large kangaroo in their travels, the bettongs, stick-nest rats and wallabies are all gone, even the dingoes and possums are a thing of the past. Since the time of European settlement there has been widespread removal of Australian Aborigines from their traditional lands, extensive soil erosion, soil and river salinisation, and the loss of many native species of animals and plants, including the extinction and or endangerment of 26 species of native mammal (Morton 1990). Given this record, even a cursory analysis of Australian environmental history can link many of the above environmental issues affecting our arid lands to the direct and indirect effects of pastoralism.

In this paper I will examine some aspects of the history of pastoralism in the Australian arid zone and its impact on the biota. In particular, I will describe the direct effects of livestock grazing on our vertebrate fauna, and the indirect effects of pastoral land management, particularly the disruption of species interactions, such as predation, that appears to have had a dramatic impact on our arid zone fauna.

Figure1. The imagery contained within this billboard from Bourke in western New South Wales is typical of the popular perception that most Australians have of arid Australia. It celebrates the myth of the outback pioneer who must wage battle against a harsh and unforgiving landscape. There is little recognition in popular imagery of the environmental degradation, including species extinction, that has occurred in arid Australia.

Pp 65 - 75 in the *Animals of Arid Australia: out on their own?* 2007, Edited by Chris Dickman, Daniel Lunney and Shelley Burgin. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

Climate and landscape in arid Australia

The arid and semi-arid zones (the arid zone) occupy approximately 70% of Australia's land surface, encompass numerous land forms and vegetation types, and are characterised by low rainfall (Fig. 2). The arid zone is bound in the north by the 750 mm rainfall isohyet, the 250 mm isohyet in the south and the west coast, and the 500 mm isohyet to the east (Young 1979). The north is hot with most of the rain occurring during late summer and autumn (Fig. 2). The south is characterised by hot summers and cold winters with rainfall occurring mainly during winter (Fig. 2). Many of the landforms of arid Australia are particularly ancient and consequently have been subject to extensive weathering. For these reasons, the arid zone is relatively flat and possesses extremely poor, nutrient deficient soils. Characteristic vegetation types within the Australian arid zone are the eucalypt woodlands, *Acacia* woodlands, hummock grasslands, Mitchell grasslands, chenopod shrublands and stony deserts (Harrington *et al.* 1984). There are also extensive wetlands in the deserts that serve as vital waterbird habitats and breeding areas (Kingsford 1999; Roshier *et al.* 2001).

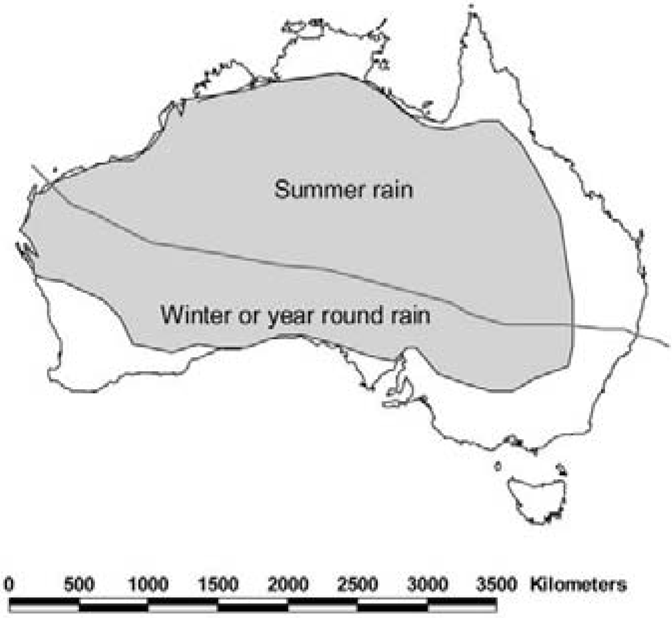

Figure 2. The approximate boundaries of the Australian arid zone (shaded) and the summer and winter rainfall zones.

In arid environments the scarcity of water, generally, limits primary productivity. Rainfall triggers biological, physical and chemical activities that result in pulses of increased primary productivity (Ludwig *et al.* 1997). The magnitude of primary productivity pulses following rainfall is dependent on the size of the rainfall event and the availability of nutrients and seeds (Ludwig *et al.* 1997). In arid Australia, small rainfall events stimulate growth pulses by perennial plants and the germination of short-lived plant species (Ludwig *et al.* 1997). Exceptionally large falls of rain, on the other hand, can prompt major biotic changes, resulting in widespread germination and growth of ephemeral, annual and perennial plant species and the recruitment of perennial species such as trees and shrubs (Ludwig *et al.* 1997).

The occurrence of rainfall and, consequently, primary productivity, in the Australian arid zone is highly variable both in time and space (Nicholls 1991). In northern and eastern Australia, the occurrence of rainfall is strongly influenced by the El Niño/Southern Oscillation (ENSO) (Chiew *et al.* 1998) which, in-turn, reflects current circulations in the Pacific Ocean (Diaz and Markgraf 1992). The two extremes of the ENSO phenomenon are known as La Niña and El Niño, and in Australia are associated with above average and below average falls of rain, respectively (Nicholls 1991). The strong influence of ENSO on the Australian climate results in large inter-annual variability in rainfall with droughts and wet periods having time scales of about one year. When they occur, both El Niño and La Niña events normally start early in the calendar year and cease early in the following year (Nicholls 1991). Thus ENSO has been described as being "phase-locked" to the calendar year (Nicholls 1991). Another characteristic of the influence of ENSO on the Australian climate is that El Niño and La Niña events may follow each other, resulting in extreme year to year changes in rainfall (Nicholls 1991).

European settlement of the arid zone

Settlement

European exploration and settlement of the Australian arid zone began in earnest following Charles Sturt's explorations along the Darling River in 1828 (Sturt 1833) and continued into the 1900s (Madigan 1946). Even in the late 1990s, there were parts of Queensland that were still being opened up for pastoral settlement. Fig. 3 shows the approximate timing of settlement across the Australian arid zone. Not all the arid zone has been used for pastoral settlement. Many areas remain Aboriginal land while other parts such as the central Simpson Desert are not presently occupied.

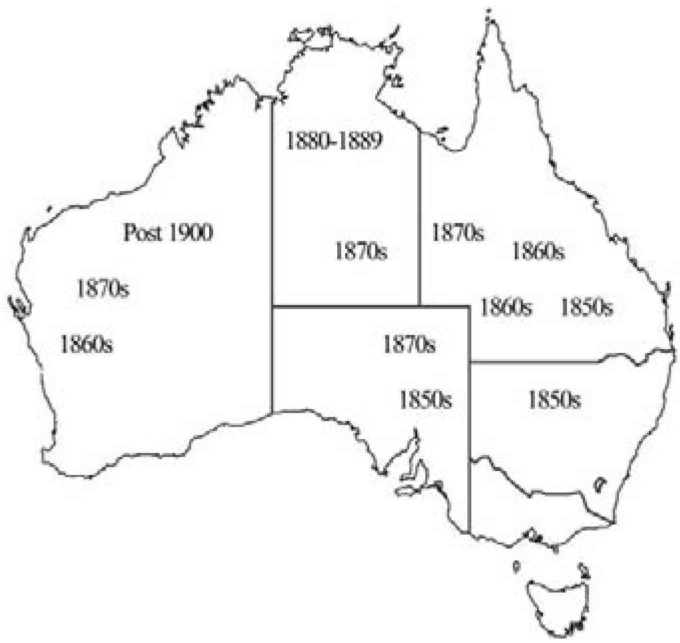

Figure 3. The approximate timing of European settlement of the Australian arid zone.

The early pastoral settlers did not have access to the technology to construct artesian bores or easily construct earthen dams and were thus reliant upon natural waters. Their strategy was to maintain herds during drought seasons that could breed-up and be sold after high rainfall seasons. With the availability of percussion drills after 1920 came the technology to construct artesian bores easily (Letts *et al.* 1979). Consequently the dependence on natural watering points decreased, allowing the utilisation of more land and the maintenance of more stock during droughts. Figure 4 shows the increase in the availability of surface waters on pastoral land in western Queensland that is typical of the pattern seen in the pastoral lands of arid Australia.

The establishment of watering points continues today. In the cattle and sheep grazing lands of the arid zone, watering points have proliferated to such an extent that it is unusual to find places that are more than 5-10 km from surface water (Landsberg *et al.* 1997).

The extinction and endangerment of fauna

Pastoral settlement of arid Australia brought with it a suite of environmental changes, some of which, such as stock and the proliferation of watering points, were directly related to pastoralism, others such as the consequences of rabbits and the red fox were the "baggage" of European settlement. Declines in the abundance of native mammals were identified soon after the colonisation of arid Australia (Krefft 1866). In 1857, Gerard Krefft described the decline of native mammals in western New South Wales and attributed cattle and sheep to be the main threat to these mammals.

Since the British colonisation of Australia, 38 species of mammals are considered to have become endangered or extinct within Australia (Morton 1990). Of these species, 26 were present within the arid zone (Morton 1990). Most of these mammals weighed between 0.3 and 5.0 kg in what has been described as a critical weight range (CWR), and included omnivorous and herbivorous rodents, carnivorous dasyurids, omnivorous bandicoots and herbivorous kangaroos. Many bird species of the Australian arid zone, particularly ground-nesters and those associated with riparian habitats, have also experienced declines in their range and abundance since colonisation (Frith 1962; Grice *et al.* 1986; Reid and Fleming 1992; Smith *et al.* 1995).

Many hypotheses have been proposed to explain the endangerment and extinction of fauna in the Australian arid zone. Among the most widely-cited processes threatening Australian fauna are predation by the introduced predators, the cat *Felis catus* and fox *Vulpes vulpes* (Dickman *et al*. 1993; Smith *et al.* 1995; Dickman 1996a; Smith and Quin 1996; Kinnear *et al.* 2002), overgrazing by rabbits *Oryctolagus cuniculus* and stock (Morton 1990; Reid and Fleming 1992; Smith *et al.* 1995), and altered fire regimes (Smith *et al.* 1995; Maxwell *et al.* 1996).

The putative processes threatening Australian fauna have frequently been hypothesised to operate synergistically with both each other and climatic processes, particularly drought (Finlayson 1961; Frith 1962; Morton 1990; Kerle *et al.* 1992; Priddel and Wheeler 2003). Morton (1990), for example, suggested that the extinction of medium sized mammals in arid Australia resulted principally from the interaction between habitat degradation by introduced herbivores, especially at drought refugia, and drought. In

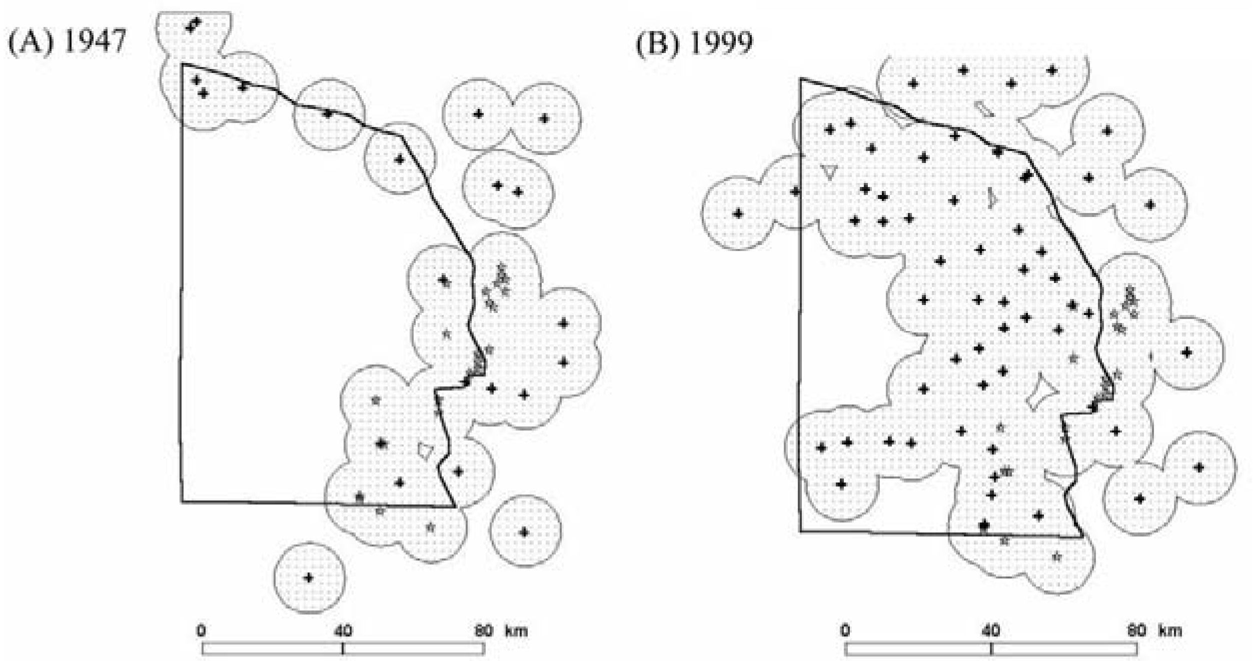

Figure 4. Maps showing the increase in the availability of surface waters within and adjacent to the study area (line) of Letnic and Dickman 2006 comprising three pastoral leases in far-western Queensland. Permanent natural springs (stars) and sub-artesian bores (crosses) are shown. The panels show the distribution of watering points in (A) 1947 and (B) 1999. A 10 km buffer zone has been placed around each watering point within which it is assumed that cattle activity is largely confined.

Morton's (1990) model, introduced predators and altered fire regimes contributed to mammal extinctions but played a lesser role than overgrazing by introduced herbivores. Similarly, Lunney (2001) suggested that extinctions of CWR mammals in western New South Wales were the by-product of overgrazing by stock during drought. He suggested that overgrazing resulted in an overall decrease in primary productivity and, consequently, native mammals could not locate sufficient food resources to persist through severe drought. Copley (1999) proposed that the principal factor contributing to the extinction of stick-nest rats *Leporillus* spp. from mainland Australia was the interaction between drought and overgrazing by introduced herbivores.

Some studies have proposed that periods of unusually high rainfall may be important periods for wildlife management and conservation. Dickman (1996b), Paltridge (2002) and Letnic *et al.* (2005), conducting studies in central Australia, have identified high rainfall periods as being important periods for the management of threats to fauna populations. They suggested that high rainfall periods are important because it is following periods of above average rainfall that introduced predators are abundant and the risk of potentially destructive wildfires is greatest.

The directs effects of sheep and cattle grazing on the landscape and fauna

Sheep and cattle grazing have had well documented effects on the vegetation of arid Australia (Fig. 5). These effects include a general reduction in vegetation cover, an increase in the amount of bare ground, changes in the composition of perennial and annual vegetation selecting against palatable species (Landsberg *et al.* 1997; Ludwig *et al.* 1997), loss of soil nutrients (Sparrow *et al.* 2003), changes in the density and composition of the seed bank (Landsberg *et al.* 1997; Kinloch and Friedel 2005), decreased seed production (Letnic 2004), increased soil erosion (Wasson and Galloway 1986), and the disruption of microbiotic soil crusts that play an important role in nutrient cycling (Eldridge and Green 1994).

Figure 5. Spinifex grassland regenerating after fire, situated approximately 1 km from an artificial watering point. The area in the foreground had been subject to grazing by cattle. The fenced area has been excluded from cattle for one year. Vegetation height, basal vegetation cover and seed production were greater in the fenced area than in the grazed area (Letnic 2004).

The activity of stock is confined largely to areas near water sources such as rivers, permanent springs and artesian bores (Landsberg *et al.* 1997). Thus most of the grazing impact occurs within 5 km of water for sheep and within 10 km for cattle (Landsberg *et al.* 1997). The impacts of grazing and trampling by stock on vegetation and soils decrease with distance from water, and other factors including prevailing wind direction and topography (Fig. 6; Stafford Smith and Pickup 1990). The sum of these effects has resulted in the creation of piospheres (Lange 1969). Piosphere is the term used for the area surrounding stock watering points that is severely degraded because of overgrazing by stock.

Grazing pressure in the southern arid zone is generally greater than in the northern arid zone due to more intensive sheep grazing and high populations of kangaroos, rabbits and goats (James *et al.* 1995; Ludwig *et al.* 1997; Pople *et al.* 2000; Newsome *et al.* 2001). In these areas overgrazing during drought is likely to be more severe and/or prevalent than in areas that are not utilised for pastoral production or in predominantly cattle grazing areas where wild herbivore populations are less abundant (Ludwig *et al.* 1997; Caughley *et al.* 1980; Pople *et al.* 2001) and surface waters fewer (James *et al.* 1995).

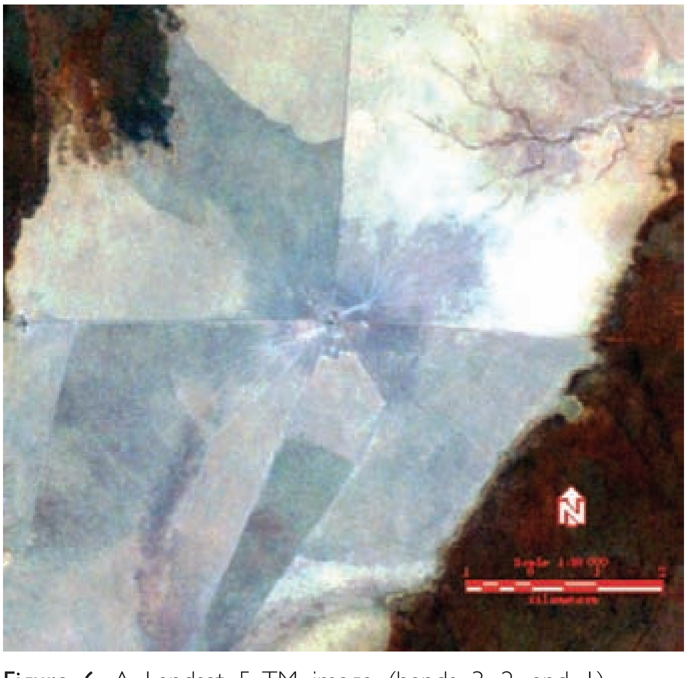

Figure 6. A Landsat 5 TM image (bands 3, 2, and 1) taken in September 2003 of a watering point (centre of picture) in the Victoria River District, Northern Territory showing a piosphere. The grey areas are black soil plains supporting open grassland. The water point is in the centre of the image with obvious linear features depicting fences and/or roads leading from it. The area is split into 4 main paddocks, with some smaller holding paddocks close to the watering point. The differences in colour on the black soil plains indicate areas of different cattle activity and impact. Dark areas in the black soil habitat indicate areas with less vegetation cover and are located near the watering point. Fence lines are clearly marked as distinct lines. The thin white coloured tracks radiating from the bore are tracks that have been worn by cattle.

Despite being widely cited as a process contributing to the demise of arid zone fauna (Reid and Fleming 1992; Maxwell *et al.* 1996), few studies have directly addressed the impact of grazing on fauna in arid Australia (James *et al.* 1995; Landsberg *et al.* 1997; Read 2002; James 2003). Most of the purported impacts of grazing on vertebrates in arid Australia come from historical observations (e.g. Krefft 1866; Lunney 2001), are inferred from literature on vegetation ecology (Morton 1990) or are studies of dietary overlap (Dawson and Ellis 1979; Lundie-Jenkins *et al.* 1993; Edwards *et al.* 1996).

Studies from North America have reported shifts in rodent and bird assemblages owing to changes in vegetation structure that accompany overgrazing (Heske and Campbell 1991; Jones and Longland 1999; Kerley and Whitford 2000); however, the effects of grazing have not always been consistent between studies (Kerley and Whitford 2000). In Australia, habitat changes owing to the impact of grazing on vegetation and soil structure have been documented to influence the distribution of birds and reptiles, favouring some species and selecting against others (Reid and Fleming 1992; Landsberg *et al.* 1997; Read 2002; James 2003). For example, the reduction of vegetation cover in areas close to water has resulted in an increase in the abundance of lizard and bird species that favour open areas (Reid and Fleming 1992; Read 2002; James 2003). Reid and Fleming (1992) have suggested that the degradation of riparian habitats, palatable perennial grasslands and chenopod shrublands by stock is the chief cause of the decline of some bird species. In addition, they stated that the conservation status of birds has been affected more adversely in the southern and central arid regions than in the north.

Livestock may compete directly for forage with native herbivores (Frith 1962; Dawson and Ellis 1979; Edwards *et al.* 1996) Consequently, shortages of food owing to overgrazing may threaten native wildlife (Morton 1990; James *et al.* 1995; Lunney 2001). Competition between livestock and native fauna is likely to be greatest during periods of low rainfall when both the environmental stress on plants and the potential for competition between herbivore species is greatest (Dawson and Ellis 1979; Edwards *et al.* 1996; Ludwig *et al.* 1997).

Many fauna species utilise dense vegetation to seek shelter from predators. Hence reduced vegetation cover, particularly of grasses and ground cover plants, owing to livestock grazing may increase the exposure of native fauna species to predation. This may be particularly the case for ground nesting birds (Frith 1962; Priddel and Wheeler 2001) and mammal species that shelter in dense vegetation.

In general, stocking rates across arid Australia fluctuate in response to rainfall, peaking after good seasons and dropping during droughts. Peak stocking rates in many parts of arid Australia were achieved soon after European settlement, and have never again achieved those peak levels (Fig. 7) despite

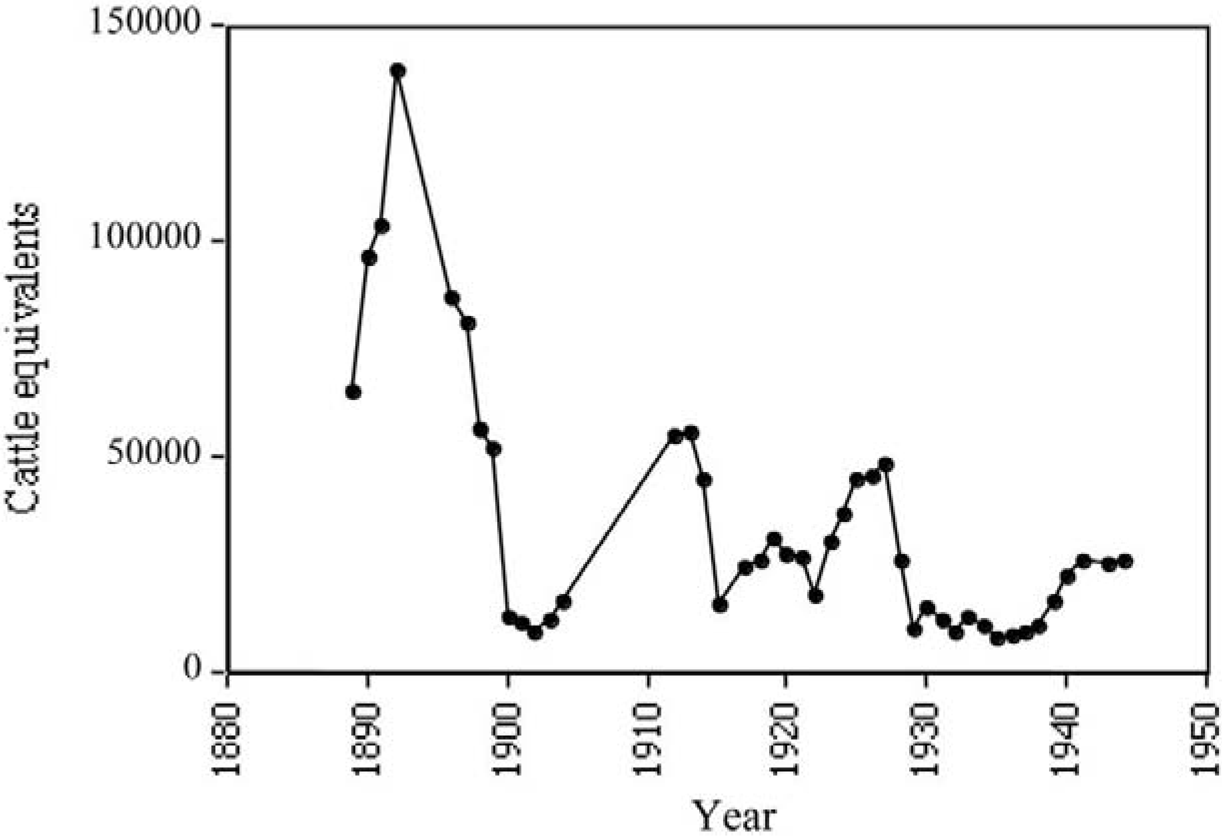

Figure 7. Stocking rates in the Cooper Creek/Diamantina region of South Australia from 1889-1950 (source South Australian Parliamentary Papers). One cattle equivalent represents eight sheep or one cow. The graph is typical of that for degraded arid pastoral country. Soon after settlement, in the 1890s, there is a peak in stocking rate reflecting a productive season. However in the following years there was a massive decline in stocking rate coinciding with drought conditions and in the following fifty years the stocking rate of 1893 was never again attained. This collapse in stocking rate is indicative of overgrazing of the perennial vegetation and loss of topsoil. Periodic peaks and declines reflect fluctuation in stock numbers due to drought and flood seasons.

the availability of artificial waters and hence a greater area of land capable of being grazed (Beadle 1948; Harrington *et al.* 1979; Friedel *et al*. 1990). In many parts of arid Australia, this collapse in stocking rates can be attributed to soil erosion that occurred during the "great drought of 1900/1901". The loss of soil nutrients and decreased seed reserves resulting from overgrazing and subsequent soil erosion have the potential to reduce the size of future growth pulses following rainfall events and result in long-term decreases in primary productivity (Ludwig *et al.* 1997), and presumably resource availability for native wildlife. The severe drought of 2002 may have had a similarly devastating effect on the landscape and fauna to the 1900/1901 drought that has not yet been fully realised.

Indirect effects of pastoralism

Grazing by livestock is not the only impact on the landscape and fauna associated with pastoralism. Pastoral enterprises require the establishment of infrastructure including watering points and fences, the manipulation and control of fire regimes, and the control of species that are perceived to be pests. The changes in landscape structure and function associated with these features of pastoral land use have had an impact on the fauna of the arid zone in addition to the impacts of livestock grazing per se.

Artificial waters have allowed species to use and persist in areas where they were less likely to have occurred previously. The increase in the availability of watering points has resulted in an increase in the abundance and range of many species that require free water. Examples of "increaser" species that are likely to have increased in abundance because of watering points include some species of waterbirds and wader, the zebra finch, some species of parrot and pigeon (Reid and Fleming 1992), grey kangaroos (Newsome 1975) and feral pigs.

Altered fire regimes have also been cited as a factor that has contributed to the extinctions of some arid zone wildlife and as a process that may potentially threaten extant populations (Burbidge and McKenzie 1989; Morton 1990; Smith *et al.* 1995; Priddel and Wheeler 2001). The threats posed by altered fire regimes to wildlife are complex and reflect the shifting and difficult-to-quantify relationships between wildfires and the pre-historic Aboriginal and contemporary burning of landscapes. Two main impacts of altered fire regimes on wildlife have generally been proposed. These are, firstly that Aboriginal burning of landscapes during pre-historic times limited the extent of wildfires and provided a mosaic of habitats regenerating after fire that facilitated diverse vertebrate communities (Burbidge and McKenzie 1989; Burrows and Christensen 1990). With European settlement, such burning practices ceased across much of the continent. As a result, the extent of broadscale wildfires is thought to have increased and relatively fine-grained habitat mosaics beneficial for wildlife have been replaced by large tracts of uniform habitat types of the same age since fire (Burrows and Christensen 1990). The second argument is that, in some areas, pastoral burning of habitat conducted with the aim of improving pasture value has been too frequent and too extensive, resulting in the elimination of habitat for species such as malleefowl *Lepoia ocellata* that prefer long-unburnt areas (Benshemesh 1990; Priddel and Wheeler 2001).

Because of the availability of carrion from dead stock and pest control activities, pastoral activities are also likely to support greater populations of predators than would otherwise be the case (Read and Wilson 2004). Thus pastoral activities may result in elevated levels of predation on native fauna. This may particularly be the case during drought periods.

Pest control has been a feature of pastoral land management since colonisation of Australia. Pest control in arid Australia probably began with the destruction of the dingo *Canis lupus dingo*. During the history of Australian settlement, enormous numbers of native animals have been destroyed in order to assist pastoral production (Hrdina 1997; Short 1998; Glen and Short 2000). This persecution was institutionalised by the passing of legislation such as the *Destruction of Native Dogs Act of 1852* and *The Marsupials Destruction Act of 1881*, of New South Wales and Queensland, respectively, coordinated aerial baiting campaigns (Fig. 8; Anon. 1948) and the erection of government run barrier fences designed to prevent the immigration of dingoes and emus (Marshall

Figure 8. Queenslanders preparing dingo baits containing strychnine for aerial baiting programs conducted in the late 1940s (source Queensland Parliamentary Papers 1947-1948).

1966). In the 19th and 20th century, bounties were paid as an incentive for the population control of native fauna including dingoes, kangaroos, wallabies, bandicoots, bettongs, emus, eagles and kites (Gooding 1955; Hrdina 1997). Dingo bounties are still paid in some parts of Australia. The campaign against dingoes was successful in reducing their populations across large areas of the arid zone (Woodall 1983; Glen and Short 2000), however, the efficacy of population control on other fauna species is unknown.

The destruction of native fauna continues, most notably through the culling of kangaroos and dingoes for pasture protection and livestock protection purposes, respectively. Ironically, the large populations of kangaroos appear to be a by-product of the proliferation of watering points and dingo control (Newsome 1975; Calaby and Grigg 1989; Pople *et al.* 2000).

Introduced animals have also been subject to widespread destruction campaigns (Coman 1999). Normally these destruction campaigns are considered to be beneficial for native species, however, in some instances such as the widespread and indiscriminate laying of poison baits, particularly for rabbits, it is likely that large numbers of native animals were also killed (Rolls 1969; Coman 1999). Similarly, some species of native carnivores may have been susceptible to poisoning by baits laid for dingoes.

The impact of dingo destruction on ecosystem structure and function

There has been considerable debate over the role that dingoes have in regulating the structure of terrestrial ecosystems in arid Australia (Caughley *et al.* 1980; Pople *et al.* 2000; Newsome *et al.* 2001). This debate began with observations that kangaroos and emus were more abundant in areas of western NSW enclosed by the Barrier Fence where dingoes had been exterminated than in adjacent areas in South Australia and Queensland where dingoes were present. Consequently, Caughley *et al.* (1980) suggested that dingoes may regulate their populations. Studies in South Australia have since indicated that populations of kangaroos and emus fluctuate in response to rainfall and that that these fluctuations are dampened in the presence of dingoes, providing further evidence that dingoes may regulate the populations of these large herbivores (Pople *et al.* 2000; Newsome *et al.* 2001). In addition, Woodall (1983), Pople *et al.* (1996) and Newsome *et al.* (2001) observed that populations of feral pigs and feral goats were greater in areas where dingoes were absent or rare. Because the availability of food appears to be the principal factor regulating herbivore populations in the absence of dingoes, some authors have suggested that there is an inherent risk of over-grazing and subsequently soil erosion in areas where dingoes have been exterminated (Ludwig *et al.* 1997).

Several authors have also suggested that dingoes may suppress red fox populations and that the abundance of red foxes is inversely proportional to the abundance of dingoes (Newsome *et al.* 2001; Glen and Dickman 2005), but there are few field data to support this hypothesis. Data for fox and dingo bounties paid in western Queensland in 1952 lend strong support for the hypothesis that dingoes regulate fox populations (Fig. 9). These data suggest that

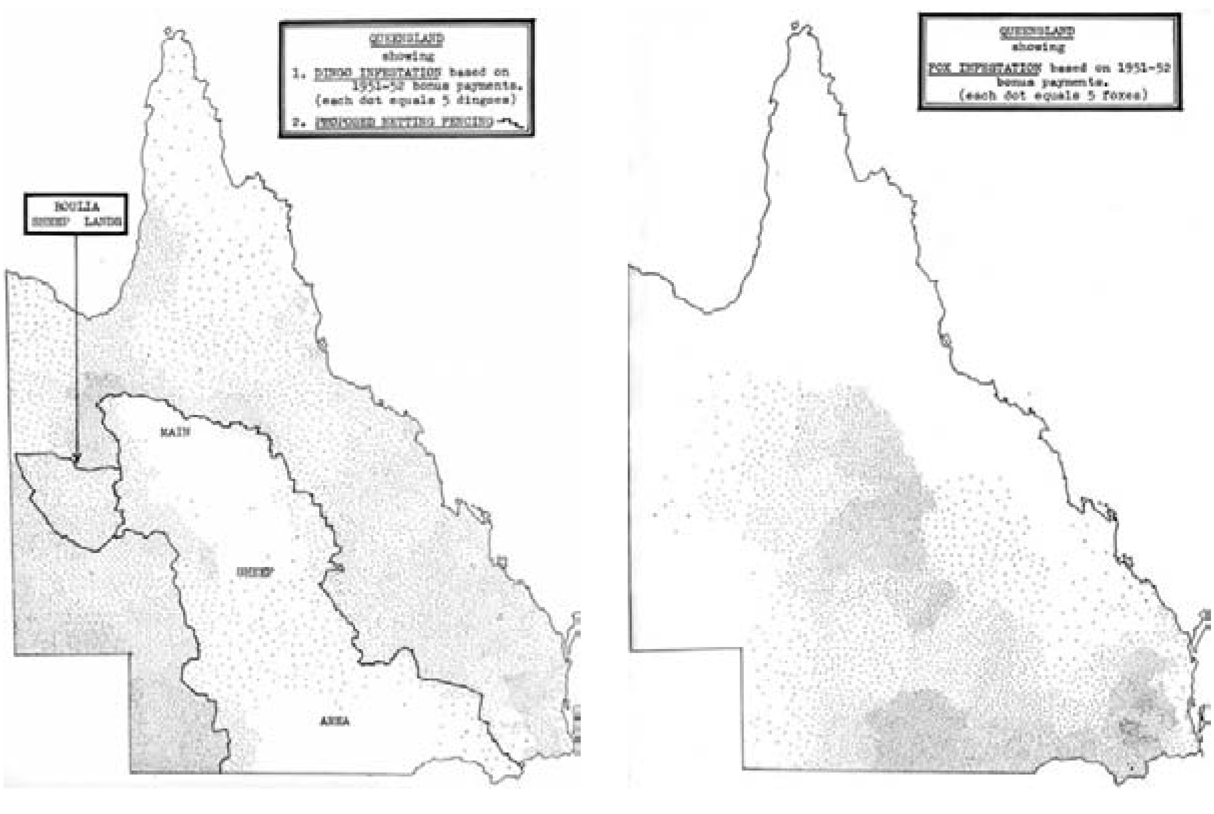

Figure 9. Bounty returns for dingoes and foxes in Queensland for the 1951-52 financial year. The data suggest that foxes were less abundant in areas where dingoes were present (Source Queensland Parliamentary Papers 1951-52). Each dot represents 5 scalps.

foxes were far more abundant in areas where dingoes were rare. Bounty data collected from Western Australia for the period 1947-1952 also show a similar, apparently inverse relationship between dingo and fox distribution and abundance (Gooding 1955).

Elevated fox populations are in turn thought to increase the impact of predation on their primary and secondary prey species (Dickman 1996a), particularly rabbits during periods of rainfall deficiency (Newsome *et al.* 1989; Risbey *et al.* 2000). The control of dingoes is likely to result in an increase in fox abundance, and hence, increase the impact of fox predation on native species. The control of foxes in dingo-free areas appears further to result in the competitive release of cat populations, thereby increasing the impacts of cat predation on small mammal species (body weight <100 g) (Risbey *et al.* 2000).

Studies from overseas lend strong support to the hypothesis that dingoes influence ecosystem structure in the arid and semi arid lands of Australia. The disruption or total cessation of interactions between top-order predators and their prey species have had well documented and dramatic effects on the organization and function of terrestrial ecosystems (Pace *et al.* 1999; Soule *et al.* 2003). These effects include the irruption of herbivores (Berger *et al.* 2001), an increase in the abundance of smaller predators owing to the absence of competition or predation by larger carnivores (meso-predator release: Rogers and Caro 1998) and changes in the abundance and composition of plant communities owing to altered plant-herbivore interactions (Berger *et al.* 1998).

Conclusion: What future for arid zone fauna?

Since European settlement there have been profound changes to the fauna of arid Australia. Some species have gone extinct, others have become rare or restricted in range and some have increased their range and abundance. Many, but not all, of these changes in species range and abundance have been linked to the direct and indirect impacts of pastoralism. There is some evidence to suggest that the impacts of pastoralism on fauna have been greater in the sheep grazing lands enclosed by barrier fences than in the cattle grazing lands. The reasons for this are that watering points are more closely spaced and there are generally higher densities of herbivores and foxes in these areas.

Restoration of the fauna of arid rangelands will require more than just reintroducing locally extinct species into predator proof enclosures. Long-term and widespread restoration of the arid zone fauna will require management strategies that tackle the underlying causes of species decline, namely loss of primary productivity and predation by introduced predators. Hence the rationale for ecological restoration, including species reintroductions should be the restoration of ecological functions, particularly nutrient cycling and species interactions such as predation.

Primary productivity and the drought resistance of vegetation can be improved through the restoration of resource sinks in the landscape (Ludwig *et al.* 1997). Patches of ground vegetation, particularly perennial grasses and saltbushes serve a vital function within landscapes as sinks for nutrients, water and seeds. Overgrazing by herbivores degrades the ability of these patches to capture and retain resources and hence reduces the ability of vegetation to respond to future pulses of rainfall. Maintaining and restoring resource sinks will assist fauna conservation by providing both food resources for fauna and shelter from predators. Reducing total grazing pressure is imperative if landscape function is to be restored. Strategies that can be employed include strategically closing watering points to reduce grazing pressure by water dependent herbivores (Freudenberger and Hacker 1997), and controlling populations of introduced animals and kangaroos.

The reintroduction or maintenance of dingo populations, in addition to fox control, may have benefits for fauna conservation, particularly in conservation reserves, by reducing fox populations and also by reducing herbivore populations and hence grazing pressure. Because of their depredations on stock, maintaining or reintroducing dingo populations is a contentious issue and is not necessarily a realistic management strategy throughout the rangelands. In areas where dingoes cannot feasibly be reintroduced, it may useful from a biodiversity conservation perspective to implement fox control programs and to consider culling programs that simulate dingo predation, to reduce the impacts of herbivores.

Some authors have argued that establishing kangaroo harvesting as an alternative use of the rangelands may be beneficial for biodiversity conservation (Lunney and Grigg 1988; Grigg 2000; Archer and Beale 2004). One argument in support of kangaroo harvesting has been that kangaroos have less impact on the landscape than hard-hoofed livestock and that utilising kangaroos may enable economic diversification and a reduction in total grazing pressure. While I generally support these sentiments, I would like to add a cautionary note. Kangaroo harvesting currently occurs in predominantly sheep grazing areas where kangaroo densities are high and thus is presumably dependent upon the same infrastructure of artificial waters, dingo control and barrier fences. Hence, a shift towards a kangaroo industry may not see the relief of fox predation impacts, one of the principal processes threatening native fauna, unless considerable effort is expended on fox control.

Acknowledgements

I would like to thank Dan Lunney and Chris Dickman for providing the opportunity to present this paper. Gordon Grigg provided insightful criticism of the manuscript. Luke Peel (Department of Infrastructure Planning and Environment, Northern Territory Government) assisted with the provision and interpretation of Landsat imagery.

References

Anon. 1948. Annual report on the operations of "The Stock Routes and Rural Lands Protection Acts, 1944-1951" for the Year 1947-48. *Queensland Parliamentary Papers* **1947-48.**

Anon. 1952. Annual report on the operations of "The Stock Routes and Rural Lands Protection Acts, 1944-1951" for the Year 1951-52. *Queensland Parliamentary Papers* **1951-52.**

Archer, M. and Beale, B. 2004. *Going Native: Living in the Australian Environment*. Hachette Livre, Sydney.

Beadle, N.C.W. 1948. *The Vegetation and Pastures Of Western New South Wales.* Department of Conservation of New South Wales, Sydney.

Benshemesh, J. 1990. Management of malleefowl with regard to fire. Pp. 206-211. in *The Mallee Lands: A Conservation Perspective*, edited by J.C. Noble, P.J. Joss and G.K. Jones. CSIRO, Melbourne.

Berger, J. Stacey, P.B, Bellis, L. and Johnson, M.P. 2001. A mammalian predator-prey imbalance: grizzly bear and wolf extinction affect avian neotropical migrants. *Ecological Applications* **11:** 947-960.

Burbidge, A.A. and McKenzie, N.L. 1989. Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biological Conservation* **50:** 143-198.

Burrows, N.D. and Christensen, P.E.S. 1990. A survey of Aboriginal fire patterns in the western desert of Australia. Pp. 297-310 in. *Fire and the Environment: Ecological and Cultural Perspectives. Proceedings of an International Symposium, Knoxville, Tennessee, 20-24th March 1990*, edited by S.C. Nodvin and T.A. Waldrop. USDA Forest Service General Technical Report SE-69, U.S.A.

Calaby J.H, and Grigg.G.C. 1989. Changes in macropodoid communities and populations in the past 200 years, and the future. Pp. 813-820 in. *Kangaroos, Wallabies and Rat Kangaroos,* edited by G. Grigg, P. Jarman and I. Hume. Surrey Beatty and Sons, Sydney.

Caughley, G., Grigg, G.C., Caughley, J. and Hill, G.J.E. 1980. Does dingo predation control the densities of kangaroos and emus? *Australian Wildlife Research* **7** 1-12.

Chiew, F.H.S., Piechota, T.C., Dracup, J.A. and McMahon, T.A. 1998. El Niño/Southern Oscillation and Australian rainfall, streamflow and drought: Links and potential forecasting. *Journal of Hydrology* **204:** 138-149.

Coman, B. 1999. *Tooth and nail: The story of the rabbit in Australia*. Text Publishing, Melbourne.

Copley, P. 1999. Natural histories of Australia's stick-nest rats genus *Leporillus* (Rodentia: Muridae). *Wildlife Research* **26** 513-539.

Dawson, T.J. and Ellis, B.A. 1979. Comparison of the diets of yellow-footed rock wallabies and sympatric herbivores in western N.S.W. *Wildlife Research* **6:** 245-254.

Diaz, H.F. and Markgraf, V. 1992. *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation.* Cambridge University Press: Cambridge, United Kingdom.

Dickman, C.R., Pressey, R.L., Lim, L. and Parnaby, H.E. 1993. Mammals of particular conservation concern in the Western Division of New South Wales. *Biological Conservation* **65:** 219-248.

Dickman, C.R. 1996a. The impact of exotic generalist predators on the native fauna of Australia. *Wildlife Biology* **2:** 185-195.

Dickman, C.R. 1996b. Incorporating science into recovery planning for threatened species. Pp. 63-73. in. *Back From the Brink: Refining the Threatened Species Recovery Process*, edited by S. Stephens and S. Maxwell. Surrey Beatty and Sons: Sydney, Australia.

Dickman, C.R., Pressey, R.L., Lim, L. and Parnaby, H.E. 1993. Mammals of particular conservation concern in the Western Division of New South Wales. *Biological Conservation* **65:** 219-248.

Edwards, G.P., Croft, D.B. and Dawson, T.J. 1996. Competition between red kangaroos (*Macropus rufus*) and sheep (*Ovis aries*) in the arid rangelands of Australia. *Australian Journal of Ecology* **21:** 165-172.

Eldridge, D.J. and Green, R.S.B. 1994. Microbiotic soil crusts: a review of their roles in soil and ecological processes in the rangelands of Australia. *Australian Journal of Soil Research* **32:** 389-415.

Finlayson, H.H. 1961. On central Australian mammals. Part IV-the distribution and status of central Australian species. *Records of the South Australian Museum* **14:** 141-191.

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 of feral goats. *Rangeland Journal* **19,** 157-165.

Frith, H. J. 1962. Conservation of the malleefowl, *Leipoa ocellata* Gould (Megapodiidae). *CSIRO Wildlife Research* **7:** 33-49.

Friedel, M.H., Foran, B.D. and Stafford-Smith, D.M. 1990. Where the creeks run dry or ten feet high: pastoral land management in arid Australia. *Proceedings of the Ecological Society of Australia* **16:** 185-194.

Glen, A.S. and Short, J. 2000. The control of dingoes in New South Wales in the period 1883-1930 and its likely impact on their distribution and abundance. *Australian Zoologist* **31:** 432-442.

Glen, A. S. and Dickman, C. R. 2005. Complex interactions among mammalian carnivores in Australia, and their implications for wildlife management. *Biological Reviews* **80:** 387-401.

Gooding, C.D. 1955. The vermin bonus system in Western Australia: Part 1-The distribution of payments. *Journal of Agriculture of Western Australia (Series 4)* **4,** 433-439.

Grice, D., Caughley, G. and Short, J. 1986. Density and distribution of the Australian Bustard *Ardeotis australis*. *Biological Conservation* **35:** 259-267.

Grigg, G.C. 2002. *Conservation Benefit from Harvesting Kangaroos: Status Report at the Start of a New Millennium* - A Paper to Stimulate Discussion and Research. Pp 53-76 in A Zoological Revolution. Using Native Fauna to Assist in its Own Survival, edited by D. Lunney and C.R. Dickman. Royal Zoological Society of New South Wales and Australian Museum.

Harrington, G.N., Oxley, R.E. and Tongway, D.J. 1979. The effects of European settlement and domestic livestock on the biological system in poplar box (*Eucalyptus populnea*) lands. *Australian Rangeland Journal* **4:** 271-279.

Harrington, G.N., Wilson, A.D., and Young, M.D. 1984. *Management of Australia's Rangelands.* CSIRO: Melbourne, Australia.

Heske, E.J. and Campbell, M. 1991. Effects of an 11 year livestock exclosure on rodent and ant numbers in the Chihuahuan Desert, southeastern Arizona. *The Southwestern Naturalist* **36:** 89-93.

Hrdina, F.C. 1997. Marsupial destruction in Queensland. *Australian Zoologist* **30:** 272-286.

James, C.D. 2003. Response of vertebrates to fenceline contrasts in grazing intensity in semi-arid woodlands of eastern Australia. *Austral Ecology* **28:**137-151.

James, C.D., Landsberg, J. and Morton, S.R. 1995. Ecological functioning in arid Australia and research to assist conservation of biodiversity. *Pacific Conservation Biology* **2:** 126-142.

Jones, A. and Longland, W.S. 1999. Effects of cattle grazing on salt desert rodents. *American Midland Naturalist* **14:** 1-11.

Kerle, J.A., Foulkes, J.N., Kimber, R.G. and Papenfus, D. 1992. The decline of the brushtail possum, *Trichosurus vulpecula* (Kerr 1798), in arid Australia. *Rangeland Journal* **14:** 107-27.

Kerley, G.I.H. and Whitford, W.G. 2000. Impact of grazing and desertification in the Chihuahuan Desert: Plant communities, granivores and granivory. *The American Midland Naturalist* **144:** 78-91.

Kingsford, R.T., Wong, P.S., Braithwaite, L.W. and Maher, M.T. 1999. Waterbird abundance in eastern Australia, 1983-92. *Wildlife Research* **26:** 351-366.

Kinloch, J.E. and Friedel, M.H. 2005. Soil seed reserves in arid grazing lands of central Australia. Part 1: seed bank and vegetation dynamics. *Journal of Arid Environments* **60:** 133-161.

Kinnear, J.E., Sumner, N.R. and Onus, M.L. 2002. The red fox in Australia- an exotic predator turned biocontrol agent. *Biological Conservation* **108:** 335-359.

Krefft, G. 1866. On the vertebrated animals of the lower Murray Darling, their habits, economy, and geographical distribution. *Transactions of the Philosophical Society of New South Wales* **1862-1865:** 1-33.

Landsberg, J., James, C. D., Morton, S. R., Hobbs, T. J., Stol, J., Drew, A. and Tongway, H. 1997. *The Effects of Artificial Sources of Water on Rangeland Biodiversity.* Environment Australia and CSIRO: Canberra, Australia.

Lange, R.T. 1969. The piosphere: sheep track and dung patterns. *Journal of Rangeland Management* **22:** 396-400.

Letnic, M. 2004. Cattle grazing in a hummock grassland regenerating after fire: the short-term effects of cattle exclusion on vegetation in south-western Queensland. *Rangeland Journal* **26:** 34-48.

Letnic, M. and Dickman, C.R. 2006. Boom means bust: interactions between the El Niño/Southern Oscillation (ENSO), rainfall and the processes threatening mammal species in arid Australia. *Biodiversity and Conservation* **15:** 3847-3880.

Letnic, M., Tamayo, B and Dickman, C.R. 2005. The responses of mammals to La Niña associated rainfall, predation and wildfire in arid Australia. *Journal of Mammalogy* **86:** 689-703.

Letts, G., Bassingthwaite, A. and De Vos, W.E.L. 1979. *Feral animals in the Northern Territory. Report of the Board of Enquiry.* N.T. Government Printer, Darwin.

Low, W.A., Hodder, R.M. and Abel, D.E. 1978. Watering behaviour of British breed cattle in central Australia. Pp. 165-177 in Studies of the Australian Arid Zone. III. Water in Rangelands, edited by K.M.W. Howes. CSIRO: Perth, Australia.

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

Lunney, D. 2001. Causes of the extinction of native mammals of the western division of New South Wales: An ecological interpretation of the nineteenth century historical record. *Rangeland Journal* **23:** 44-70.

Lunney, D. and Grigg, G. (eds). 1988. Kangaroo harvesting and the conservation of arid and semi-arid lands. *Australian Zoologist* **24:** 121-193.

McHolm, A.R. and Allan, R.J. 2004. Loss of patch scale heterogeneity on secondary productivity in the arid shrubland of Western Australia. *Journal of Arid Environments* **61:** 631-649.

Madigan, C.T. 1946. *Crossing the Dead Heart.* Georgian House, Melbourne.

Marshall, A.J. 1966. *The Great Extermination.* Panther, London.

Maxwell, S., Burbidge, A.A. and Morris, K. 1996. *The 1996 Action Plan for Australian Marsupials and Monotremes.* Wildlife Australia: Canberra, Australia.

Morton, S. 1990. The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. *Proceedings of the Ecological Society of Australia* **16:** 201-213.

Newsome, A.E. 1975. An ecological comparison of the two arid-zone kangaroos of Australia, and their anomalous prosperity since the introduction of ruminant stock to their environment. *Quarterly Review of Biology* **50:** 389-424.

Newsome, A.E., Parer, I. and Catling, P.C. 1989. Prolonged prey suppression by carnivores- predator-removal experiments. *Oecologia* **78:** 458-467.

Newsome, A.E., Catling, P.C., Cooke, B.D. and Smyth, R. 2001. Two ecological universes separated by the dingo barrier fence in semi-arid Australia: Interactions between landscapes, herbivory and carnivory, with and without dingoes. *Rangeland Journal* **23:** 71-98.

Nicholls, N. 1991. The El Niño/Southern Oscillation and Australian vegetation. *Vegetatio* **91:** 23-36.

Pace, M.L., Cole, J.J., Carpenter, S.R. and Kitchell, J.F. 1999. Trophic cascades revealed in diverse ecosystems. *Trends in Ecology and Evolution* **14:** 483-488.

Paltridge, R. 2002. The diets of cats, foxes and dingoes in relation to prey availability in the Tanami Desert, Northern Territory. *Wildlife Research* **29:** 389-394.

Pople, A.R., Grigg, G.C., Cairns, S.C., Alexander, P, Beard, L.A. and Henzell, R.P. 1996. Trends in the numbers and changes in the distribution of feral goats (*Capra hircus*) in the South Australian pastoral zone. *Wildlife Research* **23:** 687-696.

Pople, A.R., Grigg, G.C., Cairns, S.C., Beard, L. A. and Alexander, P. 2000. Trends in numbers of kangaroos and emus on either side of the South Australian dingo fence: evidence for predator regulation. *Wildlife Research* **27:** 269-276.

Priddel, D. and Wheeler, R. 2001. Malleefowl conservation in New South Wales: a review. *Zoologische Verhandelingen* **327:** 125-141.

Priddel, D. and Wheeler, R. 2003. Nesting activity and demography of an isolated population of malleefowl *Leipoa ocellata*. *Wildlife Research* **5:** 451-464.

Read, J.L. 2002. Experimental trial of Australian arid zone reptiles as early warning indicators of overgrazing by cattle. *Austral Ecology* **27:** 55-66.

Read, J.L. and Wilson, E. 2004. Scavengers and detritivores of kangaroo harvest offcuts in arid Australia. *Wildlife Research* **31:** 51 – 56.

Reid, J. and Fleming, M. 1992. The conservation status of birds in arid Australia. *Rangeland Journal* **14:** 65-91.

Risbey, D.A., Calver, M.C., Short, J., Bradley, J.S. and Wright, I.W. 2000. The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia. II. A field experiment. *Wildlife Research* **27:** 223-235.

Rogers, C.M. and Caro, M.J. 1998. Song sparrows, top carnivores and nest predation: a test of the mesopredator release hypothesis. *Oecologia* **116:** 227-233.

Rolls, E.C. 1969. *They All Ranwild.* Angus and Robertson, Sydney.

Roshier D. A., P.H. Whetton, R. J. Allan, and I. Robertson.

2001. Distribution and persistence of temporary wetland habitats in arid Australia in relation to climate. *Austral Ecology* **26:**371-284.

Short, J. 1998. The extinction of rat-kangaroos (Marsupialia: Potoroidae) in New South Wales, Australia. *Biological Conservation* **86:** 365-377.

Smith, A.P. and Quin, D.G. 1996. Patterns and causes of extinction and decline in Australian conilurine rodents. *Biological Conservation* **77:** 243-267.

Smith, P.J., Smith, J.E. Pressey, R.L. and Whish, G.L. 1995. *Birds of particular conservation concern in the western division of New South Wales: Distributions, habitats and threats.* Occasional Paper 20, N.S.W. National Parks and Wildlife Service: Hurstville, Australia.

Soule, M.E., Estes, J.A., Berger, J. and Martinez Del Rio, C. 2003. Ecological effectiveness: Conservation goals for interactive species. *Conservation Biology* **17:** 1238-1250.

Sparrow, A.D. Friedel, M.H. and Tongway, D.J. 2003. Degradation and recovery processes in arid grazing lands of central Australia Part 3: implications at landscape scale. *Journal of Arid Environments* **55:** 349-360.

Stafford Smith, D.M. and Pickup, G. 1990. Pattern and production in arid lands. *Proceedings of the Ecological Society of Australia* **16:** 195-200.

Sturt, C. 1833. *Two expeditions into the interior of Southern Australia, during the years 1828, 1829 and 1831.* (J. Waterhouse ed. 1984). Caliban Books: London, United Kingdom.

Wasson, R.J. and Galloway, R.W. 1986. Sediment yield in the Barrier Range before and after European settlement. *Rangeland Journal* **8:** 79-90.

Woodall, P.F. 1983. Distribution and population dynamics of dingoes (*Canis familiaris*) and feral pigs (*Sus scrofa*) in Queensland, 1945-1976. *Journal of Applied Ecology* **20:** 85-95.

Young, M. D. 1979. Influencing land use in pastoral Australia. *Journal of Arid Environments* **2:** 279-288.