State of evidence: Kangaroos and their management in South Australia

DEW Technical report 2018/11

October 2018

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ISBN 978-1-925964-03-5

Preferred way to cite this publication

DEW (2018). State of evidence: Kangaroos and their management in SA. DEW Technical report 2018/11, Government of South Australia, Department for Environment and Water, Adelaide.

Acknowledgements

The author greatly acknowledges the following contributions, which have made this work possible:

- Dan Rogers and Danielle Witham supported the development and management of project outcomes.
- Vicki Linton and Renate Velzeboer provided guidance on project development in line with current and planned kangaroo management policies. Fiona Fuhlbohm and Karl Hillyard provided helpful technical reviews of draft content as well as discussions relating to kangaroo management policies.
- Amanda Mclean provided guidance, data, and advice that greatly assisted with the content in this report.
- Peter Wilkins, Wendy Stubbs, Craig Gillespie, Seb Drewer, Peter Copley and Rob Brandle provided data, reports, and/or proposals that were used to develop content in this report.
- Jody O'Connor authored the report. Dan Rogers, Renate Velzeboer, Amanda McLean, Wendy Stubbs, Craig Gillespie, Sophie Harrison and Jason VanWeenen provided reviews of the draft report.

Executive Summary

Kangaroo populations are currently in high numbers across many regions of SA primarily in response to wetter-than-average conditions over the past few years. This has the potential to impact on a range of ecological, social and economic values. The impacts of kangaroos vary spatially and temporally depending on local population numbers, land-use, and the nature of the values at risk.

A more integrated approach to statewide kangaroo management is required which delivers a new policy framework that incorporates scientific, social and economic considerations. There is also a longer-term gain to be made from seeking community support for a range of new approaches and an examination of legislation to help manage impacts of abundant kangaroos.

The aim of this report is to review the current state of scientific knowledge and identify knowledge gaps on the following: kangaroo population dynamics, social values, impacts of kangaroos and options for kangaroo management. This review was primarily conducted by means of a comprehensive survey of the literature, but also incorporated local expert knowledge where possible and readily available.

Kangaroo population dynamics

Large-bodied kangaroo species (Red Kangaroo, Western Grey Kangaroo and Euro) have undergone increases in abundance since European settlement, primarily in response to pastoralism and removal of top predators. In 2018 the estimated population size for Red Kangaroos was 2,758,663, for Western Grey Kangaroos 1,613,880, and for Euros 662,134. However the density of these species varies across the state and through time, and our uncertainty with regard to these estimates varies between species.

Rainfall is recognised as a primary (though indirect) driver population dynamics in the semi-arid parts of the state. However, widespread and temporally stable food and water availability has modified kangaroo population dynamics and allowed for significant expansion into arid areas that were previously only suitable in wetter years. The relationship between rainfall, resource availability and kangaroo populations is being used to develop spatial-temporal population models that can be used to predict the response of kangaroo populations to management intervention in space and time.

Impacts of kangaroos

Kangaroos, along with other herbivores (both domestic stock, and native and non-native wild herbivores) contribute to total grazing pressure in SA. The environmental impacts of total grazing pressure, and the contribution that kangaroos make to this, vary spatially and temporally. Impacts of overgrazing are social, economic and environmental in nature, and the nature of these impacts also varies across the state. While we have some evidence of the relative impacts of different herbivores on native biodiversity (e.g. through exclusion experiments), an improved understanding of the spatial-temporal distribution of all herbivores, and how these explicitly impact on biodiversity values (such as threatened species) would help to demonstrate the need for managing total grazing pressure generally, and kangaroo impacts in particular, and where to prioritise management of these impacts.

There is some evidence that there has been an increase in vehicle collisions with kangaroos over the last decade, although data are limited. Kangaroos also contribute to fence damage and crop losses, although these impacts remain largely unquantified.

There is good evidence that the impact of kangaroos on sheep production is only significant under conditions where there is very low pasture biomass coupled with high kangaroo densities. Targeted management where these conditions occur may therefore be most effective in reducing competition with sheep, and improve the resilience of pastoral systems more generally.

More generally, our current understanding of the total economic costs of kangaroo impacts limited, especially at a state level; estimates are generally outdated, based on simplified representations of interactions with livestock and/or are based on perceived rather than true costs.

Social values towards kangaroos and their management

Perceptions of kangaroos and kangaroo management are diverse both within and between major stakeholder groups. Many stakeholders are in favour of kangaroo control via commercial harvest whereas others are strongly opposed to this method (regardless of whether it can be used as a tool for effective management of kangaroo impacts).

Kangaroos are culturally significant to some traditional nations. Representatives from traditional nations currently contribute to decision-making processes via forums including co-management of parks and the Kangaroo Management Reference Group.

Our understanding of social attitudes towards kangaroo management needs to be updated and improved. Approaches to the development of evidence-based and socially acceptable policy and management have been applied elsewhere and are published. These approaches also provide guidance with respect to understanding trade-offs, complementary outcomes, and risks associated with values (ecological, social or regulatory).

Management of kangaroos and other grazers in SA

The current kangaroo harvest system is focused on the conservation and sustainable harvest of commercially harvested species, and is not specifically designed to mitigate impacts of overabundant populations. The commercial industry is also currently constrained by a restricted and declining market for kangaroo products. However, there are potential opportunities to better utilise commercial harvest as a tool for localised impact management.

The most successful approaches to management of overgrazing in SA have taken an integrated approach to controlling densities of livestock, kangaroos and/or feral herbivores, often leading to significant vegetation recovery and habitat restoration. Standard methods or frameworks for assessing and managing total grazing pressure would benefit future management and impact reduction.

A clear limitation in this review was the limited availability of documented case studies of kangaroo impacts and the effectiveness of management approaches in SA. Much of this evidence exists within the experience of DEW staff and other stakeholders but has not been effectively synthesised or communicated in such a way that it can consistently support stakeholder engagement or management (particularly at a whole-of-state scale).

There is also a lot that South Australia can learn from international experience with respect to the management of iconic native wildlife that have a real or perceived social, economic or environmental impact (e.g. deer management in North America, badgers and beavers in the United Kingdom). These include the importance of being adaptive; integrated landscape management (rather than focusing on the 'problem' species in isolation); and using inclusive decision making processes. However, these lessons need to be adapted to South Australia's social and environmental context.

Key recommendations

Because the social, economic and environmental outcomes of kangaroo management are context-specific, setting meaningful management objectives at a state level can be challenging. Above all, kangaroo management should be designed in a way that explicitly considers the desirable social, economic and environmental outcomes for a landscape, and how kangaroo management contributes to these. This report has highlighted a number of recommendations to support kangaroo management in SA:

- Kangaroo management should be considered in the context of managing total grazing pressure. Kangaroo population control is not an outcome in its own right and should be considered as one approach within a suite of tools that manage the impacts of total grazing on the values of a landscape;
- Using an adaptive approach to kangaroo management, which is informed by clear, context-specific objectives, documented evidence of impacts, and lessons from previous management. Adaptive management should include both incremental and longer-term learning approaches, including the capacity to experiment as a way of improving our evidence for what works (or doesn't);

- Developing an anticipatory rather than reactive approach to management, informed by an improved understanding of the relationship between changes in conditions (rainfall, vegetation growth), kangaroo density, and impacts;
- Improving our understanding of the social values that inform decision-making, and integrating these values into a more holistic and context-specific decision-making process is critical to achieving positive outcomes in wildlife management. Communications should be framed in ways that acknowledge and connect with the diverse values held by key stakeholders.

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1 Introduction

Widespread changes to the Australian environment since European settlement have disrupted ecosystems and affected the abundance and diversity of native species. Many native mammal species have declined in numbers or become extinct (Short and Smith 1994; Woinarski 2015), while some other species, such as several large-bodied kangaroos (e.g. Red Kangaroo, *Macropus rufus*, Western Grey Kangaroo, *M. fuliginosus*, and the Euro *M. robustus*; hereby referred to as 'kangaroos') have adapted and benefited from the expansion of agricultural land and removal of top predators (Pople and Grigg, 1999). Kangaroos are persisting in a diverse mosaic of landscapes, including reserves, pastoral land, agricultural land and urban environments. Across Australia, kangaroo populations are assumed to be in higher numbers than they were prior to European settlement, and contribute to high overall grazing pressure on the environment (Fisher et al. 2004).

Kangaroos can have a variety of social, economic and environmental impacts that vary with context, but are also an iconic element of native biodiversity. In South Australia, kangaroo populations are managed primarily to ensure their conservation under the *National Parks and Wildlife Act 1972* (NPW Act), but also to sustainably reduce or avoid damage to crops, reduce competition with livestock, or impacts on infrastructure or the environment. Quantitative data on the impact of kangaroos on the environment is rarely collated or analysed, partly because kangaroos are but one of many native or introduced herbivore species (i.e. livestock, goats and rabbits) that contribute to total grazing pressure across the state (Fisher 2004). Our knowledge of the population dynamics, impacts, and management effectiveness, as well as the expectations of different stakeholders and the broader community, within these contexts is diverse, and currently exists as a mix of both anecdotal knowledge and scientific evidence. Current tools for managing kangaroo populations include commercial harvest and culling (either by DEW on parks and reserves, or via destruction permits), though the commercial harvest system was designed for long-term sustainable harvest and not specifically for impact mitigation. While these methods may be effective at managing some impacts at a site scale, South Australia does not have an effective system for managing the impacts of kangaroos at broader (e.g. landscape) scale, or for understanding the collective benefit of site-scale management.

The aim of this report is to review the current state of scientific knowledge on abundant kangaroo species and their management in SA, primarily by means of a comprehensive survey of the literature, but also incorporating expert knowledge where readily available. In particular, this report will focus on documenting evidence and knowledge gaps relating to:

- Kangaroo numbers and population dynamics
- Impacts of kangaroos and other herbivores in South Australia (in the context of 'Total Grazing Pressure')
- Social values towards kangaroos and their management
- Kangaroo management in SA.

The final section of the report documents some limitations, successes and 'lessons learned' from international examples of abundant native species harvest and management.

2 Kangaroo population dynamics

2.1 Current kangaroo population sizes

The three commercially harvested species in SA: Red Kangaroo, Western Grey Kangaroo, and Euro*)* are widespread and abundant (Figures 1-3; DEWNR 2017a). The biology and ecology of these species is well-understood (i.e. Caughley et al. 1987; Pople and Grigg 1999): their habitat preferences, distribution and reproduction are accounted for when setting harvest quotas (DEWNR 2017a). Numbers of Red and Western Grey Kangaroos are surveyed via aerial surveys (Grigg et al 1999; DEWNR 2017b) and via on-ground line transect surveys for Euros (DEWNR 2017b) across the commercial harvest zone in SA (Appendix 1). Raw count data are corrected to account for habitat and temperature factors that affect detection (DEWNR 2017b), and divided by the area surveyed to provide density estimates. Overall population estimates can then be calculated by multiplying the density estimate by the amount of suitable habitat across the commercial harvest zone (DEWNR 2017b). These methods continue to be actively refined and reviewed to improve accuracy (e.g. Pople, 2008; Hone and Buckmaster 2015; DEWNR 2017a, Lethbridge et al. in review). In South Australia, densities of the three harvested kangaroo species vary by region (Figures 2 and 3) and year (Table 1). In 2017, the estimated population size for all three species in the commercial harvest zone of South Australia (covering ~63% of the state) was 5,034,677. Statewide estimates of kangaroo abundance are not available, although additional smaller-scale kangaroo surveys are often conducted at targeted locations (e.g. de Preu 2006; Cobiac 2009; Collings 2010a). Given the inherent differences in the nature of the landscapes within and outside of the harvest zone, extrapolating from the harvest zone surveys to the rest of the state is not appropriate.

Table 1 Kangaroo density and population estimates across the entire SA commercial harvest zone. Red and Western Grey Kangaroo density and population estimates (in numbers) based on data from 1978–2017. Euro estimates are calculated from data collected from 1997–2017.

Species	Density (kangaroos/km^2)		Kangaroo population estimate	
	Mean ± SD (range)	Current (2017)	Mean ± SD (range)	Current (2018)
Red Kangaroo	2.29 ± 0.84 (1.1–4.0)	3.6	1,709,405 ± 500,295 (960,511–2,758,663)	2,758,663
Western Grey Kangaroo	0.54 ± 0.25 (0.18–1.59)	1.6	800,084 ± 279,256 (366,510–1,613,880)	1,613,880
Euro	N/A	N/A	462,638 ± 66,686 (388,000–662,134)	662,134

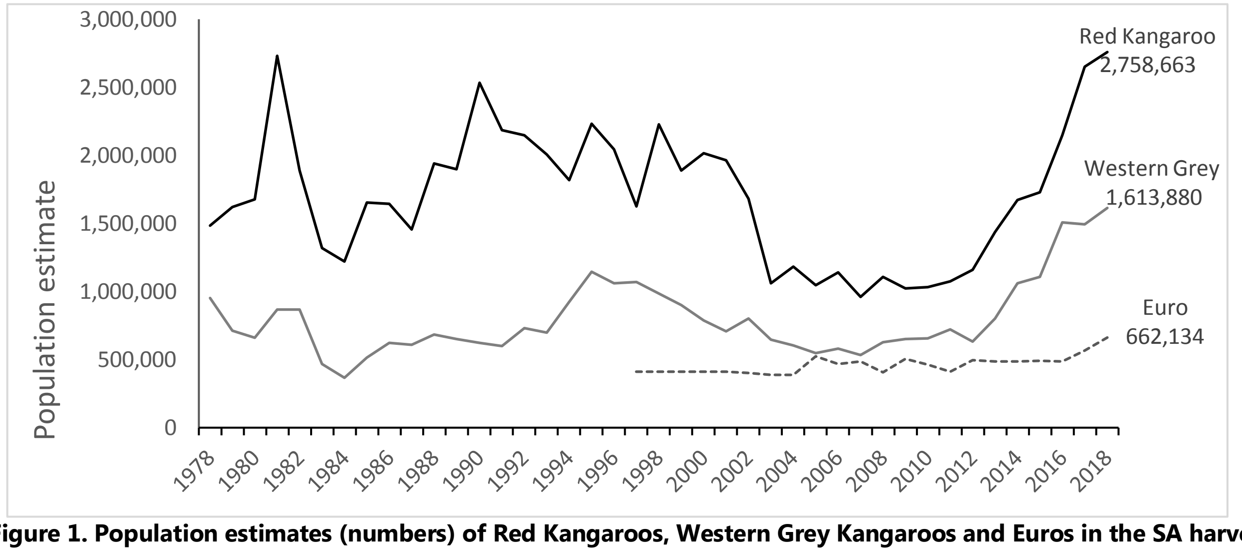

Figure 1. Population estimates (numbers) of Red Kangaroos, Western Grey Kangaroos and Euros in the SA harvest zone

Within the commercial harvest zone of SA, high local densities of Red Kangaroos (40–150 individuals km^2) occur mostly in the north-east of the state: in the North Flinders and North East Pastoral sub-regions (Figure 2a). Across years, Red Kangaroo densities are consistently high in the north-eastern corner of the harvest zone, just south of Lake Frome (Pople et al. 2006; DEWNR 2017b; Figure 2a). Peak Western Grey Kangaroo densities currently occur in hotspots across the Gawler Ranges, South Flinders, North East Pastoral, Eastern Districts and Mid North harvest sub-regions (Figure 2b). Comparisons of regional kangaroo densities compared to long term means are shown in Appendix 2.

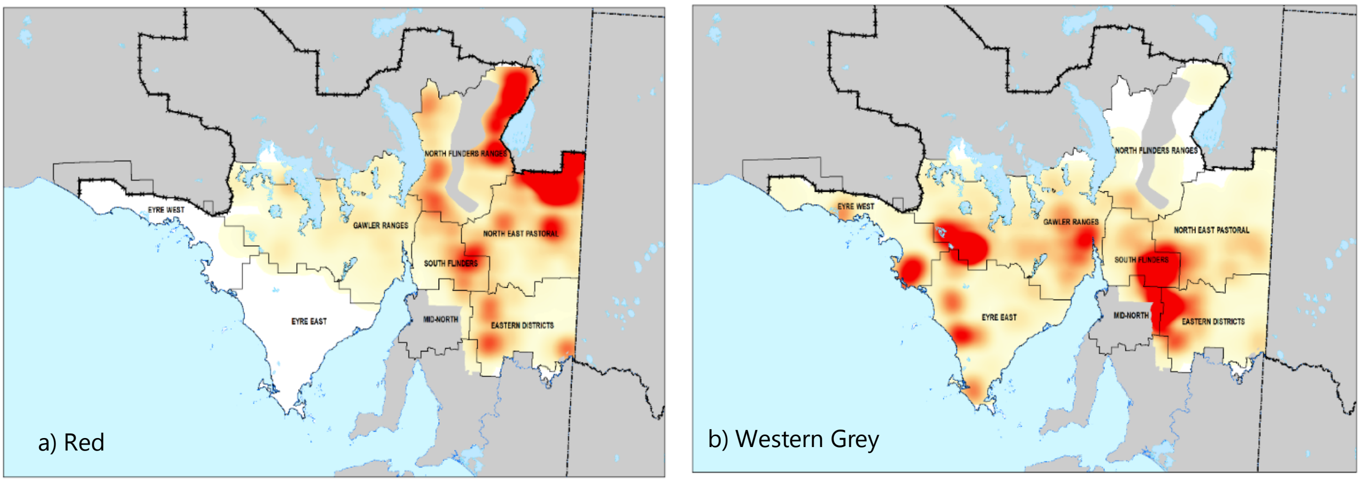

Figure 2 Distribution of a) Red Kangaroos and b) Western Grey kangaroos across the commercial harvest zone in South Australia. Densities are indicated as red: >40 kangaroos/km^2, yellow 1-5 kangaroos/km^2, and white: <1 kangaroos/km^2 (not true zero).

2.2 Factors affecting fluctuations in kangaroo numbers

2.2.1 Rainfall affects resource availability, mortality and survival

In order to understand the potential impact of kangaroo management actions, it is important to first understand the processes that influence population increase or decline (McCarthy 1996; Pople and Grigg 1999). Although the population dynamics of kangaroos in the pastoral zone of SA are well-studied, the complexities of measuring and predicting population growth or decline in a stochastic environment has proven difficult (Jonzen et al. 2005). For example, many earlier studies demonstrated strong relationships between kangaroo population growth and prior rainfall (Caughley et al. 1984; Bayliss, 1985a&b,1987; Cairns and Grigg 1993; McCarthy 1996) using data dominated by dry periods and drought-induced adult mortality (Pople et al. 2010a). These findings lent support to a relatively simple positive relationship between rainfall, resource availability and population growth (Caughley 1987), especially at the local scale (Caughley et al. 1984; Bayliss 1987).

With the availability of longer-term data, more recent studies have sometimes found weaker correlations between prior rainfall (Boyle and Hone 2014) and associated pasture condition (Pople et al. 2010a) on population growth at broad scales, especially when kangaroos occur in low average densities (Cairns et al. 2000; Pople et al. 2010). Rainfall is also less important for predicting kangaroo population dynamics in areas where resource availability is spatially and temporally stable (i.e. due to the provision of artificial water points and/or food). A more nuanced understanding of the role of rainfall in kangaroo population dynamics is that rainfall is an important driver of change in kangaroo numbers, (Pople et al. 2010a; Letnic and Crowther 2013; Fryxell et al. 2014), but that its effects on population growth are indirect, and mediated by processes of birth, death and age structure (Jonzen et al. 2010; Pople et al. 2010a). Juvenile and sub-adult survival, for example, has a particularly strong influence on kangaroo population dynamics over longer time scales when changes between years are less dramatic (Fletcher 2007; Pople et al. 2010). Despite some of the complexities around using rainfall as a surrogate for resource availability and kangaroo population growth (discussed in Jonzen et al. 2005; Pople et al. 2010a; Boyle et al. 2014), it is consistently clear that periods of drought, such as those experienced in the early 1980s and during the 2000s, are associated with substantial declines in kangaroo numbers (Cairns et al. 2000: Pople et al. 2007). Drought results in heavy mortality in juveniles and to a lesser extent the oldest age classes, and skews the sex ratio towards females due to increased mortality in males (Robertson 1986; Cairns and Griggs 1993). This results in a bias towards the most fecund female age-class and facilitates rapid population recovery, with growth rates above that of a population at carrying capacity (Cairns and Grigg 1993). This ability to rapidly increase population numbers following times of high drought-induced mortality is exacerbated by the rarity or absence of top predators (e.g. dingos) south of the dingo fence (Letnic and Crowther 2013; Appendix 1). Under favourable conditions, such as access to food, shelter and water, populations of kangaroo species are known to increase to very high densities (Bayliss 1987; Descovich et al. 2016), as is currently experienced across many regions within SA (Figures 1-2).

2.2.2 Predation

Predation increases mortality and is therefore an important driver of kangaroo population dynamics. The dingo (*Canis lupus dingo*) is a significant predator of both juvenile and adult kangaroos, limiting kangaroo population growth in areas where they co-exist (Pople et al. 2000; Letnic and Crowther 2013; Newsome et al. 2015). In SA, there is evidence that dingos play a strong role in regulating kangaroo (and emu) populations outside of the dog fence where they are more common (Pople et al. 2000; Morris and Letnic 2017). Here, dingos can supress kangaroo densities even under favourable conditions when other kangaroo populations inside the dog fence are experiencing significant post-drought recovery (Pople et al. 2000). Dingos are also more likely to kill juvenile and female kangaroos rather than large males (Shepherd 1981), which is predicted to have a stronger impact on supressing population growth than non-selective predation across gender and age-classes.

Red Foxes (*Vulpes vulpes*) also predate upon juvenile kangaroos and can limit population growth. Survival of juvenile kangaroos can increase significantly (i.e. by 25–40%) following fox control, leading to rapid population recovery (Banks et al. 2000).

Wedge-tailed Eagles (*Aquila audax*), may also prey upon juvenile kangaroos, especially in more arid areas (Leopole and Wolfe, 1970; Brooker and Ridpath, 1980).

2.2.3 Commercial harvest and Aboriginal hunting

Commercial harvesting can affect the demographics (e.g. population size, growth rates, distribution, mortality and birth rates) of harvested kangaroo populations, although these impacts currently appear to be of little conservation concern (Pople & Grigg 1999; Hacker & McLeod 2003; DEWNR 2017a). The selective harvest of larger kangaroos, usually older males, is likely to bias populations toward younger and more female individuals, which actually has a positive impact on population growth (as discussed in Section 5.5).

Kangaroos are currently harvested under a sustainable harvest system as described in Section 5.3 (see also summaries in Shepherd and Caughley 1987; Pople and Grigg 1999; DEWNR 2017a). This system is informed by robust models of kangaroo population dynamics and potential long-term effects of harvest within a stochastic environment (Caughley et al. 1987; Pople and Grigg 1999). The South Australian Commercial Kangaroo Management Plan 2018-2022 details the management controls that ensure a sustainable harvest of kangaroos and avoid adverse impacts on the habitats and ecosystems in which kangaroos exist (DEWNR 2017a).

Aboriginal harvest of native animals is permitted under the *National Parks and Wildlife (NPW) Act 1972* [SA], which exempts Aboriginal people from acquiring permits if the harvested animal will be used '(a) as food for the hunter or for his or her dependents; or (b) solely for cultural purposes of Aboriginal origin.' Aboriginal harvest is permitted on private and crown land (with landholder permission), as well as some National Parks and reserves. Aboriginal harvest is an important cultural practice (Thomsen et al. 2006), and currently occurs at rates that are considered sustainable for kangaroos (DEWNR 2017a).

2.2.4 Other factors affecting kangaroo population dynamics

Density dependence, domestic herbivore density (Jonzen et al. 2005; Pople et al. 2010a), invasive herbivore abundance (Cooke and Mutze et al. 2018), movement (Pople et al. 2007; Pople et al. 2010a) and artificial watering points (Dawson et al. 2006) are also recognised as additional and important factors that influence kangaroo population dynamics. Broad-scale movement of kangaroos, for example, may account for dramatic changes in local abundance that cannot be explained by recruitment or survival (Johnson and Bayless 1981; Cairns and Grigg 1993; Pople et al. 2007; Pople et al. 2010). The provision of artificial watering points across the grazing landscape has also facilitated the range expansion of kangaroos into arid inland areas of SA (Pople et al. 2010a) and other states (James et al. 1999; Dawson et al. 2006), changing the dynamics and grazing pressure of kangaroo populations across those regions. The impact of individual factors on population growth can vary quite significantly at the regional scale (Cairns and Grigg 1993; Cairns et al. 2000; Pople et al. 2010a and 2010b), hence models of kangaroo population dynamics are expected to most accurately identify areas in need of management when applied over smaller areas.

A simple diagram illustrating this conceptual description of kangaroo population dynamics has been included in Appendix 3.

2.3 Knowledge gaps and potential future work

- Statewide kangaroo density and population estimates: current survey efforts are restricted to the commercial harvest zone and are used to inform annual quotas. However, statewide estimates may not be needed if targeted surveys (perhaps rapid, lower cost options) could potentially be conducted in areas of concern as required (e.g. Mutze et al. 2016a; Landsberg and Stol 1996). Targeted surveys are more likely to be required if there is an identified risk to a species or when it is required to justify management actions (i.e. in proposals to cull kangaroos on parks and reserves). Statewide surveys would be very expensive with potentially limited additional benefit.
- Predictive modelling to help us forecast future kangaroo population and density trends. The University of Adelaide is currently developing a spatially explicit population model for kangaroos that can be used to forecast estimates of kangaroo population size. The main aims of this model are to produce predictive estimates of changes in population numbers, and evaluate the harvesting/culling effort required to maintain kangaroo populations below target densities (when determined).
- An understanding of patterns and drivers of kangaroo movement: this will inform the expected success of kangaroo management actions. For example what is the expected success of an action to reduce local kangaroo numbers given the likelihood of kangaroos moving in from elsewhere? An improved understanding of how and when kangaroos move across the landscape in response to certain conditions will also inform the predictive modelling exercise described above.
- Kangaroos are regularly referred to as ‘overabundant’ in SA, but we do not have an agreed definition of overabundance. This requires a context-specific understanding of the potential impacts:
    - For consideration, Caughley (1981) suggestion a simple classification of *problems* due to overabundant kangaroos, including: 1) kangaroos pose a threat to human life or livelihood, 2) depression of the density of a “favoured” species (plant or animal) by an overabundant species, 3) effect an overabundant species has on the individuals themselves, and 4) the loss of equilibrium between an animal population and its food resources.

- Can we improve the accuracy of population estimates by updating correction factors that account for detectability in different habitat types? The accuracy of population density estimates in areas of dense canopy cover has been questioned, and current trials using thermal imaging to survey kangaroos in those habitats may inform more accurate in the future (Lethbridge et al. in review).

- Measures of precision, such as a standard error (SE) or 95% confidence interval are not reported along with current density and population estimates (see Hone and Buckmaster, 2014 for a discussion of why these measures should be included with wildlife abundance estimates).

3 Impacts of kangaroos and total grazing pressure

Kangaroos can impact on a range of ecological, social and economic values, especially when they occur in high densities. Impacts can include damage to crops and fences, increased road accidents, and increased grazing pressure on pastures and the environment. The relative contributions of kangaroos and other herbivore species to total grazing pressure vary according to their distributions and densities across the landscape. The current evidence for the strength of these impacts, and the conditions under which they become problematic are discussed below.

3.1 Social and economic impacts:

3.1.1 Competition between kangaroos and livestock

In South Australia, sheep are the predominant domestic stock within the commercial harvest zone for kangaroos (inside the dog fence), with cattle run mostly on properties in the north and in the high rainfall areas of the state (Jonzen et al 2005). Kangaroos can impact on the environment in a variety of ways, but it is the perception that they compete with domestic livestock (mainly sheep) for food that is of greatest concern to pastoralists (Caughley, 1983; Pople and Grigg 1999; Thomsen and Davies 2007). Both sheep and kangaroos show a general preference for grasses and forbs (Dawson and Ellis 1994; Landsberg and Stol 1996; Dawson and Munn 2007; Munn et al. 2010). Many of the studies attempting to assess the extent of competition between sheep and kangaroos have focused on translating evidence for dietary overlap into evidence for competition (Dawson & Ellis 1994; Edwards et al. 1996; Wilson 1991). Dietary overlap may in fact only indicate resource sharing (Mcleod 1996; Dawson and Munn 2007); as by definition, for exploitative competition to occur, the interaction must cause at least one of the individuals to be impacted (Schoener 1983). In the context of kangaroos and sheep, exploitative competition is only a problem if kangaroos lower sheep productivity (i.e. measures such as body mass, fecundity, carrying capacity, survival, wool growth or drought reserves), which results in economic harm (Mcleod 1996; Edwards 1996; Pople and Grigg 1999; Dawson and Munn 2007). If competition does occur, then lowering kangaroo numbers should result in improved sheep productivity and economic returns (Pople and Grigg 1999). To explore this idea, Mcleod (1996) and Dawson and Munn (2007) reviewed experimental studies that measured sheep condition or productivity in relation to kangaroo densities and resource availability in NSW. These reviews concluded that decreased productivity in sheep only occurred in unusual circumstances, such as when pasture biomasses were very low and kangaroo densities were high (Mcleod 1996; Dawson and Munn 2007). For example, there is limited evidence of competition between sheep and kangaroos above the very low pasture biomass of 50–60 g/m^2, where the liveweight of sheep was reduced in the presence of kangaroos at biomasses below that threshold (Edwards 1995, 1996; Mcleod 1996). Competitive impacts of kangaroos on sheep were not normally considered to be an issue when vegetation was in good condition (undegraded land, not in drought) in the arid rangelands of NSW (Edwards et al. 1996; McLeod 1996; Dawson and Munn 2007). Another study by Wilson (1991) reported reduced wool growth and sheep weight gain under conditions of high kangaroo densities and low food availability, but the results of this study are considered questionable given the unrealistically high numbers of sheep and use of fences to artificially confine kangaroos (Mcleod 1996; Olsen and Braysher 2000; Dawson and Munn 2007). Improving our understanding of how kangaroos compete with livestock, and under what circumstances competition is an issue, will improve how we target our management effort to reduce or minimise this competition (Mcleod 1996; Pople and Grigg 1999; Dawson and Munn 2007; DEWNR 2015a). Studies from SA are also lacking; the research conducted so far has focused on semi-arid woodlands and arid rangelands in NSW. An improved understanding of the conditions under which competition between kangaroos and livestock occurs may be useful in targeting management to places and times when competition is likely to be significant.

There are very few studies that address dietary overlap or competition in co-existing populations of kangaroos and cattle. Studies from central Australia show little evidence for dietary overlap or possible competition between cattle and kangaroos outside of drought (Low et al. 1973; Dudzinski 1982). However, our understanding of how dietary overlap, spatial overlap, and competition vary, across different environments and under different climatic conditions, is limited. Assuming direct competition for pasture biomass, a recent simplified model of dingo, cattle and kangaroo interactions estimated that an unbaited dingo population in the NSW rangelands could reduce kangaroo grazing and increase pasture biomass by 53 kg/ha (Prowse et al. 2015b). This impact was estimated to improve gross margins by $0.83/ha and reduce inter-annual variation in financial returns, even when considering losses due to dingo predation of calves (Prowse et al. 2015b). Allen (2014) similarly suggests that kangaroos compete with beef cattle for resources in the pastoral regions of SA, and economic benefits could be realised through a reduction in dingo control. These results are only applicable to cattle enterprises (and not to sheep farming) as dingos can kill sheep more easily than calves, which would affect economic outcomes (Prowse et al 2015b).

There is also general consensus that kangaroos behaviourally avoid areas used by sheep and cattle (McLeod 1996), and often concentrate their grazing in paddocks that are being rested from use by livestock (Edwards et al. 1996; Wilson 1991; Andrew & Lange 1986; Mcleod 1996). This may impede land management practices, as uncontrolled grazing of kangaroos may cancel out any benefits gained by removing livestock (Fisher 2004). The application of dynamic ecosystem models, as originally developed by Westoby et al. (1989), will also help understand the barriers to recovery following the removal of domestic stock, and where kangaroo management is an appropriate response to improve recovery

3.1.2 Damage to infrastructure and crops

Kangaroos are known to damage fences (Thomsen and Davies 2007), which can be problematic for land managers in terms of the time and cost required to undertake repairs. The extent and cost of this issue has not been quantified in SA (however, see national estimates based on perceived costs in McLeod 2004). Other species, including goats, camels, pigs, wombats, are also known to cause significant damage to fences in certain areas (Mcleod 2004; Dickman 2002). Anecdotally, kangaroos are also currently damaging horticultural infrastructure in the Mount Lofty Ranges by breaking through netting and damaging trees (J. van Weenen (DEW) 2018, pers. comm. September). Kangaroos are likely causing damage to infrastructure and/or crops in various regions of SA, though much of this information currently existing anecdotally, or in proposals to apply for Destruction Permits (see Section 5.2).

The loss of crops to kangaroos is considered a significant problem to landholders (Thomsen and Davies 2007) and has been estimated to cause losses of $11.9 million Australia-wide (McLeod 2004). There are few studies documenting this impact other than a small study by Arnold et al. (1989) in an area of woodland adjoining farmland in Western Australia. This study found that Western Grey Kangaroos showed a ‘marked preference for lupin crops’, followed by barley, wheat and oats. Kangaroos reduced the biomass of lupin crops within 100 m of the boundary between woodland and farmland by up to 95%, and the maximum reduction with oats was 24% (Arnold et al 1989).

There is also recent anecdotal evidence that abundant emu populations are damaging crops (particularly canola) and fences in the northern Eyre Peninsula, and into parts of the SA Arid Land region (S. Drewer (DEW)] 2018, pers. comm. August). In some cases, large numbers of emus have been observed concentrating around water troughs, causing significant local impacts including trampling (of crops, stubble and pasture) and soil erosion.

3.1.3 Vehicle collisions

Kangaroos account for over 75 per cent of all animal-related vehicle collisions in SA (SGIC 2014), resulting in significant repair costs, with few causing serious human injury (Mcleod 2004). Animal collisions are ranked as the 9th most frequent cause of road accidents (out of 12 possible causes) in SA (RAA 2017), with dogs, livestock, cats and emus identified as the other animals most likely to be involved in a collision (SGIC 2014).

There is limited information relating to the incidence of collisions with kangaroos, and the magnitude of costs. However, since 2013, Data.SA Road Crash databases have recorded all crashes that were reported to the police and involved a collision with a wild animal (where the crash resulted in at least one person being killed or injured, vehicle towed away, or total property damage of $5000 or greater). Due to these criteria, the data do not reflect the full extent of animal-related crashes that occurred, but can still be used to show trends in the occurrence of more significant crashes. Figure 3 shows a general trend in increasing incidence of collisions with wild animals (but not domestic animals) across SA with increasing kangaroo abundance in the commercial harvest zone. The species involved within these crashes were not identified, however it may be assumed that kangaroos (and wallabies on Kangaroo Island in particular) constitute the majority of crashes with 'wild animals'.

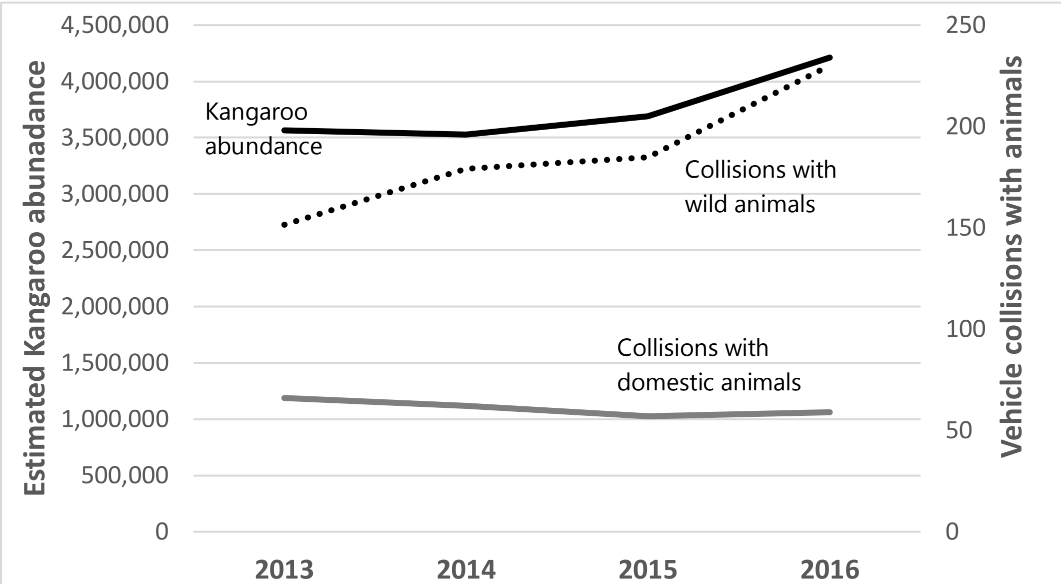

Figure 3. Estimated kangaroo abundance in the commercial harvest zone (Black line: Red, Western Grey and Euros combined) in relation to reported vehicle collisions with wild (dotted line) or domestic animals in South Australia (grey line). Data source: Data.SA

3.2 Environmental impact: Total Grazing Pressure

Total Grazing Pressure can be defined as 'the sum impact of stock, native herbivores and introduced species on pastures' (Choquenot et al. 1998). In SA, cattle, sheep, kangaroos, goats, deer and rabbits contribute to significant total grazing pressure (Tiver and Andrew 1997; Fisher 2004; DENR 2012; Mutze 2016a; Gillespie 2017). Additional invasive herbivores, such as donkeys, horses, pigs and camels will also contribute to total grazing pressure in some areas, but are typically less widespread (Fisher 2004). Koalas are significant grazers of native gum species on Kangaroo Island and in parts of the Adelaide and Mount Lofty Ranges region. There is also recent anecdotal evidence that abundant emu populations are significant grazers in the northern Eyre Peninsula and some surrounding areas.

Over-grazing from abundant herbivores can simplify the structure, composition and function of vegetation communities and has contributed to increased land degradation and biodiversity loss in South Australia

(Alexander 1997; James 2003; Read and Cunningham 2013; Eldridge et al. 2016). While all herbivore species will contribute to total grazing pressure, their impacts on vegetation will vary according to dietary preferences and behavioural differences. This report will focus on describing impacts of kangaroos, but the contributions of some other herbivore species are also acknowledged below.

3.2.1 Impacts of kangaroos on native vegetation and biodiversity

Kangaroos can have severe detrimental effects on vegetation. Grazing pressure from high kangaroo numbers has been associated with altered composition and structure, reduced biomass, and limited regeneration of native vegetation (Shepherd and Caughley 1983; Neave and Tanton 1989; Page and Beeton 2000; McIntyre 2010; Table 2). These impacts can lead to flow on-effects including reduced reptile species richness and diversity (Howland 2014) and reduced bird habitat quality (Howland 2016; Neave and Tanton 1989). Across Australia, significant improvements in vegetation condition, composition and structure have been reported when abundant kangaroo populations are controlled in conjunction with the management of livestock and feral herbivores (goats, deer, horses and/or rabbits) (Gowans et al. 2010, Sinclair, 1996 & 2005; Cobiac 2009; DENR 2012). Dingos can also play a role in regulating kangaroo populations and their impacts: kangaroo grazing has a strong impact on vegetation cover in areas where dingos are rare, and negligible impact where dingos are common (Morris and Letnic 2017). Exclusion experiments (summarised in Table 2) are particularly useful to identify the relative impacts of each herbivore species, and the densities at which they exert negative impacts (also discussed below: 'Total Grazing Pressure'). A summary of relevant studies that refer to grazing impacts of kangaroo and other herbivores in SA (not an exhaustive list) is provided in Table 2. Collectively, these studies provide evidence that the relative impacts of kangaroos and other grazers show significant spatial and temporal variation. Kangaroos are not always the primary cause of overgrazing (Sinclair 1996; Tivers and Andrew 1997; Mutze et al. 2016a; Tschirner and Tschirner 2016), and recovery of vegetation from overgrazing typically occurs when total grazing pressure is managed, rather than the management of individual grazing species in isolation (de Preu 2006; DENR 2012; Willoughby 2018).

Anecdotally, there are currently high numbers of kangaroos in heavily overgrazed habitats across many areas of the state, including (but not limited to) areas of the Mount Lofty Ranges, Barossa valley, Mid North, Northern and Yorke region, North East Pastoral region, and floodplain wetlands of the River Murray, including Chowilla and Katarapko. Survey and monitoring data provides evidence for impacts of kangaroo grazing across additional regions in SA, including the Mount Lofty, Olary, Gawler and Flinders Ranges, and the Eyre Peninsula (Table 2). Grazing pressure from kangaroos is considered to be a threat within many conservation parks in the Mount Lofty Ranges due to its impact on the condition, flowering and seed production of native vegetation (Wilson and Bignall 2009; Quarmby 2011; Paton 2016; Jenner 2016; Department of Environment and Energy 2017), which has likely contributed to local declines in a suite of native bird species (J van Weenen (DEW), 2017, pers. comm.; D. Paton (The University of Adelaide) 2018, pers. comm. May). Efforts to monitor and control the impacts of kangaroos and other grazers have been initiated across all of the above-mentioned regions of the state (as well as those described in Table 2), although these remain largely undocumented. Appendix 5 gives examples of grazing pressure around exclosures at Chowilla wetland (Riverland).

Various park management plans describe ongoing problems with overgrazing by kangaroos, rabbits, deer, and/or goats following the exclusion of livestock (e.g. DEWNR 2014a, 2015b, 2017c). Some management plans, such as that for Eastern Eyre Peninsula parks and the Gawler Ranges, have specific objectives to assess total grazing pressure and implement culling programs where necessary (DEWNR 2014a & 2017c). Much of the evidence for current impacts of kangaroos on parks and reserves in SA is detailed in population control proposals (in line with DEW's Kangaroos on Reserves [Population Control] Policy). Many recent proposals provide results of exclusion experiments, and/or density assessments to demonstrate that kangaroos are limiting the recruitment and diversity of: perennial grasses, trees, and woody shrubs (DEWNR 2014b, c & d; DEW2018a). Other proposals have included qualitative assessments of high kangaroo densities leading to declines in native plant floristic and structural diversity (DEW 2014d; DEW2018b). For many regions, information on kangaroo population numbers, their impacts and results of management actions remain largely undocumented outside of these proposals.

Table 2 Summary of some South Australian studies documenting grazing pressure (including impacts of kangaroos) in South Australia

Reference	Location	Method of identifying species' impacts	Herbivore species studied/identified as main grazers	Findings: impacts
Sinclair (1996), Sinclair (2005), Lawley et al. (2013)	TGB Osborn Vegetation Reserve (Koonamore Station),~200 km east of Pt Augusta	Livestock and rabbits excluded from study site. Kangaroos not excluded. Kangaroo densities inferred indirectly (dung)	Sheep, rabbits, kangaroos	• Dramatic regeneration of Mulga stands following the exclusion of sheep and rabbits, but in the presence of variable kangaroo densities (Sinclair 1996). • 76-year study found evidence for both episodic and gradual long-term regeneration in a range of woody and non-woody vegetation species (Sinclair 2005). • Long-term exclusion of sheep and rabbits allowed for the recovery of natural processes and variation in vegetation community assembly (Lawley 2013)
Tivers and Andrews (1997)	Eastern South Australia	Herbivore identities/impacts inferred indirectly (dung, tracks etc.)	Sheep, rabbits, goats, kangaroos	• Sheep were the 'most significant vertebrates affecting regeneration of woody species'. • Kangaroos and goat browsing did not threaten recovery of vegetation. • Rabbits were considered to have short-term impacts on regeneration.
Petit and Dickson (2002)	Northern Adelaide (Parra Wirra, Warren Conservation Park, and Old Kersbrook Forestry Reserve	Kangaroo, deer and sheep excluded from exclosures	Kangaroos, sheep, deer	• Exclusion of Kangaroo, deer and sheep and culling of kangaroos did not decrease grazing pressure on native orchids. In some years, grazing pressure was higher inside of exclosures, indicating that Kangaroos, sheep and deer were not the main grazers of orchid species.
de Preu (2006)	Flinders Ranges National Park	Exclosures: • Rabbits/kangaroos excluded • Kangaroos excluded Control (no exclusion)	Rabbits, kangaroos, goats	• Increased biomass of native plant species (chenopods, grasses, perennials) in the Flinders Ranges in areas where Red Kangaroos, Euros, and rabbits were culled and/or excluded
Mutze (2006)	Flinders Ranges National Park and Gum Creek Station	Control of rabbits and Euros (but not Red Kangaroos). Sheep present in some treatments.	Sheep, rabbits, kangaroos, goats	• No significant recovery of native herbs or forbs following rabbit control (rabbit haemorrhagic disease virus (RHDV) and warren ripping) in the Flinders Ranges, likely due to compensatory grazing by kangaroos and sheep. However a significant reduction in 'weediness' was observed, which may indicate an initial phase in successional recovery
Jenner (2006)	Southern Mount Lofty Ranges (Sandy Creek,	Exclusion of kangaroos, deer and presumably livestock (but not rabbits) via 1.5m mesh	Kangaroos, deer, rabbits and livestock	The following key findings were statistically demonstrated in exclusion plots compared to control plots: • Higher growth rate of seedlings in exclusion plots at Sandy Creek

Reference	Location	Method of identifying species' impacts	Herbivore species studied/identified as main grazers	Findings: impacts
	Cromer & Charleston Conservation Parks)	fences. No grazers are excluded in control plots.		• Greater number of flowering grass stems in exclusion plots at Cromer and Charleston • Differences in understorey composition, including greater dominance of grasses in exclusion plots at Cromer and more bare ground in control plots at both Cromer and Charleston.
Westbrooke et al. (2007)	Parra Wirra Conservation Park (40 km NE of Adelaide)	Livestock excluded, goats eradicated, rabbit and hare populations controlled to 0.2 individuals/km^2.	Livestock, goats, rabbits, hares and kangaroos	• Exclusion/control of introduced herbivores and management (culling) of Western Grey Kangaroos from densities of 50/km^2 to around 10/km^2 resulted in anecdotal regeneration of native tree and understory species.
Cobiac (2009) Peeters et al. (2006) Willoughby (2015, 2018)	Coffin Bay National Park and Lincoln National Park	Four experimental treatments: • Control (rabbits & kangaroo grazing) • Total exclosure (no grazing) • Kangaroo exclosure (rabbit grazing only) Rabbit exclosure (kangaroo grazing only)	Rabbits, kangaroos, horses	• Management of total grazing pressure via removal of horses, culling of kangaroos and warren-ripping/biological control (RHDV) of rabbits. • Management interventions have resulted in increased plant cover and height, decreased browsing damage and an increase in the number of young sheoaks • Plant cover (especially native grasses) increased significantly within all exclosures • Dung counts, supported by anecdotal evidence, show Western Grey Kangaroos are considered to be the most abundant herbivore in the park (about 40/km^2 in 2013). • The management of total grazing pressure is now mainly focused on controlling kangaroos (given that horses are absent and rabbits controlled).
Collings (2010b)	Northern Adelaide (Parra Wirra Conservation Park)	Grazed and ungrazed study plots. No separation of herbivore impacts but four species are being controlled: kangaroo, deer, goats and rabbits	Kangaroos, deer, goats and rabbits	• Ground cover abundance and the proportion of woody species demonstrating regeneration were lower in plots where kangaroo grazing occurred • Difficult to separate relative impacts of grazers and prove statistically that kangaroos are having an impact
Read and Cunningham (2010)	Roxby Downs region	Livestock excluded from some areas, kangaroos and rabbits present in variable densities.	Cattle, rabbits, kangaroos	• Significantly less small mammals were captured in areas with high cattle grazing pressure. • Kangaroo numbers were higher in control areas (no cattle), which may have negated the benefits of removing grazing pressure from cattle.

Reference	Location	Method of identifying species' impacts	Herbivore species studied/identified as main grazers	Findings: impacts
		Rabbit, kangaroo and cattle grazing pressure was indirectly inferred by dung counts.		
Paton (2016)	Sandy Creek, Cromer and Charleston Conservation Parks	Kangaroos and other large herbivores excluded from fenced areas.	Kangaroos, (but rabbits were also present)	• Heavy grazing outside exclosures (presumably by kangaroos) led to reduced growth, reduced floral production and higher mortality of plants.
Mutze et al. (2016a)	Flinders Ranges National Park	Livestock excluded, goats in very low numbers. Rabbit and Kangaroo densities inferred indirectly (dung)	Rabbits and kangaroos	• Native pasture cover and species richness declined exponentially with increasing rabbit density (within the range of 0–5 rabbits ha-1) • Cover of unpalatable exotic pasture species increased with increasing rabbit density • Kangaroo abundance was positively related to palatable native pasture cover
Tschirner and Tschirner 2016	Flinders Ranges National Park Vulkathunha-Gammon Ranges National Park Bimbowrie Conservation Park Plumbago Station	Rabbit, goat and kangaroo densities inferred indirectly (dung)	Rabbits, kangaroos, goats	• Areas with long histories of sustained high grazing pressure have experienced declines in diversity of palatable vegetation species. • Densities and impacts of grazing species show considerable spatial variation: - Localised evidence of heavy shrub browsing was attributed to either goats, rabbits or kangaroos according to inferred densities across sites - Poor grass cover at most sites was mainly attributed to uniformly high kangaroo grazing pressure and significant rabbit grazing pressure at specific sites. Goat scats were rarely observed in sites containing grassland habitats
Prowse and O'Connor (2018)	Agricultural areas in the Adelaide and Mt Lofty ranges, Eyre Peninsula, Northern, SAMDB and Yorke and St Vincent	None: looked at trends in indices of grazing pressure	Sheep, rabbits, kangaroos, goats, deer	• High proportion (45–54%) of plant species that were heavily or severely grazed (across regions) in 2016 • Increase in grazing severity over past 12 years in the AMLR, SAMDB, and the Yorke and St Vincent region, suggested an impact of abundant native and/or feral grazers

3.2.2 Grazing pressure from other major grazers in SA: livestock, rabbits and goats

It is well established that grazing by domestic livestock can be a major degrading process in Australian ecosystems (Yates et al. 2000; Landsberg et al. 2003; Waters et al 2017). Even very low levels of livestock grazing can have negative effects on ecosystem structure, function, and composition (Eldridge 2016), with increasing levels of grazing associated with decreased abundance of native and dominance of invasive plant species (Hobbs 2002). Grazing by cloven-hoofed livestock can also have a significant impact on soil structure and processes that deliver water and nutrients to plants (Yates et al. 2000). Livestock grazing pressure is intensified around artificial watering points, leading to increased land degradation (Landsberg et al., 1997; James, Landsberg & Morton, 1999; Fisher et al., 2003), and decreased abundance of native flora and fauna species (Landsberg et al. 1997).

Goats are generalist feeders that can adapt and thrive in a broad range of habitats including semi-arid environments of the state (DENR 2012). Feral goats contribute to overgrazing across many areas of the state, and their reduction or removal has been associated with improved vegetation condition and structure in the Riverland (Gillespie 2017) and the Flinders and Olary Ranges (DENR 2012; Tschirner and Tschirner 2016). During drought, feral goats can cause significant damage to grasses, shrubs and trees when clambering to reach food; foul waterholes, which are critical resources for native wildlife (Fisher 2004; DENR 2012); may prevent regeneration and cause soil erosion, which may result in ecosystem degradation and biodiversity loss. Feral goats also occupy the same habitat as Yellow-footed Rock Wallabies in the Flinders Ranges, where they compete for food, water and shelter (DENR 2012). Aerial culling of goats at Bimbowrie Conservation Park (Olary Ranges), has led to improved vegetation conditions including a doubling in height of previously-browsed mulga plants and increased abundance of *Acacia* species (DENR 2012).

Introduced European rabbits cause severe damage to native vegetation in Australia (Mutze et al. 2016b; Cooke et al. 2010). Rabbits have broad diets that include a range of grasses and herbaceous species (Mutze et al. 2016a) that can become more biased towards browse (bark, twigs and roots) in drier conditions (Dawson and Ellis 1994). Current research suggests that rabbits can prevent recruitment of highly palatable plants at very low densities of 50 rabbits/km^2 (Murdoch 2005; Mutze et al. 2016b) and suppress moderately palatable species (including grasses) at ~200 rabbits/km^2 (Mutze et al. 2016b). Control of rabbits via (RHDV) was associated with dramatic range expansions of three threatened native desert mammal species in north-eastern pastoral area of SA (Pedlar et al. 2016). These landscape-scale recoveries were attributed to both bottom-up and top-down trophic effects of effective rabbit control (in the presence of livestock); e.g. decreased competition for food and declines in rabbit-dependent predators (Pedlar et al. 2016). A new strain of rabbit haemorrhagic disease virus (RHDV2) was detected in the Flinders Ranges in 2016, which has led to an estimated average 80% decline in rabbit populations at two long-term monitoring sites in SA (Mutze et al 2018). It is probable that the recent decline in rabbit populations will contribute to short-medium term recovery of some vegetation characteristics (Mutze et al. 2018), but over time, genetic resistance to RHDV2 will likely lead to an increase in the rabbit population (Mutze et al. 2015).

3.2.3 Inferring total grazing pressure

Understanding the total grazing pressure on a particular system can help inform management decision that affect both the environment and/or livestock productivity. In SA, two main methods of inferring total grazing pressure have included: Land Condition Index assessments for the Bounceback program (DePreu, 2000; DENR 2012), and calculating indices of grazing pressure from Bushland Condition Monitoring data (Prowse and O'Connor 2018). Rapid assessment methods have used dung counts (to identify grazer identity) to assess relative densities of primary grazing species (see Read and Cunningham 2010; Mutze 2014). Rapid assessment methods that incorporate using both dung counts and rapid vegetation assessments (to assess grazing impact) are also being trialled to assess relative grazing impacts on the Eyre Peninsula and in SA's Bounceback program (Brandle 2017). Numerous other methods are used to assess grazing pressure in other regions (i.e. Gillespie 2017), though documentation of these methods is rarely readily available.

Herbivore-grazing pressure can also be compared using a standard measure called the 'Dry Sheep-Equivalent' (DSE), which describes the energy requirements of a standard 45 kg mature sheep (Landsberg & Stol, 1996; Kirkpatrick, Bridle & Leith, 2007). Current scientific consensus is that the energy requirements of an 'average' 25 kg kangaroo is equivalent to 0.35 DSE (Dawson and Munn 2007; Munn et al 2009 & 2013); that is, that the energy requirements and relative grazing pressure of a standard kangaroo is estimated at 35% that of a standard sheep. Using this conversion factor, the current 5 million kangaroos in the commercial harvest zone is equivalent to 1.75 million sheep (Table 3). There are also an estimated 11 million sheep, 1.1 million cattle (equivalent to up to 11 million sheep: Table 3), and unknown, but significant numbers of other feral herbivores (such as goats, rabbits) that contribute to total grazing pressure across SA (Fisher 2004; Livestock SA, 2018).

Table 3. Estimated populations, DSE conversion factors and sheep equivalents for three herbivore species in South Australia. Note that the estimated kangaroo population represents that which currently occurs in the commercial harvest zone only.

Species	Estimated population (2018)	DSE conversion factor	DSE equivalent
Sheep	11 million	1	11 million
Beef cattle	1.1 million	8–10[1]	8.8–11 million
Kangaroo	>5 million*	0.35[2]	>1.75 million

Landholders use DSEs to calculate 'stocking rates' (DSE/hectare = total DSEs ÷ total grazing hectares) according to the carrying capacity of land areas. The effects of livestock grazing will vary with herbivore and habitat type, as some species cause more damage to certain vegetation assemblages than others (Eldridge et al. 2016, Mutze et al. 2016a). Stocking rates of sheep and cattle are relatively straightforward to manage as they can be moved and contained between fenced areas. Goats, rabbits and particularly kangaroos are more difficult to control and contain. DEW's Pastoral Unit currently advises landholders on appropriate stocking rates according to assessments of physical disturbance and vegetation characteristics (community structure, condition and age class) on leased land.

3.3 Managing total grazing pressure on reserves: case studies

Many approaches to management of overgrazing in SA have taken an integrated approach to controlling the impacts of multiple herbivore species (DENR 2012, Sinclair 1996 & 2005; Willoughby 2018).

Bounceback is a major ecological restoration program that has taken a broad, integrated approach to restoration in the Flinders, Gawler and Olary Ranges since its inception in 1990. A main aim of this program is to reduce total grazing pressure (from livestock, goats, rabbits and kangaroos), which has included culling kangaroos when local densities were above management thresholds (DePreu 2000; DENR 2012). Major outcomes of this program that have been accomplished through multiple management interventions include: native species reintroductions, recovery of Yellow-footed Rock-wallaby populations, reduced goat, fox and rabbit numbers, regeneration of native vegetation and linking public and private land managers (DENR 2012). Ongoing challenges for this program include high grazing pressure from Red Kangaroos, Western Grey Kangaroos and Euros which has reversed recoveries for grasses that had shown recovery following removal of livestock (Brandle et al. 2018), and anecdotal reports of abundant Yellow-footed Rock-wallabies contributing to overgrazing in some areas. The broader aims of Bounceback 'rely on reducing total grazing pressure', which is 'likely to require added investment in management and innovative policy development' (Brandle 2018)

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[1] SA MDB Grazing livestock in the MLR – stocking rates Fact sheet: August 2015. Accessed from: http://www.naturalresources.sa.gov.au/samurraydarlingbasin/publications/grazing-livestock-mlr-stocking-rates

[2] Munn et al. 2013

On the lower Eyre Peninsula, sheoak grassy woodlands are gradually recovering due to the successful reduction in total grazing pressure. Kangaroos have been managed in Coffin Bay National Park and Port Lincoln National Park since 2001, followed by the removal of horses in 2004, and intensive rabbit control (warren ripping) in 2005. Since the beginning of the project in 2003, several positive changes have occurred at this site, with evidence suggesting that these have occurred in response to management interventions (Cobiac 2009: Wiloughby 2015, 2018). Observed responses to reduced numbers of grazing animals in management areas include increased plant cover and height, and increased recruitment and reduced grazing on sheoaks (Peeters 2006; Cobiac 2009; Willoughby 2015, 2018).

The control of kangaroos to target densities on the Eyre Peninsula (5 kangaroos/km^2) and at Bounceback sites within the Flinders Ranges (≤5 to 35 kangaroos/km^2) appears to have aided restoration (Cobiac 2009; Willoughby 2015; de Preu 2006; DENR 2012). It is also important to note that these target densities are considered to be relatively arbitrary and are not linked to expected ecological responses.

Another long-term study of vegetation changes following exclusion of sheep (since 1925), and control of rabbits (since the mid-1970s) has shown an often gradual recovery of native plant species over time at the TGB Osborn Reserve (Koonamore Vegetation Reserve), 450km north of Adelaide (Sinclair 1996 & 2005; Lawley et al. 2013). Neither kangaroos nor emus have been excluded or culled at this site, but there has still been an improvement in vegetation cover/ diversity compared to outside of the reserve.

3.4 Knowledge gaps

1. The cost of damage caused by high kangaroo numbers to pastoral and agricultural enterprises (competition with sheep, cattle, crops, damage to fences):
    a. Including studies of dietary preferences of kangaroos in South Australia and how evidence for dietary overlap translates to competition with livestock.
2. The relationship between kangaroo density and the desired ecological response has not been described (Pople 2004: Hacker et al. 2004; de Preu 2006). We need a better understanding of how particular kangaroo densities translate to impacts on productivity, land condition and biodiversity (discussed in Hacker et al. 2004). Our understanding of how kangaroo impacts on vegetation translate to broader biodiversity values (i.e. impacts on other native fauna, including threatened species) is particularly lacking.
3. Rapid survey methods to determine indices of Total Grazing Pressure and identify relative impacts of herbivore species (to allocate resources for control effectively and efficiently):
    a. Brandle (2017) describes methods used to rapidly assess relative herbivore densities and impacts on indicator vegetation at two sites on the Eyre Peninsula. Mutze et al. (2014) also proposes rapid survey methods that allows estimates of rabbit density to be obtained from just a few hours work and can be undertaken alongside vegetation condition surveys to quantify rabbit impacts.
4. Impacts of overgrazing are already being considered within the context of total grazing pressure in SA, though there are no standard guidelines for doing so. The development of integrated guidelines or frameworks for managing total grazing pressure on pastoral or conserved land should:
    a. Consider the abundance and relative impacts of herbivore species:
    b. Be developed with the intention to increase our capacity to manage total grazing pressure and account for the resources required to do so
    c. Allow for the efficient and effective management of whichever species (native or feral) are causing significant impacts within a given area:
        i. Current options include: reducing livestock stocking rates (pastoral land), harvest/cull kangaroos, control rabbits (biocontrol or warren ripping), or culling feral herbivores (i.e. goats, horses).

ii. Most feral herbivores (i.e. rabbits, goats, deer, camels) are considered 'declared pests' and must be contained or destroyed under the *Natural Resources Management Act 2004*. As a native species, Kangaroos are protected under the South Australian *National Parks and Wildlife Act 1972*, and there are greater restrictions and regulations on their management (discussed in detail in Section 5). These differences have anecdotally led to greater efficiency in controlling impacts of feral herbivores compared to sometimes inefficient control of kangaroo impacts due to administrative barriers and resource constraints (also discussed in Section 5).

5. For many regions, information on kangaroo (and other herbivore) population numbers and impacts, as well as the different management approaches and responses to management actions remain largely undocumented. Much of this knowledge exists anecdotally, which constrains our ability to learn from different case studies to inform improved management approaches.

4 Social values towards kangaroos and their management

Including social values in environmental decision-making can assist with the development and acceptance of new management regimes and help to minimise potential stakeholder conflict (Ives and Kendal 2014).
Although the biology and ecology of common kangaroo species is relatively well-studied, there is limited research on community and stakeholder expectations towards kangaroos and their management. Kangaroo management can be particularly controversial and divisive because kangaroos are valued as a national wildlife icon, resource, and can also be seen as a pest when they become overabundant (Pople and Grigg 1999; Higginbottom et al. 2004). Kangaroos, along with koalas, are by far the most popular native animals for international tourists (Higginbottom et al. 2004). Therefore, the potential international response to kangaroo management actions adds further complexity for decision makers (Pople and Grigg 1999). Collectively these diverse social values affect the capacity of kangaroo management methods to contribute to conservation and management objectives (Choquenot et al 1998). Understanding the differing values of relevant stakeholders may assist managers in understanding the social license for potential management actions, and help with framing messages which connect with diverse audiences. This can assist in improving community acceptance of management methods, or help to identify opportunities for alternative management approaches (Ives and Kendal 2014).

4.1 Traditional owners

Kangaroos are highly significant to some traditional owners, with some species being central to creation history, important in ceremonies or valued as personal totems (WWF 2011, Thomsen et al. 2006; Thomsen and Davies 2007). A survey of two South Australian Traditional owners from the commercial harvesting area (Anangu from the Western Desert region and Adnyamathanha group from the Northern Flinders Ranges) has allowed some insights into the diverse perspectives of Traditional owners towards kangaroo harvesting (Thomsen et al. 2006: summarised in Table 4).

4.1.1 Views on kangaroo management:

The practice of culling overabundant kangaroos without utilising the carcass was considered universally offensive, mainly due to the perceived 'wastage' of the animal (Thomsen et al. 2006). Despite the commonalities, there were also some major differences in culture and customs among the two groups, which reinforces the need to understand and incorporate views from diverse Traditional nations in kangaroo management. For Anangu, the Red Kangaroo (Malu) is of especially high cultural significance, and some Anangu elders oppose the commercial harvest of this species on their lands because the culling and processing was not in accordance with their beliefs (Thomsen et al. 2006). The Adnyamathanha people, however, had very different views towards kangaroo harvest and were interested in developing their own commercial kangaroo harvest enterprises (Thomsen et al. 2006). Anangu people observe strict cultural protocols for hunting Red Kangaroos and aim to shoot the animal in the heart as they believe that head shooting damages the spirit of the animal (Thomsen et al. 2006). This is in discord with SA's Kangaroo Harvesting Regulations and the National Code of practice for humane shooting of macropods (commercial), which describe head shooting as the preferred standard for commercial harvesting on animal welfare grounds.

Table 4 Major issues relating to kangaroo harvesting as identified by Aboriginal research participants from Anangu and Adnyamathanha nations (adapted from Thomsen 2006)

	Issue/aspect	Western Desert region (Anangu)	Northern Flinders Ranges region (Adnyamathanha)
Cultural: Significance, sensitivities and beliefs	Red Kangaroos have cultural significance (very significant to Anangu)	✓	✓
	Euros have cultural significance		✓
	Some people have the Red Kangaroo or Euro as their personal totem	✓	✓
	Culling of kangaroos (without utilisation) is offensive	✓	✓
	Buying kangaroo products harvested using non-indigenous practices/laws is not culturally appropriate, however the purchase of tails from commercial harvest is acceptable	✓	✓
	Many survey participants believe that kangaroos belong to Aboriginal people	✓	✓
	People who live on the Anangu Pitjatjantjara Yankunyjatjara Lands (APY Lands) stated that the commercial harvest of kangaroos should not occur north of Coober Pedy	✓	
	Eating kangaroo is very important to the physical and spiritual health of Aboriginal people	✓	
	Anangu believe that to shoot a kangaroo in the head damages the spirit of that animal and is therefore cruel.	✓	
Engagement with decision-making and harvesting	There is a need for communication with Aboriginal people and respect for their views	✓	✓
	Obtaining a gun licence can be a problem	✓	✓
	Access to national parks and pastoral leases for hunting can be an obstacle		✓
	Potential benefits from the commercial harvest of kangaroos should flow back to Aboriginal communities		✓

4.1.2 Engagement in decision-making

From the available social surveys, it is clear that Traditional owners within SA want to be engaged in decisions regarding kangaroo management, and that there are both common and diverse values held by different groups (Thomsen and Davies 2005; Thomsen et al. 2006). Current avenues for such engagement include:

- **Representation on the Kangaroo Management Reference Group (KMRG),** which is convened by DEW. This is "the primary forum through which stakeholder group representatives can raise issues for discussion, as well as communicate their group's positions and interests to Government and other stakeholders on a regular basis" (DEWNR 2017a).
- **Involvement in the implementation of the South Australian Commercial Kangaroo Management Plan (2018-2022).** This involvement includes (adapted from Section 4.2, Action 7 of DEWNR 2018):
  - holding "specific discussions with representatives of Traditional nations to develop more effective ways of sharing information"
  - Encouraging "Aboriginal participation in kangaroo management"
  - Involving "Aboriginal people in the development of the communication strategy for the Kangaroo Management Program", and

- Requesting feedback on “kangaroo management strategies, and implementation of the commercial management plan”

- **Co-management of national parks with traditional owners** via co-management boards or advisory committees.

4.2 Primary producers

A large scale study of 906 graziers in five pastoral zones across Australia found that kangaroos were generally perceived as pests by this group (Gibson and Young 1988). The main concern was that kangaroos consume pasture, and are perceived to compete with livestock, especially when resources are scarce (Gibson and Young 1988). The landholders’ perception of losses due to kangaroo impacts was estimated at $AU113 million. Half of this cost was attributed to the cost of lost fodder, while lost crop production and fence repairs were seen as other significant losses (Gibson and Young 1988). While these estimated costs are based on perceptions and may not be economically accurate, they are nonetheless a measure of the extent to which kangaroos are seen as ‘pests’ by landholders. Another, more recent study has actually estimated the total annual agricultural losses due to kangaroos (across Australia) at a much lower figure of $AU27 million (McLeod, 2004), which demonstrates some of the difficulties when estimating the cost of kangaroo impacts.

A smaller South Australian study (Thomsen and Davies 2007) found that the majority of SA landowners surveyed in their study (95%) did not perceive kangaroos to be pest all the time, but instead described them as being a problem ‘at times’ when they were overabundant. This nuanced description may actually be an artefact of the different methods of questioning landowners rather than a true difference in landowner perceptions from that described in Gibson and Young (1988). In Thomsen and Davies (2007), landholders acknowledged both an economic value of kangaroos (producing meat and leather) as well as an intrinsic value (their ‘right to exist’). When asked ‘who owns kangaroos’, most landholders believed that kangaroos belonged to them, or to no-one (that kangaroos had no true ‘owners’) (Thomsen and Davies 2007).

4.2.1 Views on kangaroo management

The primary motivation for landholders allowing field processors on their property was to manage grazing pressure, with secondary reasons including conserving water and allowing income for field processors/processors (Thomsen and Davies 2007). The fact that a landholder allows a field processor on their land at all indicates a level of support for harvesting, and it appears that this arrangement is seen to provide mutual benefit. As well as reducing kangaroo numbers on the properties, landholders often gain additional benefits from field processors that are often also skilled in other trades, such as electrical, plumbing, welding, or station hand. The majority of landowners believed that discontinuing the harvest would result in kangaroo population increases, which would in turn lead to excessive grazing and land degradation (Thomsen and Davies 2007). Landholders were also concerned about the potential for kangaroos to be killed inhumanely (via poisoning or amateur shooters) in the absence of effective harvesting to control the population. Landholders located near Flinders Ranges National Park expressed ‘dismay’ that kangaroos were being culled without utilisation of carcasses, and considered it to be a waste of resources (Thomsen and Davies 2007).

Social values do change over time (Ives and Kendall 2014) and it would be useful to repeat this survey again now that overall kangaroo population numbers are more than double what they were during the millennium drought (2001–09) when Thomsen and Davies (2007) conducted their initial surveys.

4.3 Commercial kangaroo harvesting industry

The values that the kangaroo harvesting industry places on the kangaroos themselves are largely undocumented. However it would be safe to assume that kangaroos are important to these stakeholders in an economic sense as their harvest and trade provides financial returns. Attitudinal surveys found that South Australian field processors and processors believe kangaroos 'belong' to the Crown/government or have no owners at all (Thomsen and Davies 2007). This could indicate a possible intrinsic value for kangaroos (their 'right to exist') from these groups, but it is recommended that future work describe field processor and processor values directly.

4.3.1 Views on kangaroo harvesting

Most of the research into the views of field processors and processors focused on identifying barriers to productive harvest and what can be done to improve the industry (see also section 5 'Kangaroo management in SA).

Most of the kangaroo field processors in the Thomsen and Davies (2007) study indicated that although harvesting kangaroos helped to reduce grazing pressure, they also wanted to maintain kangaroo numbers so that they could continue harvesting in areas of high density (Thomsen and Davies 2007). The majority of field processors generally did not support culling of kangaroos without utilising the carcasses as it was considered to be a waste of resources (Thomsen and Davies 2007).

In terms of industry standards for animal welfare, the Kangaroo Industries Association of Australia (KIAA) states that it 'takes animal welfare very seriously', and has 'tight controls and monitoring to ensure welfare outcomes are optimal' (KIAA, 2018).

Records from a recent 'kangaroo management' forum held in Yunta, SA (2 November 2017) also provide current insights on common issues/values expressed by landholders, harvesters, field processors, Livestock SA, NRM, pastoral boards; and DEW. Some of the values and concerns captured in this forum involve a 'confusion about how kangaroos are valued' and challenges to managing kangaroos and the kangaroo industry. For example:

- Questioning whether kangaroos should be considered a pest or a resource
- Acknowledgement of a 'moral responsibility to not waste a resource'
- A decline in the number of field processors and challenges in attracting younger people into the industry
- Concern that landholders are destroying kangaroos without a Permit to Destroy Wildlife
- Establishment of a peak body for the industry in South Australia
- Concern about a lack of compliance (for non-commercial culling) due to lack of resources.
- Lack of awareness and support for industry by public and government.

4.4 General public

4.4.1 Views on kangaroo management

A 2017 study of 350 members of the SA general public showed a high level of awareness (70% of respondents) that kangaroo numbers are large and increasing, and that this change was mainly attributable to human-induced landscape changes (land clearance, cropping etc.) (Olsson 2017). Most (70–83%) respondents agreed with the use of harvested kangaroos for skins, or meat for human consumption/pet food. Respondents who did not agree with the commercial use of kangaroos either identified as vegetarian, referred to kangaroos as totems and national icons, or considered the killing of kangaroos to be cruel. The respondents were equally split in their preference for management techniques that were considered 'active' (shooting) or 'passive' (contraception, relocation, removing access to water or doing nothing) to manage the population at all (Olsson 2017). The Olsson (2017) study did not identify any demographic information about the survey participants, and mentioned a possible bias in the sample towards those who are interested in/aware of kangaroo population issues.

4.5 Animal rights advocates and welfare organisations

We were unable to find any structured social surveys of the attitudes of animal rights/welfare groups towards kangaroos and their management, so the information presented here represents anecdotal evidence of a small subsection of this stakeholder group (values described in position statements from organisation websites or in published reports).

The general perception of animal rights advocates and welfare organisations is that kangaroos have intrinsic value and deserve protection from cruelty. Organisations such as the Australian Wildlife Protection Council, RSPCA, THINKK: the think tank for kangaroos, and Fauna Rescue SA actively promote the protection of kangaroos.

4.5.1 Views on kangaroo management

The views of some welfare organisations (not an exhaustive list) that have expressed some concerns about current kangaroo management methods via their organisation websites and publications. These are summarised below and in Table 5 to give a snapshot of common issues:

RSPCA: Do not specifically oppose kangaroo control but question the 'humaneness of kangaroo shooting and the basis for current government policies on the management and killing of kangaroos' (RSPCA 2018a).

Animal Liberation SA: Oppose the killing of kangaroos, which is described as 'slaughter', and are concerned about the long-term effects of kangaroo control on population numbers (especially Red Kangaroos).

Australian Wildlife Protection Council: Strongly oppose the harvest and culling of kangaroos, and use terms such as 'slaughter', 'barbaric', 'inhumane' and 'government-sanctioned cruelty' to describe legal shooting of kangaroos. They do not consider kangaroos to be overabundant and describe the Red Kangaroo as a threatened species.

Fauna Rescue SA: Supports the Australian Wildlife Protection Council's campaign to 'End the commercial killing of kangaroos' (no other information is available on their website in relation to views on kangaroo management).

THINKK: Questions the need to kill kangaroos and advocates research for non-lethal approaches. One THINKK publication advocates a 'total prohibition on killing' in order to adequately address welfare concerns (Boom and Ben-ami 2011). This organisation includes a number of scientists that specialise in ecology, environmental management and sustainability and thus overlaps with stakeholders from the 'scientific community'.

Table 5 Major issues with current kangaroo management identified by four animal welfare organisations[3]

Issue	RSPCA	Animal Liberation SA	AWPC	THINKK
Inhumane killing of adults due to shooting inaccuracy	✓	✓	✓	✓
Inhumane killing of joeys	✓	✓	✓	✓
Need for improved standards and/or training for killing joeys	✓	✓	✓	✓
The process for developing harvest quotas: methodology and/or that the primary aim of quota setting should be based on mitigation of environmental impacts	✓	**N/A**	✓	**?**
Lack of field auditing to ensure that animals are killed in accordance with national codes of practice or that injured kangaroos are not left to die inhumanely	✓	✓	**N/A**	✓
Lack of non-lethal methods being used for population control	**N/A**	**N/A**	**N/A**	✓
Do not consider kangaroos to be 'overabundant'	**N/A**	✓	✓	✓
Do not consider kangaroos to cause land degradation	**N/A**	✓	✓	**?**

[3] RSPCA, AWPC and THINKK are national organisations, and their views are not constrained to kangaroo management in SA.

4.6 Scientific community/conservationists

We were unable to find any structured social surveys of the attitudes of the scientific community towards kangaroos and their management, so the information presented here represents anecdotal evidence of a small subsection of this stakeholder group (individual interviews and published papers).
Ecologists and environmental scientists generally tend to place high value on biodiversity, which includes kangaroo populations that are 'in balance' in their ecosystems. Scientists often state human-induced landscape changes, namely the expansion of pastoral land and removal of dingos, as the reason for high kangaroo numbers and therefore place blame on humans rather than de-valuing the animals themselves (Pople and Grigg, 1999; Fedorowytsch, 2017, 14 Sept). Species' status assessments (at a regional, state or national level) could also be examined as an indication of perceived population trends and/or conservation concerns from ecologists.

4.6.1 Views on kangaroo management:

Most ecologists and conservation organisations in the scientific community acknowledge that kangaroos can cause negative impacts (summarised in Section 3 of this report) and are generally in favour of the principle of ethical and sustainable kangaroo control (especially via harvest) (Caughley 1983; Alexander 1997: Grigg 1989 and 2002).
The International Union for the Conservation of Nature (IUCN), also endorses the 'ethical, wise and sustainable use of some wildlife' (IUCN 2000). The legal harvest of kangaroos using professional shooters is generally supported by this group, some of whom have acknowledged the risk of less humane outcomes if inexperienced and illegal shooters attempt to control kangaroos in the absence of organised control measures (Grigg 1989; Caughley and Sinclair 1994). There is also support for current methods used to set harvest quotas (Pople, 2008; Hone and Buckmaster 2015; Johnson et al. 2015). Some ecologists have voiced their disapproval of culling in the case where carcasses are not used, as opposed to harvesting, and/or advocate for alternative approaches to kangaroo management, such as re-establishing dingos as top predators south of the dog fence (Royal 2018; 4 Feb; Fedorowytsch, 2017, 14 Sept).

4.7 Knowledge gaps and future work

Social values change over time (Ives and Kendall 2014), and some of the perspectives described in specific surveys of social values towards kangaroos in SA (Thomsen et al. 2006; Thomsen and Davies 2007) may have changed. Capturing current values is especially relevant given the current unprecedented high impact of the kangaroo population in SA and issues associated with low rates of harvesting (also discussed in Section 5: Kangaroo management in SA).

This review has identified the following knowledge gaps, which may require further investigation:

1. Identifying relevant stakeholders for consultation on statewide kangaroo management. This may include representative/s from the following groups: traditional owners, primary producers, field processors and processors, animal welfare organisations (i.e. RSPCA), conservation groups, public land managers (DEW), PIRSA, and the scientific community.
2. Gaining an up-to-date understanding of the socio-political demographic elements that influence stakeholder values towards:
    a. The environment (whether it be agricultural land or protected land)
        i. What is valued within those environments and how do these values link with or inform the way that we manage grazing impacts?
    b. Kangaroos themselves (i.e. pest, resource, intrinsic value etc.)
    c. Management of kangaroos:
        i. Identifying stakeholder perceptions and concerns regarding management options
        ii. Identifying values that may result in conflict when taking particular management approaches

iii. Using knowledge of stakeholder values to frame messages about management decisions
iv. Identifying opportunities to work together with diverse stakeholders for mutually beneficial outcomes.

3. A method/strategy to capture social values in a way that can be used to inform management decisions (also in the context of understanding overlap with knowledge, economic values and regulations).
4. Published information on perspectives of traditional owners is lacking outside of the commercial harvest zone. The management of kangaroos via destruction permits/culling on reserves is relevant to Traditional owners throughout the state.
5. A plan or model for how to deal with potential conflict:
    a. See Madden and McQuin (2014), as discussed in the context of kangaroo management in Descovich (2016)
    b. Stakeholders are more likely to accept management decisions that are not completely in line with their views or values if they feel genuinely respected and included in decision-making processes (Descovich 2016).

Of relevance for future efforts, Ives and Kendall (2014) provide guidelines for managers wanting to incorporate social values in environmental decision-making that focus on:

- **Understanding the values of relevant stakeholders in advance to help predict which actions are likely to cause negative responses**. For example, if culling animals is required to protect ecosystem health, then people with strong values for animal protection are likely to react in opposition of such actions. Recognising these values can assist managers in aligning messages to responsive groups before taking action in order to minimise potential conflict. An understanding of social values should ideally be sought early in the planning process.
- **Communicating and framing messages in different ways to connect with diverse stakeholders**. Messaging about environmental management is less effective if it is framed in a way that only a subset of the stakeholders will consider important. Effective and targeted messaging is particularly important when ecological outcomes rely on changing human behaviour.
- **Identifying positive overlaps in values held by different stakeholders.** In the case of stakeholder values toward land use, determining areas of compatibility and trade-off can be particularly important.

5 Kangaroo management in SA

All kangaroo species are protected under the South Australian *National Parks and Wildlife Act 1972* (the Act). Under the Act, there are provisions to:

1. Sustainably harvest protected animals for which there is a management plan (Division 4B – Harvesting of protected animals)
2. Cull (take) protected animals in accordance with DEW policies and permit requirements (Section 53 - Permits to take protected animals).

5.1 Culling on reserves

Section 60G(1) of the Act limits the harvesting or protected animals to the following species

1. Red Kangaroo
2. Western Grey Kangaroo
3. Euro (Wallaroo) (Hill Kangaroo)

However, Section 60G(3) enables additional species (e.g. Eastern Grey Kangaroo—*Macropus giganteus*) to be declared by regulation on the recommendation of the Minister.

DEW's Kangaroos on Reserves (Population Control) Policy (DENR 2014), describes the framework for the control of kangaroos within reserves proclaimed under the Act, the *Wilderness Protection Act 1992* and land dedicated to the Minister for conservation purposes under the *Crown Land Management Act 2009*.

The requirement of section 60J(2) of the Act is that kangaroos may only be controlled on reserves when there is a demonstrated effect on conservation values and the Minister has adopted a plan of management under section 38(10a) in relation to the reserve that provides for the culling of animals.

The Kangaroos on Reserves (Population Control) Policy also refers to barriers (i.e. a fence) limiting self-regulation of a population, and/or alterative control measures deemed or demonstrated to be unsuccessful (DENR 2014a). The control of kangaroos cannot occur on reserves if it poses a risk to the regional conservation status of that species (DENR 2014a). In order to undertake kangaroo control on reserves, a formal proposal must be completed and approved in accordance with both DEW policy (DENR 2014a) and procedure (DENR 2014b). The proposal must:

- Provide sufficient qualitative or quantitative evidence to demonstrate a significant impact of kangaroos on identified conservation values in the reserve
- Justify that feral herbivores are being controlled when risks to conservation values as a result of total grazing pressure (from multiple herbivores)
- Describe monitoring and research needs that focus on: 1) the population of kangaroos and impacts to conservation values and 2) the potential impact of the proposed program on the regional conservation status of the targeted species
- Describe clear goals and objectives that are achievable and measurable
- Provide operational detail, such as timing of control activities
- Demonstrate that an adaptive management strategy is being utilised;
- Outline stakeholder issues and management through the development and implementation of a communications strategy
- Consider the risks associated with both action and inaction (precautionary principle).

Control programs must submit reviews at the end of the approved control period to assess progress towards the achievement of stated objectives (DENR 2014b).

5.2 Permits to Destroy Wildlife ('Destruction Permits')

Section 53(1)(c) of the Act provides for the granting of a permit to allow the destruction or removal of protected animals that are causing, or are likely to cause, damage to the environment or to crops, stock or other property.

Landholders can apply for Permits to Destroy Wildlife ('Destruction Permits') and their application must provide sufficient information to justify a permit. If approved, DEW will grant a permit that allows culling of specified species and quantity (Appendix 5a and b). Destruction Permits require that carcasses remain on the property, unless 'personal use' (yellow) tags have been purchased against the permit and attached to the carcass.

The granting of Destruction Permits for Western Grey Kangaroos has increased from about 500 to 800 permits in the period 2010–17, whereas the number of permits issued for all other species has consistently stayed below 100 for each species across all of SA (Appendix 5a). The number of Western Grey Kangaroos that have been approved to be destroyed via these permits has increased from around 16,000 to 37,000 individuals in the same period. The overall number of Red Kangaroos, Eastern Grey Kangaroos and Euros issued on destruction permits has more than doubled in the same time period (though <5000 animals are approved per species) (Appendix 5b). The number of Kangaroo Island Tammar Wallabies issued on destruction permits fluctuates from 5000–10,000 across years (Appendix 5b).

The increases in the numbers of permits and the number of animals approved for destruction are likely influenced by both trends in macropod numbers and environmental conditions, but also by officer delegations for approval of permits.

5.3 Harvest of kangaroos in the commercial zone

Under Section 60I of the Act, the harvesting of kangaroos in South Australia requires a Management Plan. The primary goal of the current management plan is to 'ensure an ecologically sustainable harvest of kangaroos and to provide an alternative management option for reducing the damage caused by overabundant kangaroos' (DEWNR 2017a).

In accordance with the current management plan (*South Australian Commercial Kangaroo Management Plan 2018-2022*) (DEWNR 2017a), the following three species may be commercially harvested: Red Kangaroo, Western Grey Kangaroo and Euro. Commercial harvest is conducted by professional licenced field processors (who hold a Class 13/14 Permit to Harvest and Sell or Use Protected Animals [Kangaroo Field Processor]) with the consent of landholders. All animals must be killed humanely, in accordance with the *National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Commercial Purposes* (DEWHA 2008). Carcasses are tagged, stored in chillers and then sold to licensed kangaroo meat processors. DEW estimates the population of the three harvested species via annual aerial and on-ground surveys across the commercial harvest zone, and uses these data to set annual harvest quotas. The actual number of harvested kangaroos is also monitored via industry returns (i.e. kangaroo field processor and meat processor returns). Quotas are designed to ensure sustainable harvest over the long-term (Caughley 1987; DEWNR 2017a) and are set at a maximum of 20% of the estimated population size for Red Kangaroo, and 15% of the estimated population size for Western Grey Kangaroo and Euro within each Commercial Harvest Sub-Region. The management plan also describes minimum target densities for which each species should be maintained within each subregion (DEWNR 2017a). The SA commercial harvest zone covers ~63% of the state (Appendix 1; DEWNR 2017), and commercial harvest is not currently permitted outside of that zone. The majority of kangaroos (89%) are harvested from pastoral regions, with most being harvested in the Eastern Pastoral Region (59%) (DEWNR 2017b) where kangaroo densities are generally higher. The commercial harvest of kangaroos has occurred for over 30 years in South Australia, and the industry generated $32 million in revenue in 2016/17 (PIRSA 2018).

5.4 Current effectiveness/issues with harvest

Harvest rates in the SA commercial harvest zone are currently very low, and have been steadily declining over the past 10 years (i.e. Figure 6). In 2016, the total quota for all three species combined was 684,600, but only 98,560 individuals (14% of quota and 2% of the overall population) were harvested (DEWNR 2018). The reasons for these low harvest rates have been discussed by representatives from a range of stakeholder groups (DEW, field processor, Landholders, Livestock SA, PIRSA, SAAL NRM Board, SA Pastoral Board) during workshops in late 2017 and interviews (DEWNR Kangaroo management forum 2017; DEWNR, PIRSA and Livestock SA 2017; PIRSA 2018) and interviews (Thomsen and Davies 2007) and are summarised below:

- **High start-up costs for field processors**: costs of accreditation, vehicle, gun, and tags
- **Isolation of harvest areas:** lack of towns and infrastructure including long distances and travel times between home, harvest locations and chillers. This also increases the cost of harvest because of increased fuel and vehicle maintenance costs and puts pressure on families and social life. Field processors often have limited access to power and basic amenities while working.
- **Topography**: difficult terrain in many areas can restrict access to property and impede visibility (particularly when harvesting Euros). This limits the areas in which field processors can work.
- **Low financial returns**: low prices paid to field processors.
- **High costs for tags:** tags are more expensive in SA compared to other states.
- **Shortage of field processors:** attributed to low economic returns and the difficult nature of the work (e.g. isolation (see above) and night work). Long waiting time for payment to field processors.
- **Importation and processing of kangaroos that were harvested interstate:** reduces the incentive to harvest SA populations.
- **Low consumer demand for kangaroo meat (national and overseas)**.

Harvest is less likely to be a viable management option for reducing impacts of overabundant kangaroos in areas that are less attractive to field processors. For example, areas that are geographically isolated and have difficult terrain and/or thick vegetation (restricting access and visibility), may be less commercially attractive. Areas with smaller property sizes may also be less attractive to field processors, who would then need to engage with multiple landholders for access to land that is also restricted by numerous fences.

The current harvest system allows a degree of control over the management of kangaroos, and has no direct cost to the landholder. A survey by Gibson and Young (1988) found that 80% of landholders said they would undertake shooting themselves if commercial shooters were not available. Non-professional culling of kangaroos may have serious ethical drawbacks if amateur shooters are less accurate (and therefore less humane than professionals), or if other methods, such as poisoning water supplies are utilised (see Gibson and Young 1988).

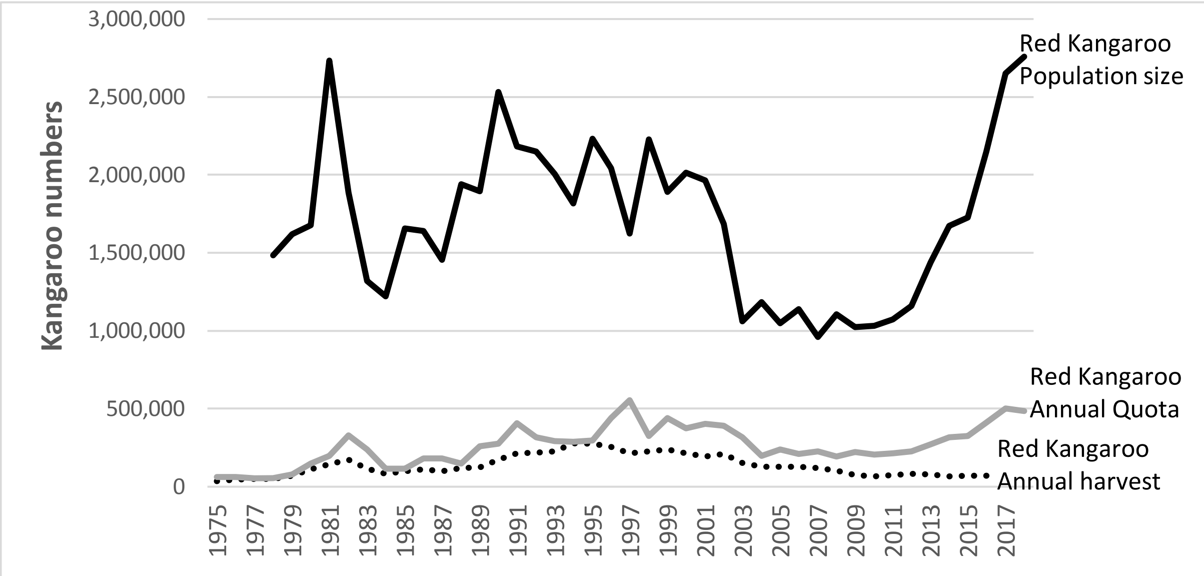


Figure 4 Red Kangaroos in the Commercial harvest zone: estimated population size, annual quota and annual harvest

5.5 Impacts of sex and size-biased harvests

The current low harvest rates are inadequate to control abundant kangaroo populations in SA (or even within the harvest zone). The selective harvest of males may exacerbate the problem by biasing the sex ratio of the population towards females, although the current very low harvest rates are unlikely to impact on overall populations. Major drivers of male-biased harvest include:

- The major processor in SA has a male-only take policy (a response to avoid the animal welfare issues of shooting does with joeys, and therefore ensure compliance with the code of practice: DEWNR, PIRSA & Livestock SA 2017)
- Male carcasses attract higher financial returns than females:
    - Meat processors pay for carcasses by weight and males are larger than females
    - Skin tanners do not accept female skins so meat processors reduce the price paid (per kg) for female carcasses.

Hacker et al. (2004) found that 'markets or policies that favour a higher proportion of males will result in a smaller reduction in the population (possibly no reduction) and lower pasture biomass'. The converse was found to be true for females: harvesting more females results in lower population sizes and higher pasture biomass (Hacker et al. 2004). Selective harvest of large males may also have longer-term impacts on the genetic diversity and social structure of kangaroo populations. However, recent studies found no evidence for decline in kangaroo body size (any species), which may be explained by low overall mortality in the population due to dingo (predator) control and increased availability of pasture (Prowse et al. 2014; Correll et al. 2017). There is no evidence for loss of genetic diversity in Red Kangaroos; their high genetic interconnectedness and strong ability to disperse and recolonise makes them robust to present low rates of harvesting (i.e. Clegg 1998).

5.6 Alternative control methods

Managing kangaroos via contraception or relocation is considered expensive, logistically difficult and relatively ineffective (Pople and Grigg 1999; Olsen and Braysher 2000). These techniques are not included in the current *SA Commercial Kangaroo Management Plan 2018-2022*. There have, however, been some recent advances in small-scale application of GonaCon Immunocontraceptive Vaccine within populations of Eastern Grey Kangaroos in the ACT (Wimpenny and Hinds 2018) as discussed in Section 6.4.2 of this report. This vaccine has been shown to decrease fecundity, but it is still unclear as to whether a single dart-delivered dose will cause long-term infertility or effectively limit population growth (Wimpenny and Hinds 2018). The translocation of kangaroos would pose animal welfare concerns (ACT Parks, Conservation and Lands, 2010), and would be especially difficult given both the lack of appropriate translocation sites where kangaroos occur in low densities and the high ability of kangaroos to disperse back away from those areas.

The very low water needs of kangaroos (Munn et al. 2010) allows them to travel long distances between water sources (Fuduka et al 2009). For this reason, often kangaroos do not appear to benefit from artificial watering points (Montague-Drake & Croft 2004; Fukuda et al., 2009). Food availability tends to be a stronger predictor of kangaroo distribution than water availability (Montague-Drake and Croft 2004; Olsen and Low 2006). However there are now many artificial waterpoints in inland areas that were previously unsuitable for large herbivores outside of wet years and are now subject to sustained grazing (Landsberg et al. 1997). Closure of these points is more likely to impact herbivore grazing but elsewhere the situation is less clear.

Another potential method of limiting kangaroo impacts is via Finlayson's troughs which are selective electric repellent devices designed to exclude kangaroos while still allowing livestock to drink. Finlayson's troughs are generally considered ineffective as a management tool (King *et al*. 1997), except in very dry periods when there are few water sources to choose from (Pople and Grigg 1999), or when used as a technique to facilitate short-term rest from grazing by kangaroos (Fisher 2004).

Fencing has been used to exclude predators and grazing species in various contexts across Australia. Small-scale exclusion plots (typically 0.4–2.5km^2) are often used to experimentally demonstrate impacts of grazers on vegetation growth and composition (de Preu 2006; Jenner 2016; Willoughby 2018). Larger scale fencing can be used to:

- create sanctuaries (e.g. the 123 km^2 feral predator-free Arid Recovery sanctuary in SA's arid north),
- act as barriers (i.e. SA's 2225 km long 'dog fence'), or
- create 'cluster fencing' around adjoining properties to protect livestock from predators and exclude other herbivores from feeding on crops and pasture.

All of the abovementioned uses of fencing can potentially exclude kangaroos, with some of the larger-scale methods (particularly barrier and cluster fencing) being associated with poor animal welfare outcomes in some cases (RSPCA 2018b). Emus and kangaroos are prone to entrapment in fences and can also amass in large numbers and starve or die of thirst along long fence lines such as Western Australia's 1170 km State Barrier Fence (Bradby et al. 2014).

The use of 'Livestock Guardian Dogs' (i.e. Maremma Sheepdogs) to deter kangaroos is discussed in Section 6.4.1.

5.7 Knowledge gaps and future work

Commercial harvest*

1. Identify opportunities to simplify processes and reduce costs associated with applying for and carrying out kangaroo harvest. What changes would result in attracting new field processors to the industry, and which of these options are within DEW's control? For example, can we evaluate options for reducing the price of tags (universally, by species or sex). What can be done to make areas unattractive to the commercial harvesters (e.g. heavily vegetated areas) more cost effective and hence attractive to them?
2. There is currently no empirical evidence to show that kangaroo harvesting reduces grazing pressure.
3. Current evidence suggests that increasing commercial harvest will not have the desired impact on reducing the kangaroo population if the commercial harvest continues to be biased towards males. To this end, the practicality of managing the sex ratio in the harvest should be evaluated for individual species. For example,

Hacker et al. (2004) suggests that a total harvest rate of 20%, with males comprising 70% of the total harvest, would be the best compromise to meet stakeholder interest in the Murray–Darling Basin.

4. Evaluate options for expanding the commercial zone across new areas of the state to encourage harvest rather than culling of kangaroos, noting that a trial harvest zone in the south-east in 2014 was unsuccessful (no kangaroos were commercially harvested in the trial). If the commercial zone was expanded, would this require extended aerial surveys to inform quota setting?
5. Rejuvenate the commercial kangaroo harvesting industry. There is no current peak body to support all stakeholders within the commercial harvest industry (although some are represented within the DEW Kangaroo Management Reference Group (KMRG).

*Future investigations should involve PIRSA from an industry development perspective, and could benefit from engaging a business analyst/economist to identify further gaps and options.

Broader kangaroo management

6. In the long-term, consider the development of a coordinated cross-regional strategy to integrate total grazing pressure and/or kangaroo management efforts across the state. This strategy would need to address different types and scales of kangaroo impacts across regions and land-uses, and involve stakeholder and community engagement processes (including consideration of social values: see Section 3). This strategy would also need to deal with current competing objectives for kangaroo management and clarify our roles/responsibilities in each:
   a. Conservation (i.e. National Parks and Wildlife Act is designed to protect species)
   b. Sustained-yield harvesting (for financial gain)
   c. Control of 'overabundant' populations (Destruction Permits, culling on reserves and harvest).

   DEW is planning to develop a new, integrated approach to statewide kangaroo management, which is expected to make some progress on the ideas described above.

7. Investigate simplifying the policy or application requirements to allow culling of kangaroos on reserves:
   a. What are the minimum requirements (socially, ecologically and regulatory) to demonstrate impacts of kangaroos on park values?
   b. Evaluate and review requirements for Reserve Management Plans to include wildlife management programs for kangaroos (currently required under the *National Parks and Wildlife Act 1972*).
   c. Is the 'rare' status of the Eastern Grey Kangaroo in SA (under the *National Parks and Wildlife Act 1972*), representative of the current population, and does this limit management options? Consider within review of Schedules 7, 8 and 9 ('the Threatened Species Schedules') of the NPW Act.

8. Can we engage landholders to co-develop and trial new approaches to kangaroo management? For example, the National Landcare Program Smart Farms program offers grants to support the development of new tools and technologies to improve land management practices, and may provide opportunities for innovation.

9. Establish linkages with Nature of SA project (DEW).

6 Management of abundant native species: Case studies

The issue of overabundant native species management is not unique to kangaroos nor Australia. Similar patterns of human-induced landscape changes favouring the increase of native species have been described worldwide (Nugent et al. 2011; Smith et al. 2015). The removal of apex predators is a primary cause of overabundance in populations of native species (Ripple et al. 2001; Nugent et al. 2011; Licht 2017) as is the conversion of landscapes for farming or urbanisation (Conover and Chasko 1985; Shelton et al. 2014). Native species can also be highly abundant without being considered problematic, and abundant game species in particular are often subject to unique hunting or harvesting management programs (i.e. Johnson et al. 2015; Nichols et al. 2015).

The main management options to control or utilise abundant species have included harvesting (Alisauskas et al. 2011; Nichols et al. 2015), culling (Licht 2017; Nugent et al 2011), and re-introduction of top predators (Ripple et al. 2001). Culling of native species has also been utilised in an attempt to reduce disease transmission between wildlife and domestic animals (Bielby et al. 2014). A few case studies exploring the limitations and successes of these management options are discussed below, as well as a few emerging alternative kangaroo management options.

6.1 Adaptive population management: harvesting Mallard ducks (USA)

In 1995, the U.S. Fish and Wildlife Service implemented a successful adaptive harvest management program for large-scale sport harvest of mallard ducks (*Anas platyrhynchos*) (Johnson et al. 2015). The mallard example utilises a repetitive cycle of population and habitat monitoring, modelling and prediction, and decision making to clarify the relationships among hunting regulations, harvests, and waterfowl abundance. Each year, optimal regulatory alternatives are identified and assessed against a range of biological models to predict the following year's population size. When monitoring data becomes available, the model is updated to reduce uncertainty in future iterations (US Fish and Wildlife Service 2018). The program has successfully reduced contention around regulatory processes, but has also integrated science with policy in a clear, rigorous, and transparent method (Nichols et al. 2015; Johnson et al. 2015). This case study is most relevant to the commercial harvest of kangaroos in SA, but lessons relating to adaptive management, objective-setting, decision-making, and social values are more broadly applicable to other areas of kangaroo management.

Some key lessons from this program include:

- Adaptive management requires unambiguous objectives, which are difficult to express as measurable objectives that integrate both ecological, regulatory and social values. An understanding of benefits, trade-offs and risks associated with integrated landscape objectives (ecological, social and/or regulatory) is crucial in this context (Johnson et al. 2015) The incorporation of social values is particularly challenging as satisfaction and participation of mallard hunters was affected by both regulatory conditions and broader social and cultural values (Case 2004). Even very liberal hunting regulations and abundant mallard populations could not improve declining hunter participation (Johnson et al. 2015; Vrtiska et al. 2013).
- Using transparent and participatory decision-making processes enhances credibility and ownership among stakeholders; but complex approaches (i.e. the use of some statistical models) can also create divide between individuals with technical and practical expertise (Johnson et al. 2015).

- A recognition of important adaptive learning processes that occur at different scales to address both ongoing and emerging issues, for example (Johnson et al. 2015; Nichols et al. 2015):
    - incremental improvements to management in annual cycles
    - longer-term learning that involves re-examination of management objectives, and consideration of alternate population processes or regulatory processes and/or governance.
- Ideally, managers would identify the scale of appropriate management approaches based on expected net benefits to both population and harvest objectives, but in reality, management can be constrained to fairly coarse scales by limited resources for monitoring and assessment (Figure 7; Johnson et al. 2015). An understanding of where proposed management strategies sit on this scale helps determine feasible options and where trade-offs occur.

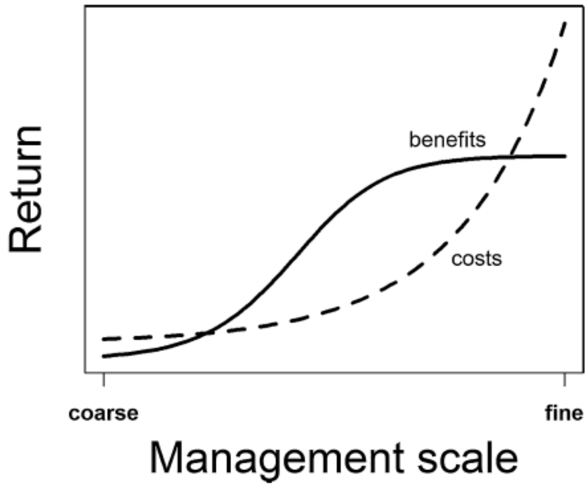


Figure 7. Taken from Johnson et al. (2015). Conceptual representation of how management returns (benefits and costs) change with the scale of management. A fine scale of harvest management would involve creating spatially explicit harvest targets for multiple species and populations and is characterised by a high degree of regulatory complexity.

6.2 Unexpected responses to culling: Badgers (UK and Ireland)

In the United Kingdom and Ireland, the cattle industry suffers significant losses due to the infectious disease bovine tuberculosis (TB) (DEFRA 2011). Wild Eurasian badger (*Mele meles*) populations act as reservoir hosts of the bacterium that causes bovine TB, and have been culled under a variety of strategies since 1973 in an attempt to reduce disease transmission to cattle (Carter et al. 2007; DEFRA 2011). More recently, badger culling has occurred against the recommendation of an independent Randomised Badger Culling Trial (RCBT: from 1998 to 2006), and despite strong opposition from the independent scientific community (McCulloch and Reiss 2017). The same evidence base (from the RCBT trial) led to the development of three distinct badger control policies across Great Britain (Spencer 2011). Scientific consensus is that culling actually changes badger behaviour to increase transmission of the disease and is often counter-productive to management goals (Carter et al. 2007; Bielby et al. 2014). While culling reduces local badger densities (Woodroffe et al. 2008), it promotes dispersal both into and outside of the culled areas (Carter et al. 2007; Pope et al 2007), resulting in an increased proportion of both badgers and cattle infected with bovine TB (Donnelly et al. 2007; Bielby et al. 2014).

The UK Government has received widespread criticism for its policies and management actions (Grant 2009; Fisher 2013), which have failed to effectively controlled bovine TB in cattle herds (Bielby et al. 2014). An incomplete and contested evidence base (Grant 2009; McCulloch and Reiss 2017), lack of trust between farmers and decision-makers and frequent changes in policy direction (Fisher 2013) have contributed to ongoing issues. Recent responses to these issues have included:

- An independent review of trapping, culling and population monitoring to inform improved control policies/actions (DEFRA 2014)
- Trialling alternative methods to culling: for example, a trial TB vaccine for badgers led to a 50% decreased incidence of bovine TB in Wales (in conjunction with increased cattle controls; Animal and Plant Health Agency 2015),
- The disbanding of the 'Badger Panel': a broad stakeholder forum, with strongly opposed interests that did not produce workable solutions (Grant 2009). DEFRA now works more effectively with a limited group of core stakeholders, but is also open to criticism for exclusion.

New strategies/frameworks have also been developed and suggested by the scientific community for incorporating social values (along with scientific evidence and economic considerations) into policy options:

- A conceptual framework and methodology for building trust and social capital between farmers and government policy/decision makers is presented in Fisher, 2013.
- McCulloch and Reiss (2017) argue for an ethical analysis of policy options conducted by independent experts, and for an approach to TB control that considers both science, economics and public opinion. Specifically, they describe an approach that includes:
    - 'An Animal Welfare Impact Assessment (AWIA) to assess the impacts of policy options on cattle and badger populations'
    - 'Robust ethical analysis, informed by the empirical evidence base, of badger control policy options'.

The issue of how to control bovine TB via policy and management is ongoing and provides useful lessons regarding the incorporation of science and social values in policy, especially in regards to justifying a particular policy position. Although the control of disease transmission is not a factoran issue in kangaroo management, the badger control case study provides lessons regarding the role of social and dispersal behaviour in wildlife management. Movement of kangaroos, for example, is recognised as a major factor influencing both local and landscape-scale population dynamics, but is also the factor that we are least able to predict (Pople et al. 2007; 2010a). A final lesson from the badger example is the need to reassess and alter wildlife management strategies if their impacts are unequivocal (or even counterproductive). Wildlife management is typically both expensive and controversial, thus raising the stakes to provide evidence of beneficial impacts. When managing charismatic and/or iconic wildlife species (i.e. badgers in the UK and kangaroos in Australia), there may be particular scrutiny on both the justification for and outcomes of management programs.

6.3 Reintroducing top predators: Yellowstone National Park (USA)

'There is global interest in restoring populations of top predators, both to conserve them and to harness their ecological services' (Newsome et al. 2015), particularly for their role in regulating large herbivores. In Yellowstone National Park (USA), wolf–elk–willow interactions provide a classic example of both trophic cascade and ecosystem restoration through reintroduction of a top predator (Ripple and Beschta, 2007). In the 1960s, elk were considered overabundant and were culled until the 1970s, when public outcry ended the shooting. Gray wolves were reintroduced to Yellowstone National Park (USA) in 1995 (after being eliminated from the park by 1926), to manage the rising elk population, which had been overgrazing much of the park. The reintroduced wolves contributed to ecological cascades by changing elk browsing patterns and decreasing their abundance to allow regeneration of riverine vegetation (Ripple and Beschta, 2007), which was subsequently linked to the recovery of songbirds (Baril 2009) and beaver populations (Ripple and Beschta 2011). Similar responses have been recorded at Banff National Park in Canada, where willow trees reappeared and songbird populations doubled after wolves returned on their own in the 1980s (Hebblewhite et al. 2005).

The Yellowstone case study provides the following key lessons:

- Preliminary evidence strongly suggest that top predators can play a significant role in controlling abundant prey, which may have cascading benefits at lower trophic levels:
    - However, there is still debate over the relative contributions of wolves versus other environmental factors (i.e. climate and water availability) on ecosystem recovery in Yellowstone (Mech 2012; Garrot et al. 2005).
- Changing social values towards the wolf have framed a debate about its reintroduction: wolves were once killed as a matter of government policy, but were 'recast' as endangered species in the 1970s, and later (1990s onwards) as engineers of ecosystem restoration
    - Polarised views towards wolf reintroduction have been attributed to deeper social issues, including differential access to social power, conflicting ideas about private property, and divergent views on the natural environment.
- Conflicting values towards wolves may actually be 'socially constructed' by stakeholders in an attempt to give meaning to their relationship with the landscape (Wilson 1997; McBeth et al. 2005).
    - With or without the wolf, land use (i.e. environmental or economic use) remains highly contested and will continue to be a source of conflict unless deeper social issues are addressed (Wilson 1997).
    - Wolf reintroduction to Yellowstone was opposed by some farming organisations despite being offered compensation for livestock deaths via private funds (Wilson 1997)

In Australia, dingos play an important role as top predators by effectively regulating populations of kangaroos and other native and invasive species (Letnic and Crowther 2013; Newsome et al. 2015; Morris and Letnic 2017). The trade-off with using dingos to control kangaroos is that they will also prey on domestic stock, particularly lambs and calves, which may have both positive and negative economic and ethical consequences. Both Ritchie et al. (2012) and Newsome et al. (2015) describe and propose reintroduction experiments to assess the role of dingos in ecological restoration. This option is not possible under the *Natural Resources Management Act 2004*, which requires that dingos be destroyed south of the dog fence (where they declared pests).

6.4 Alternative non-lethal kangaroo management options in Australia

6.4.1 Livestock guardian dogs (Maremma Sheepdog) can deter kangaroos

Livestock guardian dogs are medium to large-sized dogs that are kept with livestock to protect them from predators. The Maremma Sheepdog is by far the most commonly used breed of livestock guardian dog in Australia (van Bommel 2010). Unlike herding dogs, Maremma integrate themselves with groups of livestock, where they live permanently and relatively independently from humans (van Bommel 2010). Maremma effectively protect livestock from predators such as foxes and dingos (van Bommel 2010), but also deter large herbivores such as deer, wallabies and kangaroos (van Bommel and Johnson 2016). From an ecological point of view, Maremma can therefore play a similar role to top predators by reducing or excluding native herbivores from pastoral areas (van Bommel and Johnson 2016). Maremma can be utilised to limit the access of kangaroos and other wild herbivores to pastoral areas, allowing landowners to more effectively regulate total grazing pressure and plan for resting of pastures on their property (van Bommel and Johnson 2016). In Australia, some farmers are already using Maremma for this purpose (van Bommel, 2010). There is some evidence that livestock guardian dogs can provide additional conservation benefits by reducing predation on ground-nesting birds due to suppression of mesopredators (Gehrig et al. 2010), though this effect is yet to be explored within an Australian context. Some of the main advantages and disadvantages of using livestock guardian dogs in Australia are described in Table 6.

Table 6. Common advantages and disadvantages of using livestock guardian dogs (adapted from van Bommel, 2010)

Advantages	Disadvantages
Reduced predation of stock	Dogs need to be fed
Reduced need for other forms of predator control, saving time and money	Problems with neighbours: for example if the dog's barking is seen to be excessive
Self-reliance in managing predator problems	Not all dogs work equally well
More efficient use of land	Requires high start-up investment in time and money
Livestock are more relaxed	Dogs can dig, chew or cause property damage
Additional (free) rabbit/pig/kangaroo control	Dogs can get ill, injured or die prematurely
Family and property protection	Additional care must be taken when using lethal predator control to prevent harm to the livestock guardian dog

6.4.2 Immunocontraceptives reduce fertility in kangaroos

Fertility control can be used to reduce kangaroo population growth, thus reducing, or in some cases eliminating the need for lethal intervention (Massei and Cowan 2014; Wimpenny and Hinds 2018). Several fertility control methods have been used on Kangaroos including:

- Surgical sterilisation (vasectomy, castration, tubal ligation), which is costly, invasive and requires veterinary expertise (Wimpenny and Hinds 2018).
- Hormone implants, which require animals to be captured and anaesthetised in order to insert implants under the skin, but can last for up to 4 years (Wilson and Coulson 2016).
- Immunocontraceptives or 'contraceptive vaccines', which are administered as an intramuscular injection. These include the GonaCon Immunocontraceptive Vaccine, which works by triggering an immune response whereby GnRH specific antibodies inhibit function of the ovaries and testes.

Of these options, the GonaCon™ Immunocontraceptive Vaccine is currently considered the most viable option for managing free-ranging kangaroo populations, due to its high efficacy and potential to be administered remotely via darts (Wimpenny and Hinds 2018). GonaCon has been trialled most extensively in the ACT, where it has been found to be effective for at least eight years in more than 80% of female Eastern Grey Kangaroos when administered by hand (ACT Government 2017). In 2016, the ACT government commenced trials to assess the effectiveness of delivering GonaCon vaccines via a single dart-delivered dose within free-ranging Eastern Grey Kangaroo populations. This study found a short-term effect on fecundity with only 20.8% of dart-vaccinated females producing young, compared to 63% of females at untreated sites (Wimpenny and Hinds 2018). Since this study is still in its initial phase, the effect dart-delivered GonaCon on population growth is not yet clear: further monitoring is required to determine if an acceptable level and duration of kangaroo population control can be achieved via this method.

As immunocontraceptives reduce population growth rather than rapidly reducing population numbers (as occurs via culling), it is generally considered unsuitable for situations when immediate or large-scale population control is required. It is instead proposed that immunocontraceptives be used in conjunction with multiple techniques and is most effective in populations that have been reduced to the desired level using other methods, such as shooting (Herbert et al. 2010; Wimpenny and Hinds 2018).

6.5 Parks Canada agency's *Hyperabundant Wildlife Policy*

Management of abundant native wildlife is a growing challenge in many of Canada's National Parks, where changes in land-use have disrupted processes that historically regulated wildlife populations (Waithaka 2008). Species such as Black-tailed Deer (*Odocoileus hemionus*), White-tailed Deer (*O. virginianus*), Moose *(Alces alces americana*) and Elk (*Cervus canadensis*) have been considered hyperabundant in some areas due to their negative impacts on park values (Nugent et al. 2011; Smith et al. 2015), and can also pose significant threats to public safety due to collisions with vehicles (Nugent et al. 2011). In 2007, Parks Canada published a policy framework addressing the management of hyperabundant overabundant species to ensure the maintenance of 'ecological integrity' in National Parks (Waithaka 2008). The current policy: *Management of hyperabundant wildlife populations in Canada's national parks* provides:

- Nationally consistent guidelines for the evidence-based management of hyperabundant native wildlife
- Flexibility for innovation and adaptation
- Criteria for classifying a species as 'hyperabundant'
- Broad, ecosystem-based management principles that must form the basis of management
- Guidelines for implementing management actions.

Parks Canada requires that the following steps be taken before implementing management actions:

- Demonstrate that the population meets the policy definition of 'hyperabundant'
- Develop a hyperabundant wildlife population management plan that includes:
  - Justification that management is required (using science and knowledge)
  - Evidence that the reasons or impacts of hyperabundance are understood
  - Clear objectives and targets
  - A prediction of positive and negative impacts of proposed management
  - A monitoring, reporting and evaluation framework, and consultation with aboriginal people and/or other key stakeholders.

The overabundant policy by Parks Canada is currently under revision, given over 10 years of learning since its initial publication. Some successes, key lessons and challenges include:

- The policy provides a 'good model for identifying the problem, designing solutions and gaining societal acceptance for the need to maintain or restore ecological integrity' (Nugent et al. 2011).
- The current process can be resource-intensive given:
  - the 'lengthy process required to achieve meaningful and effective public engagement'
  - the expertise, cost and personnel needed for developing and implementing hyperabundant population management plans' (Nugent et al. 2011).
- As with most wildlife management programs, implementation challenges included conflict with some members of the public that are opposed to lethal culling (Nugent et al. 2011).
- Emily Gonzales, the national lead for Hyperabundant Willdlife Management in Parks Canada provided the following insight (pers comm, June 2018): 'The objectives of hyperabundant wildlife management programs should be quantified, evidenced-based, and focus on the desired future conditions (Latham et al., 2009). Internal and external communication must also be consistent with these objectives, that is, the purpose of hyperabundant wildlife management is to mitigate the impacts of hyperabundant wildlife on ecological integrity. Focusing on wildlife population densities distracts audiences from the objective of management, which is to recover ecological integrity. This key point will be reflected in Parks Canada's updated (2018) hyperabundant policies.'

A recent review of worldwide abundant deer control programs (Nugent et al. 2011) concluded that: 'for dealing with overabundance (where that results in a wide and complex range of major changes in ecosystem composition and health, the quality of ecosystem services, and/or issues such as human health and accident risk) the *most reliable, sustainable*, *and effective* approach will be to gain public support (via governmental funding) for dealing with the problem. The Canadian National Parks model is a good example of this'. All of the case studies described above place major emphasis on linking social values with management approaches in order to achieve management goals. This is a key lesson that should be incorporated into any new strategies or approaches to kangaroo management in South Australia.

7 Conclusion

Kangaroos are adapted to dynamic systems with unpredictable rainfall and some larger-bodied species have greatly benefitted from changed land-use conditions and the removal or control of dingos as top predators. As a consequence, some kangaroo populations currently occur at unprecedented high numbers across the commercial harvest zone and are anecdotally in high numbers across much of the state. Combined with the significant impacts of livestock and feral grazers (such as goats and deer), total grazing pressure is estimated to be very high in some regions, but remains largely unquantified. Limited studies have experimentally demonstrated impacts of kangaroos on changing vegetation biomass, structure and composition, and some studies provide evidence for flow-on effects for birds and reptiles. Exclosure studies are particularly useful for understanding the relative impacts of different grazers.

Long-term, integrated management of total grazing pressure (kangaroos, livestock, goats, rabbits and other ferals) has led to positive outcomes within the Bounceback program (Flinders, Olary and Gawler Ranges), and in smaller-scale programs on the Eyre Peninsula and in the TGB Osborn Reserve. Recovery of vegetation following a reduction in total grazing pressure can be gradual or episodic, with improved overall outcomes being recognised over longer timeframes. Despite the successes of these programs, overgrazing continues to be a major challenge in some cases and requires innovative policy development to support improved management of total grazing pressure.

In addition to impacts on biodiversity, kangaroos are also a significant concern for pastoralists mainly due to perceived competition with livestock, but there is limited evidence for competition here except under conditions of very low pasture biomass and high kangaroo densities.

Current tools for managing kangaroos include commercial harvesting and culling, and these are currently ineffective for managing the overabundant population. The main issues with current management options have been well-documented via recent stakeholder forums and there are many potential solutions that can be explored.

Various international examples of abundant species management highlight the importance of including social values in environmental decision-making. Understanding social values towards the broader environments in which kangaroos co-exist, and an understanding of what we can practically achieve (from scientific, economic and regulatory perspectives), will be central to achieving desired goals.

8 References

ACT Parks, Conservation and Lands (2010) ACT Kangaroo Management Plan. ACT Government, Canberra. Accessed on July 1 2018 from: http://www.environment.act.gov.au/__data/assets/pdf_file/0020/902423/Kangaroo_Management_Plan_complete_for_web.pdf.

Alexander, P. (1997) Kangaroo culling, harvesting and farming in South Australia: an ecological approach. Australian Biologist. 10 (1): 23-29

Andrew, M. and Lange, R. (1986) The spatial distributions of sympatric populations of kangaroos and sheep: examples of dissociation between the species. Australian Wildlife Research. 13: 367-373.

Animal and Plant Health Agency. 2015. Badger Vaccine Deployment Project. Final Lessons Learned Report. March 2015

Arnold, G.W., Steven, D.E., Weeldenburg, J.R. (1989) The Use of Surrounding Farmland by Western Gray Kangaroos Living in a Remnant of Wandoo Woodland and Their Impact on Crop Production. Wildlife Research. 16: 85-93.

Banks, P.B., Newsome, A.E., Dickman, C.R. (2000), Predation by red foxes limits recruitment in populations of eastern grey kangaroos. Austral Ecology. 25: 283-291. doi:10.1046/j.1442-9993.2000.01039.x

Baril, L.M. (2009) Change in Deciduous Woody Vegetation, Implications of Increased Willow (Salix spp.) Growth for Bird Species Diversity and Willow Species Composition in and around Yellowstone National Park's Northern Range. MS, Montana State University, Bozeman, USA.

Barton, P.S., Manning, A.D., Gibb, H., Wood, J.T., Lindenmayer, D.B., Cunningham, S.A. (2011) Experimental reduction of native vertebrate grazing and addition of logs benefit beetle diversity at multiple scales. Journal of Applied Ecology. 48: 943–951. doi:10.1111/j.1365-2664.2011. 01994.x

Bayliss, P. (1987) Kangaroo dynamics. Pp. 119-134 in: Caughley, N. Shepherd and J. Short (eds) *Kangaroos: Their Ecology and Management in the Sheep Rangelands of Australia*. Cambridge University Press, Cambridge.

Ben-Ami, D., Boom, K., Boronyak, L., Townend, C., Ramp, D., Croft, B. D., and Bekoff, M. (2014) The welfare ethics of the commercial killing of free ranging kangaroos: an evaluation of the benefits and costs of the industry. Animal Welfare. 23(1): 1-10

Boom, K., and Ben-Ami, D. (2011) Shooting our wildlife: An Analysis of the law and its animal welfare outcomes for kangaroos & wallabies. Australian Animal Protection Law Journal. 5: 44-75

Boyle, M. and Hone, J. (2014) Wildlife management aims and ecological processes: A case study of kangaroos. Wildlife Society Bulletin. 38: 503-512. doi:10.1002/wsb.429

Bradby, K., Fitzsimmons, J.A., Del Marco, A., Driscoll, D., Ritchie, E., Lau, J., Bradshaw, C.J.A. and Hobbs, R.J. (2014) Ecological connectivity or barrier fence? Critical choices on the agricultural margins of Western Australia. Ecological Management and Restoration 15(3): 180-190

Brandle, R., Mooney, T. and de Preu, N. (2018) Broad-scale feral predator and herbivore control for yellow-footed rock-wallabies: improved resilience for plants and animals= Bounceback. Pp. 135-145 in Garnett, S., Latch, P. Lindenmayer, D. and Woinarksi, J (eds)*: Recovering Australian threatened species: a book of hope*. CSIRO Publishing, Australia

Brandle, R. (2017) Iron stone hill herbivore impact investigations 2016 & 2017. Department of Environment, Water and Natural Resources, Adelaide

Brooker, M.G. and Ridpath, M.G. (1980) The Diet of the Wedge-Tailed Eagle, Aquila Audax, in Western Australia. Wildlife Research. 7: 433-452.

Cairns, S.C., Grigg, G.C., Beard, L.A., Pople, A.R. and Alexander, P. (2000) Western Grey Kangaroos, *Macropus fuliginosus*, in the South Australian pastoral zone: populations at the edge of their range. Wildlife Research. 27:309–318.

Carter, S.P., Delahay, R.J., Smith, G.C., Macdonald, D.W., Riordan, P., Etherington, T.R., Pimley, E.R., Walker, N.J., Cheeseman, C.L (2007) Culling-induced social perturbation in Eurasian badgers *Meles meles* and the management of TB in cattle: an analysis of a critical problem in applied ecology. Proceedings of the Royal Society B: Biological Sciences. 274(1626):2769-77

Caughley, G. (1981) Overpopulation. Pp 7-19 in *Problems in the management of locally abundant wild animals*, edited by Jewell, P.A., Holt, S., and Hart, D. Academic Press, New York.

Caughley, N. Shepherd and J. Short (eds) (1987) *Kangaroos: Their Ecology and Management in the Sheep Rangelands of Australia*. Cambridge University Press, Cambridge.

Caughley, J., Bayliss, P., and Giles, J. (1984) Trends in kangaroo numbers in western New South Wales and their relation to rainfall. Australian Wildlife Research. 11:415–422.

Choquenot, D., Caughley, J. and McLeod, S. (1998) Scientific and Other Issues Relating to the Commercial Use of Wildlife in Australia. Bureau of Resource Sciences, Canberra.

Clegg, S., Hale, P. and Moritz, C. (1998) Molecular population genetics of the Red Kangaroo (*Macropus rufus*): mtDNA variation. Molecular Ecology. 7:679-686.

Cobiac, M. (2009) Analysis of Coffin Bay National Park Vegetation Monitoring Data 2003 to 2009. Report prepared for Department of Environment and Heritage, South Australia.

Collings, G. 2010a. Para Wirra Western Grey Kangaroo Density Survey 2009. Report prepared for Department of Environment and Heritage.

Collings, G. 2010b. Para Wirra Recreation Park Kangaroo Grazing Impact Analysis. Report prepared for Department of Environment and Heritage.

Conover, M.R. and Chasko, G.C. (1985) Nuisance Canada Goose problems in the eastern United States. Wildlife Society Bulletin. 13:228-233.

Croft, D.B. (2000) Sustainable use of wildlife in western New South Wales: Possibilities and problems. The Rangeland Journal. 22:88-104.

Cooke B.D. (2014) Daily food intake of free-ranging wild rabbits in semiarid South Australia. Wildlife Research. 41, 141-148.

Cooke, B.D., Mutze, G.J. (2018) How introduced rabbits *Oryctolagus cuniculus* limit the abundance of red kangaroos *Macropus rufus* and other native grazers in Australia. Food Webs.15: e00079. https://doi.org/10.1016/j.fooweb.2018.e00079

Dawson, T. and Ellis, B. (1996) Diets of mammalian herbivores in Australian arid, hilly shrublands: seasonal effects on overlap between euros (hill kangaroos), sheep and feral goats, and on dietary niche breadths and electivities. Journal of Arid Environments. 34: 491-506.

Dawson, T.J. and Munn, A.J. (2007) How much do kangaroos of differing age and size eat relative to domestic stock?: implications for the arid rangelands. In C. Dickman, D. Lunney & S. Burgin (Eds.), *Animals of Arid Australia: Out on Their Own*? (pp. 96-101). Australia: Royal Zoological Society of New South Wales

DEFRA (2011) The government's policy on bovine TB and badger control in England. Accessed on May 1 2018 from: www.defra.gov.uk/publications/files/pb13691-bovinetb-policy-statement.pdf.

DEFRA 2014. Defra response: Pilot Badger Culls in Somerset and Gloucestershire: Report by the Independent Expert Panel. April 2014. Accessed on April 15 2018 from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/300424/pb14158-defra-response-independent-expert-panel.pdf

DePreu, N. (2000) Operation Bounceback Interim Report. Report prepared for the Department for Environment and Heritage, South Australia.

DePreu, N. (2006) Vegetation response to management of herbivores. In: *Bounceback Progress Report 2006*. Department for Environment and Heritage, South Australia.

DEW (2018a) Proposal to control kangaroos in Mokota Conservation Park (Northern and Yorke region). Department for Environment, Water and Natural Resources, South Australia.

DEW (2018b) Proposal to control kangaroos in the Murray River National Park and adjoining Crown lands. Department for Environment, Water and Natural Resources, South Australia.

DEWHA (2008) National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Commercial Purposes: First Edition published 2008.

DENR (2012) Celebrating 20 years BOUNCEBACK. Department of Environment and Natural Resources, Adelaide. Accessed on 10 April 2018 from: http://www.environment.gov.au/system/files/resources/8aa49426-1677-4d62-b75e-8a70d0611332/files/bounceback.pdf

DENR (2014a) Kangaroos on reserves (population control) Policy. Government of South Australia.

DENR (2014b) Kangaroos on reserves (population control) Procedure. Government of South Australia.

DEWNR (2014a) Eastern Eyre Peninsula Parks Management Plan. Prepared for the Department of Environment, Water and Natural Resources, South Australia.

DEWNR (2014b) Proposal to control kangaroos in the Flinders Ranges National Park. Department for Environment, Water and Natural Resources, South Australia.

DEWNR (2014c) Proposal to control kangaroos in the Gawler Ranges National Park. Department for Environment, Water and Natural Resources, South Australia.

DEWNR (2014d) Proposal to control kangaroos in the Barossa Valley Parks. Department for Environment, Water and Natural Resources, South Australia.

DEWNR (2015a) Marginal to Mainstream: Rejuvenating productive pastures in the Murraylands. Department for Environment, Water and Natural Resources, South Australia.

DEWNR (2015b) Deep Creek and Talisker Conservation Parks Management plan Amendment 2015. Prepared for the Department of Environment, Water and Natural Resources, South Australia.

DEWNR (2017a) South Australian Commercial Kangaroo Management Plan 2018-2022. Report prepared by: Natural Resources South Australian Arid Lands Department of Environment, Water and Natural Resources, South Australia.

DEWNR (2017b) 2018 Quota Report for Commercial Kangaroo Harvest in South Australia. Report prepared by: Natural Resources South Australian Arid Lands Department of Environment, Water and Natural Resources, South Australia.

DEWNR (2017c) Gawler Ranges National Park Management Plan. Prepared for the Department of Environment, Water and Natural Resources, South Australia.

DEWNR Kangaroo management forum (2017). Record of kangaroo management forum, 2 November 2017, Yunta, SA

DEWNR, PIRSA & Livestock SA (2017) Minutes from meeting: 'Kangaroo Round table with Livestock SA members'. 5 December 2017, Adelaide, SA.

Dickman C.R. (2012) Fences or Ferals? Benefits and Costs of Conservation Fencing in Australia. In: Somers M., Hayward M. (eds) *Fencing for Conservation*. Springer, New York, NY.

Donnelly, C.A., Woodroffe, R., Cox, D.R., Bourne, J., Gettinby, G., Le Fevre, A.M., McInerney, J.P. and Morrison, I. (2003) Impact of localized badger culling on tuberculosis incidence in British cattle. Nature. 426(6968):834–837.

Donnelly C.A., Wei, G., Johnston, W.T., Cox, D.R., Woodroffe, R., Bourne, F.J., Cheeseman, C.L., Clifton-Hadley, R.S., Gettinby, G., Gilks, P., Jenkins, H.E., Le Fevre, A.M., McInerney, J.P. Morrison, W.I. (2007) Impacts of widespread badger culling on cattle tuberculosis: Concluding analyses from a large-scale field trial. International Journal of Infectious Diseases. 11(4):300–308.

Dudzinski, M.L., Lowe, W.A., Muller, R,W.J. and Low, B.S. (1982) Joint use of habitat by red kangaroos and shorthorn cattle in arid central Australia. Australian Journal of Ecology. 7: 69-74. doi:10.1111/j.1442-9993.1982.tb01301.x

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. doi:10.1111/j.1442-9993.1996.tb00597

Eldridge, M (Ed.) (2010) *Macropods: The biology of kangaroos, wallabies and rat-kangaroos* (pp. 197-210) Collingwood, Vic., Australia: CSIRO Publishing.

Eldridge, D.J., Poore, A.G., Ruiz-Colmenero, M., Letnic, M. and Soliveres, S. (2016) Ecosystem structure, function, and composition in rangelands are negatively affected by livestock grazing. Ecological Applications. 26: 1273-1283. doi:10.1890/15-1234

Fedorowytsch, T. (2017). Bigger appetite for kangaroo meat needed to rein in booming roo numbers, ecologist says. ABC news September 14 2017. http://www.abc.net.au/news/2017-09-10/cull-kangaroos-and-eat-their-meat-scientist-urges/8887432

Fisher, A., Hunt, L., James, C., Landsberg, J., Phelps, D., Smyth, A., Watson, I. (2004) Review of total grazing pressure management issues and priorities for biodiversity conservation in rangelands: A resource to aid NRM planning. Desert Knowledge CRC Project Report No. 3 (August 2004); Desert Knowledge CRC and Tropical Savannas Management CRC, Alice Springs.

Fisher, R. (2013) A gentleman's handshake: The role of social capital and trust in transforming information into usable knowledge. Journal of Rural Studies. 31:13-22.

Fletcher D 2007 'Managing Eastern Grey kangaroos M.giganteus in the Australian Capital Territory : reducing the overabundance of opinion' in Lunney, D, Eby P, Hutchings, P & Burgin, S (eds) Pest or Guest , Royal Zoological Society of New South Wales, NSW, Australia pp.117-127.

Fryxell, J.M., Sinclair, A.R.E., Caughley, G. (2014). *Wildlife ecology, conservation, and management (3rd edition)*. Oxford, England: Blackwell Publishing,

Fukuda, Y., McCallum, H.I., Grigg, G.C., Pople A.R. (2009) Fencing artificial waterpoints failed to influence density and distribution of red kangaroos (*Macropus rufus*). Wildlife Research. 36: 457-465.

Garrott, R.A., Gude, J.A., Bergman, E.J., Gower, C., White, P.J. and Hamlin, K.L. (2005) Generalizing wolf effects across the Greater Yellowstone Area: a cautionary note. Wildlife Society Bulletin. 33:1245-1255. doi:10.2193/0091-7648(2005)33[1245:GWEATG]2.0.CO;2

Gehring, T., Vercauteren, K., and Landry, J. (2010). Livestock protection dogs in the 21st century: Is an ancient tool relevant to modern conservation challenges? BioScience. 60: 299–308.

Gibson, L. M. and Young, M. D. (1988) Kangaroos: Counting the Cost. The Economic Effects of Kangaroo Culling On Agricultural Production. CSIRO, Melbourne.

Gillespie, C. 2017. Feral Goat Browse Impact Assessment Monitoring in the Riverland Biosphere 2012-2017. Preliminary Report prepared for Natural Resources SA Murray-Darling Basin

Gowans, S.A., Gibson, M.S., Westbrooke, M.E., and Pegler, P. (2010) Changes in vegetation condition following kangaroo population management in Wyperfeld National Park. In '*Macropods: the Biology of Kangaroos, Wallabies and Rat*-kangaroos'. (Eds G. Coulson and M. Eldridge.) pp. 361–370. (CSIRO Publishing: Melbourne.)

Grant, W. (2009). Intractable policy failure: The case of bovine TB and badgers. The British Journal of Politics & International Relations. 11(4): 557–573.

Grigg, G. (1989) Kangaroo Harvesting and the Conservation of Arid and Semi-arid Rangelands. Conservation Biology. 3:194-197. doi:10.1111/j.1523-1739.1989.tb00072.x

Grigg, G.C., Beard, L.A., Alexander, P., Pople, A.R., and Cairns, S.C. (1999) Aerial survey of kangaroos in South Australia 1978 – 1998: A brief report focusing on methodology. Australian Zoologist 31:292–300.

Hacker, R. and McLeod, S. (2003) Living with kangaroos: a guide to kangaroos and their management in the Murray-Darling Basin, New South Wales Department of Agriculture, Orange.

Hebblewhite, M., White, C.A., Nietvelt, C.G., McKenzie, J.A., Hurd, T.E., Fryxell, J.M., Bayley, S.E., Paquet, P.C., (2005) Human activity mediates a trophic cascade caused by wolves. Ecolog.y 86: 2135–2144.

Herbert, C.A., Renfree, M.B., Coulson, G., Shaw, G., Trigg, T.E., and Cooper, D.W. (2010) Advances in fertility control technologies for managing overabundant macropodid populations' In Coulson, G and Eldridge, M (eds) *Macropods: The biology of Kangaroos, Wallabies and Rat-Kangaroos* CSIRO, Collingwood, VIC, pp. 313-324.

Higginbottom, K., Northrope, C.L., Croft, D.B., Hill, B., and Fredline, E. (2004) The role of kangaroos in Australian tourism. Australian Mammalogy. 26: 23–32.

Hobbs, R.J. (2001) Synergisms among Habitat Fragmentation, Livestock Grazing, and Biotic Invasions in Southwestern Australia. Conservation Biology, 15: 1522-1528. doi:10.1046/j.1523-1739.2001.01092.x

Hone, J. and Buckmaster, T. (2015) How many are there? The use and misuses of continental-scale wildlife abundance estimates. Wildlife Research. 41:473-479. Doi: http://dx.doi.org/10.1071/WR14059

Howland, B., Stojanovic, D., Gordon, I.J., Manning, A.D., Fletcher, D., Lindenmayer, D.B. (2014) Eaten Out of House and Home: Impacts of Grazing on Ground-Dwelling Reptiles in Australian Grasslands and Grassy Woodlands. PLoS ONE 9(12): e105966. https://doi.org/10.1371/journal.pone.0105966

Howland, B., Stojanovic, D., Radford, J. Q., Gordon, I. J., Manning, A. D., and Lindenmayer, B.D. (2016). Birds of a feather flock together: Using trait-groups to understand the effect of macropod grazing on birds in grassy habitats. Biological Conservation. 194: 89-99.

IUCN (2000) IUCN Policy Statement on Sustainable Use of Wild Living Resources. Accessed on April 1 2018 from https://portals.iucn.org/library/efiles/documents/Rep-2000-054.pdf

James, C.D. Landsberg, J. Morton, S.R. (1999) Provision of watering points in the Australian arid zone : a review of effects on biota. Journal of Arid Environments. 41:87-121.

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. doi:10.1046/j.1442-9993.2003.01259.x

Jenner, S. 2016. The impact of overgrazing by Western Grey Kangaroos in the Southern Mount Lofty Ranges. Unpublished honour's thesis), University of Adelaide, Adelaide, Australia.

Johnson, C., Woinarski, J., Cooney, R. (2015) October 5. Bans on kangaroo products are a case of emotion trumping science. https://theconversation.com/bans-on-kangaroo-products-are-a-case-of-emotion-trumping-science-47924

KIAA (2018) Animal Welfare. Accessed on 26 April 2018 from: http://www.kangarooindustry.com/industry/animal-welfare.aspx

King, D.R., Norbury, G.L., Eliot, G.J., (1997) The Efficacy of Finlayson Troughs as a Means of Repelling Kangaroos From Water and Altering Grazing Pressure in Pastoral Areas. The Rangeland Journal. 19:57-69.

Landsberg, J., Stol, J. (1996) Spatial Distribution of Sheep, Feral Goats and Kangaroos in Woody Rangeland Paddocks. The Rangeland Journal. 18:270-291

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. Final report to Environment Australia. *Biodiversity Technical Paper* No. 3. 203 pp. accessed from: http://www.environment.gov.au/archive/biodiversity/publications/technical/artificial-water/ch4.html

Landsberg, J., James, C.D., Morton, S.R., Müller, W.J. and Stol, J. (2003) Abundance and composition of plant species along grazing gradients in Australian rangelands. Journal of Applied Ecology. 40: 1008-1024. doi:10.1111/j.1365-2664.2003.00862.x

Latham, R.E., Grund, M.D., Horsley, S.B., Jones, B.C., McWilliams, W.H., Nielsen, C.K., Rosenberry, C.S., Seymour, R.S., Shissler, B. P., and Waller, D.M. (2009) Monitoring Deer Effects on Forest Ecosystems in Pennsylvania State Forests. Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry.

Lawley, V., Parrott, L., Lewis, R., Siinclair, R., Ostendorf, B. (2013) Self-organization and complex dynamics of regenerating vegetation in an arid ecosystem: 82 years of recovery after grazing, Journal of Arid Environments. 88:156-164.

Leopole, A.S. and Wolfe, T.O. (1970) Food habits of nesting Wedge-Tailed Eagles, Aquila audax, in South-Eastern Australia. CSIRO Wildlife Research. 15:1-17.

Lethbridge, M., Stead, M., and Wells, C. (in review) A comparison of thermal camera technology versus human observers for aerial population estimates.

Licht, D.S. (2017) Bison Conservation in Northern Great Plains National Parks: *No Need to Panic*. Great Plains Research. 27(2):83-92.

Livestock SA (2018) Importance of livestock to SA. Accessed from https://livestocksa.org.au/livestock-in-sa/ on 1st May 2018.

Madden, F., and McQuinn, B. (2014). Conservation's blind spot: the case for conflict transformation in wildlife conservation. Biological Conservation. 178: 97–106. doi:10.1016/j.biocon.2014.07.015

Massei, G, and Cowan, D. (2014). Fertility control to mitigate human–wildlife conflicts: a review. Wildlife Research. 41:1-21.

McBeth, M.K., Shanahan, E.A. and Jones, M.D. (2006) The Science of Storytelling: Measuring Policy Beliefs in Greater Yellowstone. Society & Natural Resources. 18(5):413-429, DOI: 10.1080/08941920590924765

McCulloch, S.P. and Reiss, M.J. (2017) Bovine Tuberculosis and Badger Control in Britain:Science, Policy and Politics. Journal of Agricultural and Environmental Ethics. 30: 469. https://doi.org/10.1007/s10806-017-9686-3

McIntyre S., Stol J., Harvey J., Nicholls A.O., Campbell M., Reid A., Manning A.D. and Lindenmayer D., (2010) Biomass and floristic patterns in the ground layer vegetation of box-gum grassy eucalypt woodland in Goorooyarroo and Mulligans Flat Nature Reserves, Australian Capital Territory. Cunninghamia. 11:319–357.

McLeod, S. (1996) The foraging behaviour of the arid zone herbivores the red kangaroo (*Macropus rufus*) and the sheep (*Ovis aries*) and its role in their competitive interaction, population dynamics and life-history strategies. Ph.D. Thesis, University of New South Wales, Sydney.

Montague-Drake, R. and Croft, D.B., (2004) Do kangaroos exhibit water-focused grazing patterns in arid New South Wales? A case study in Sturt National Park. Australian Mammalogy. 26:87- 100.

Morello, S. (2018) May 2. New call for kangaroo cull, increasing numbers create hazard on region's roads. The Border watch.

Morris, T., Letnic, M. (2017) Removal of an apex predator initiates a trophic cascade that extends from herbivores to vegetation and the soil nutrient pool. Proceedings of the Royal Society B. 284: 20170111

Munn, A.J., Dawson, T.J., McLeod, S.R., Dennis, T., Maloney, S.K. (2013). Energy, water and space use by free-living red kangaroos *Macropus rufus* and domestic sheep *Ovis aries* in an Australian rangeland. Journal of Comparative Physiology B. 183(6):843-858. https://doi-org.ezproxy.flinders.edu.au/10.1007/s00360-013-0741-8

Munn A.J., Dawson T.J., McLeod S.R., Croft D.B., Thompson M.B., Dickman C.R. (2009) Field metabolic rate and water turnover of red kangaroos and sheep in an arid rangeland: an empirically derived dry-sheep-equivalent for kangaroos. Australian Journal of Zoology. 57:23-28.

Munn, A.J., Dawson, T.J. and McLeod, S.R. (2010) Feeding biology of two functionally different foregut-fermenting mammals, the marsupial red kangaroo and the ruminant sheep: how physiological ecology can inform land management. Journal of Zoology. 282: 226–237. doi:10.1111/j.1469-7998.2010.00740.

Mutze. G. (2006) The effect of rabbit grazing on vegetation in the Moodlatana Valley of Flinders Ranges National Park and Gum Creek Station. In: Bounceback Progress Report 2006. Department for Environment and Heritage, South Australia.

Mutze, G., Cooke, B., Lethbridge, M., Jennings, S. (2014) A rapid survey method for estimating population density of European rabbits living in native vegetation. The Rangeland Journal. 36: 239-247.

Mutze, G., Bird, P., Jennings, S., Peacock, D., de Preu, N., Kovaliski, J., Cooke, B., Capucci, L. (2015) Recovery of South Australian rabbit populations from the impact of rabbit haemorrhagic disease. Wildlife Research. 41:552-559.

Mutze, G. (2016) Barking up the wrong tree? Are livestock or rabbits the greater threat to rangeland biodiversity in southern Australia? The Rangeland Journal. 38:523-531.

Mutze, G., Cooke, B., Jennings, S., (2016a) Density-dependent grazing impacts of introduced European rabbits and sympatric kangaroos on native pastures. Biological Invasions. 18(8): 2365:2376.

Mutze, G., Cooke, B., Jennings, S. (2016b) Estimating density-dependent impacts of European rabbits on Australian tree and shrub populations. Australian Journal of Botany. 64:142-152.

Mutze, G., De Preu, N., Mooney, T., Koerner, D., McKenzie, D., Sinclair, R., Kovaliskli, J., Peacock, D. (2018) Substantial numerical decline in South Australian rabbit populations following the detection of rabbit haemorrhagic disease virus 2. Veterinary Record Published Online First: 08 March 2018. doi: 10.1136/vr.104734

Neave, H.M. Tanton, M.T. (1989) The Effects of Grazing by Kangaroos and Rabbits on the Vegetation and the Habitat of Other Fauna in the Tidbinbilla Nature Reserve, Australian Capital Territory. Wildlife Research. 16: 337-351.

Newsome, T.M., Ballard, G., Crowther, M.S., Dellinger, J.A., Fleming, P.J., Glen, A.S., Greenville, A.C., Johnson, C.N., Letnic, M., Moseby, K E., Nimmo, D.G., Nelson, M.P., Read, J.L., Ripple, W.J., Ritchie, E.G., Shores, C.R., Wallach, A.D., Wirsing, A.J. and Dickman, C.R. (2015), Resolving the value of the dingo in ecological restoration. Restoration Ecology, 23: 201-208. doi:10.1111/rec.12186

Nugent, G., McShea, W. J., Parkes, J., Woodley, S., Waithaka, J., Moro, J., Gutierrez, R., Azorit, C., Mendez Guerrero, F., Flueck, W. T., and Smith-Flueck, J. M. (2011). Policies and management of overabundant deer (native or exotic) in protected areas. Animal Production Science. 51:384–389.

Olsen, P. and Braysher, M. (2000) Situation Analysis Report: Current State of Scientific Knowledge on Kangaroos in the Environment, Including Ecological and Economic Impact and Effect of Culling. Report to the Kangaroo Management Advisory panel Panel (NSW Department of Environment and Climate Change, Sydney).Viewed on 1 June 2018 < http://www.environment.nsw.gov.au/resources/nature/Scireview.pdf>.

Olsen, P. and Low, T. (2006) Situation Analysis Report: Update on Current State of Scientific Knowledge on Kangaroos in the Environment, Including Ecological and Economic Impact and Effect of Culling. Report to the Kangaroo Management Advisory Panel (NSW Department of Environment and Climate Change, Sydney). Viewed on 1 May 2018<http://www.environment.nsw.gov.au/resources/nature/SituationAnalysisFinal.pdf>.

Olsson, E. (2017) Social License for Ethical Culling: A paper on the Social Response to Kangaroo Management in South Australia. Report prepared for the Department of Environment, Water and Natural Resources, South Australia.

Page, M., and Beeton, R. (2000) Is the removal of domestic stock sufficient to restore semi-arid conservation areas? Pacific Conservation Biology, 6:245-253.

Parks Canada Agency (2007) Management directive 4.4.11: Management of hyperabundant wildlife populations in Canada's national parks. Ottawa, ON: Parks Canada.

Paton, D.C. (2016) Report on the achievements and lessons from the use of fenced plots to assess the extent of grazing on understorey plants in the Mt Lofty Ranges. Attachment to DEWNR Volunteer grant 2014-15 final report form.

Pedler, R.D., Brandle, R., Read, J.L., Southgate, R., Bird, P., and Moseby, K.E. (2016) Rabbit biocontrol and landscape-scale recovery of threatened desert mammals. Conservation Biology. 30(4): 774-782. doi:10.1111/ cobi.12684

Peeters, P., Gerschwitz,, T. and Carpenter, R. (2006) Restoring Sheoak Grassy Woodlands on Lower Eyre Peninsula. Report prepared for Department of Environment and Heritage, South Australia

Petit, S., Dickson, C.R. (2005) Grass-tree (*Xanthorrhoea semiplana*, Liliaceae) facilitation of the endangered pink-lipped spider orchid (*Caladenia* syn. *Arachnorchis behrii,* Orchidaceae) varies in South Australia. Australian Journal of Botany. 53:455-464.

PIRSA (2011) Policy on the management of dingo populations in South Australia.

Pope, L.C., Butlin, R.K., Wilson, G.J., Woodroffe, R., Erven, K., Conyers, C.M., Franklin, T., Delahay, R.J., Cheeseman, C.L. and Burke, T. (2007) Genetic evidence that culling increases badger movement: implications for the spread of bovine tuberculosis. Molecular Ecology. 16:4919-4929. doi:10.1111/j.1365-294X.2007.03553.x

Pople, T. and Grigg, G. (1999). Commercial harvesting of kangaroos in Australia. Department of the Environment and Heritage: Canberra (http://www.environment.gov.au/biodiversity/trade-use/wild-harvest/kangaroo/harvesting/index.html).

Pople, A.R., Grigg, G.C., Cairns, S.C., Beard, L.A. and Alexander, P. (2000) Trends In The Numbers Of Red Kangaroos And Emus On Either Side Of The South Australian Dingo Fence: Evidence For Predator Regulation? Wildlife Research. 27(3):269-276. https://doi.org/10.1071/WR99030

Pople, A.R. (2008) Frequency and precision of aerial surveys for kangaroo management. Wildlife Research. 35:340-348.

Pople, A.R., Phinn, S.R., Menke, N., Grigg, G.C., Possingham, H.P., and McAlpine, C. (2007) Spatial patterns of kangaroo density across the South Australian pastoral zone over 26 years: aggregation during drought and suggestions of long distance movement. Journal of Applied Ecology. 44:1068–1079.

Pople, A.R., Grigg, G.C., Phinn, S.R., Menke, N., McAlpine, C. and Possingham, H.P. (2010) Reassessing the spatial and temporal dynamics of kangaroo populations. In Graeme Coulson and Mark Eldridge: *Macropods: the biology of kangaroos, wallabies and rat-kangaroos.* CSIRO Publishing, pp. 197-210

Pople, A.R., Evans, M.C., Farroway, L., Gilroy, J., Grigg, G., Lundie-Jenkins, G, and Payne, N. (2010) Using harvest statistics to monitor temporal variation in kangaroo density and harvest rate. In: *Macropods: the biology of kangaroos, wallabies and rat-kangaroos*. CSIRO Publishing, pp. 371-397.

Prowse, T. A., Correll, R. A., Johnson, C. N., Prideaux, G. J., Brook, B. W. and Lele, S. (2015a), Empirical tests of harvest-induced body-size evolution along a geographic gradient in Australian macropods. Journal of Animal Ecology, 84: 299-309. doi:10.1111/1365-2656.12273

Prowse, T. A., Johnson, C. N., Cassey, P. , Bradshaw, C. J., Brook, B. W. and Toit, J. (2015b), Ecological and economic benefits to cattle rangelands of restoring an apex predator. Journal of Applied Ecology. 52: 455-466. doi:10.1111/1365-2664.12378

Quarmby, J. (2011) Action Plan for Mount Compass Oak-bush (*Allocasuarina robusta*). Department of Environment, Water and Natural Resources, South Australia.

RAA (2017) RAA Crash Report shows most crashes avoidable. Media Release. 22nd March 2017. Accessed from: https://www.raa.com.au/community-and-advocacy/media-releases/1198

Read, J.L. and Cunningham, R. (2010) Relative impacts of cattle grazing and feral animals on an Australian arid zone reptile and small mammal assemblage. Austral Ecology. 35: 314-324. doi:10.1111/j.1442-9993.2009.02040.x

Ripple, W.J., Larsen, E.J., Renkin, R.A., and Smith, D.W., (2001) Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range: Biological Conservation. 102(3):227-234.

Ritchie, E.G., Elmhagen, B., Glen, A.S., Letnic, M., Ludwig, G. and McDonald, R.A. (2012) Ecosystem restoration with teeth: what role for predators? Trends in Ecology and Evolution. 27: 265-271.

Royal, S. (2018). Dingo fence dismantlement could help farmers and the environment, ecologist claims. ABC News February 4. Retrieved from http://www.abc.net.au/news/2018-02-04/ecologist-questions-environmental-value-of-dingo-fence/9393380

RSPCA (2018a) Is there a need to kill kangaroos? Accessed on June 10 2018 from: http://kb.rspca.org.au/is-there-a-need-to-kill-kangaroos-or-wallabies_77.html

RSPCA (2018b) What are the welfare issues associated with barrier and cluster fencing? Accessed on July 15 from: http://kb.rspca.org.au/what-are-the-welfare-issues-associated-with-barrier-and-cluster-fencing_713.html

Schoener, T.W. (1983).Field experiments on interspecific competition. American Naturalist. 122**:**240-285.

SEWPaC (2008a) National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Commercial Purposes.. Department of Sustainability, Environment, Water, Population and Communities: Canberra. Available at https://www.environment.gov.au/system/files/ resources/8ae26c87-fb7c-4ddc-b5df-02039cf1483e/files/code-conductcommercial. pdf [Verified 1 November 2016]

SGIC (2014) SA drivers urged to roo-main aware on the roads. Media release 22 July 2014. Accessed from: https://www.sgic.com.au/sa-drivers-urged-roo-main-aware-roads

Shelton, A.L., Henning, J.A., Schultz, P., and Clay, K. (2014) Effects of abundant white-tailed deer on vegetation, animals, mycorrhizal fungi, and soils. Forest Ecology and Management. 320:39-49. DOI: 10.1016/j.foreco.2014.02.026

Shepherd, N. and Caughley, G. (1987) Options for management of kangaroos. In '*Kangaroos: Their Ecology and Management in the Sheep Rangelands of* Australia'. (Eds G. Caughley, N. Shepherd and J. Short.) pp. 188-219. (Cambridge University Press: Cambridge.)

Short, J., Smith, A. (1994) Mammal Decline and Recovery in Australia. Journal of Mammalogy. 75(2):288–297. https://doi.org/10.2307/1382547

Sinclair, R. (1996) Mulga regeneration at Koonamore. In '*Focus On the Future - The Heat Is On*!' (Eds L. P. Hunt and R. Sinclair.) pp. 255-6. Australian Rangeland Society: Adelaide.

Sinclair, R. (2005) Long-term changes in vegetation, gradual and episodic, on the TGB Osborn Vegetation Reserve, Koonamore, South Australia (1926–2002). Australian Journal of Botany. 53:283-296

Smith, R., Smith, M., Paul, C., Bellemeore, C. (2015) Hyperabundant moose management plan for North Mountain, Cape Breton Highlands National Park. Parks Canada Agency

Spencer, A. (2011) One body of evidence, three different policies: Bovine tuberculosis policy in Britain. Politics. 31(2): 91–99.

Tschirner, K. and Tschirner, A. (2016) Herbivore Browse & Grass Assessment, Autumn 2016. Report prepared for the Department of Environment, Water and Natural Resources, Adelaide.

Thomsen, D., and Davies, J. (2005) Social and cultural dimensions of commercial kangaroo harvest in South Australia. Australian Journal of Experimental Agriculture. 45:1239–1243. doi: 10.1071/ EA03248

Thomsen D. A., Muir K., and Davies J. (2006) Aboriginal perspectives on kangaroo management in South Australia. The Rangeland Journal. 28:127-137.

Thomsen, D.A., and Davies, J. (2007) People and the Kangaroo Harvest in the South Australian Rangelands. Rural Industries Research and Development Corporation: Canberra.

Thomsen, D.A., Muir, K., and Davies, J. (2006) Aboriginal perspectives on kangaroo management in South Australia. The Rangeland Journal. 28: 127–137. doi:10.1071/RJ05028

Tiver, F. and Andrew, M.H. (1997) Relative effects of herbivory by sheep, rabbits, goats and kangaroos on recruitment and regeneration of shrubs and tree in eastern South Australia. Journal of Applied Ecology. 34: 903-914

U.S. Fish and Wildlife Service. 2018. Adaptive harvest management: 2018 hunting season. U.S. Department of the Interior, Washington, D.C., USA.

van Bommel, L. and Johnson, C.N. (2016) Livestock guardian dogs as surrogate top predators? How Maremma sheepdogs affect a wildlife community. Ecology and Evolution. 6: 6702–6711. doi: 10.1002/ece3.2412

van Bommel, L. (2010) Guardian dogs: Best practice manual for the use of livestock guardian dogs. Canberra, ACT: Invasive Animals CRC.

van Weenen, J. (2017) Kangaroos in the Adelaide and Mt Lofty Ranges Region. *The Birder: the official newsletter of BirdsSA,* March 2017

Vrtiska, M.P., Gammonley, J.H., Naylor, L.W. and Raedeke, A.H. (2013) Economic and conservation ramifications from the decline of waterfowl hunters. Wildlife Society Bulletin 37:380–388.

Westbrooke, M., Gowans, S., Gibson, M., (2007) Review of vegetation monitoring of the kangaroo management program at Para Wirra Recreation Park. Prepared for the Department for Environment and Heritage, Government of South Australia by: Centre for Environmental Management, University of Ballarat

Westoby, M., Walker, B., Noy-Meir, N. (1989) Opportunistic management for rangelands not at equilibrium. Journal of Range Management, 42: 266-274.

Willoughby, N. (2017), Analysis of grazing impacts on Coffin Bay and Lincoln National Park Grassy Sheoak Woodland 2003 to 2014. DEWNR Technical Note, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

Willoughby, N. (2018) Analysis of grazing impacts on Coffin Bay and Lincoln National Park Grassy Sheoak Woodland 2003 to 2017. DEW Technical Note, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

Wilson, A.D. (1991) Forage utilization by sheep and kangaroos in a semi-arid woodland. The Rangeland Journal. 13:81-90.

Wilson, M.A. (1997) The wolf in Yellowstone: Science, symbol, or politics? Deconstructing the conflict between environmentalism and wise use, Society & Natural Resources. 10:5:453-468, DOI: 10.1080/08941929709381044

Wilson, A. and Bignall, J. (2009) Regional Recovery Plan for threatenend species and ecological communities of Adelaide and the Mount Lofty Ranges, South Australia. Department for Environment and Heritage, South Australia.

Wimpenny, C. and Hinds, L.A. (2018) Fertility control of Eastern Grey Kangaroos in the ACT - Assessing efficacy of a dart-delivered immunocontraceptive vaccine. Environment, Planning and Sustainable Development Directorate, ACT Government, Canberra.

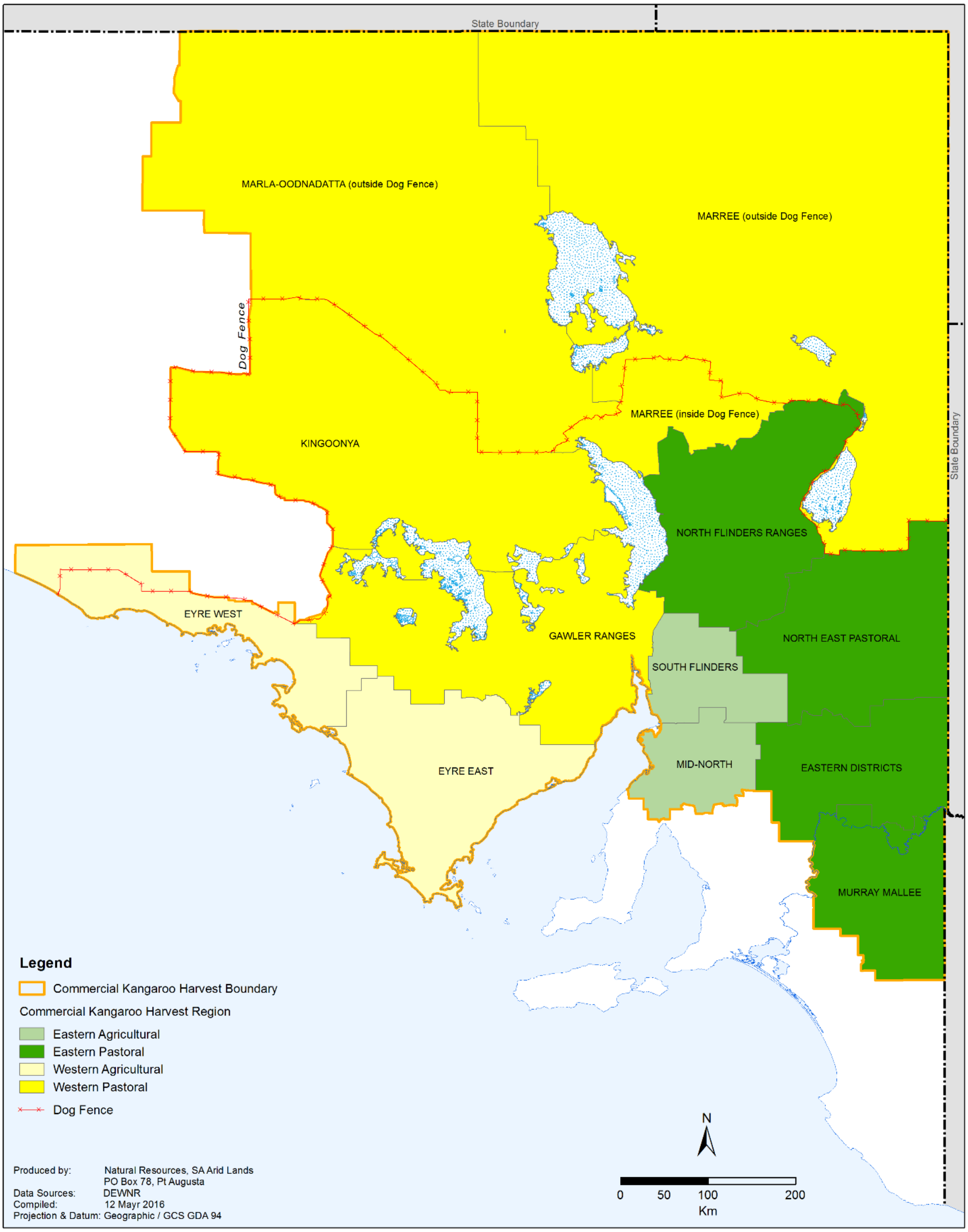
Woodroffe, R., Gilks, P., Johnston, W.T., Le Fevre, A.M., Cox, D.R., Donnelly, C.A., Bourne, F.J., Cheeseman, C.L., Gettinby, G., McInerney, J.P. and Morrison, W.I. (2008) Effects of culling on badger abundance: implications for tuberculosis control. Journal of Zoology. 274: 28-37. doi:10.1111/j.1469-7998.2007.00353.x

Yates, C.J., Norton, D.A. and Hobbs, R.J. (2000) Grazing effects on plant cover, soil and microclimate in fragmented woodlands in south-western Australia: implications for restoration. Austral Ecology. 25:36-47. doi:10.1046/j.1442-9993.2000.01030.x

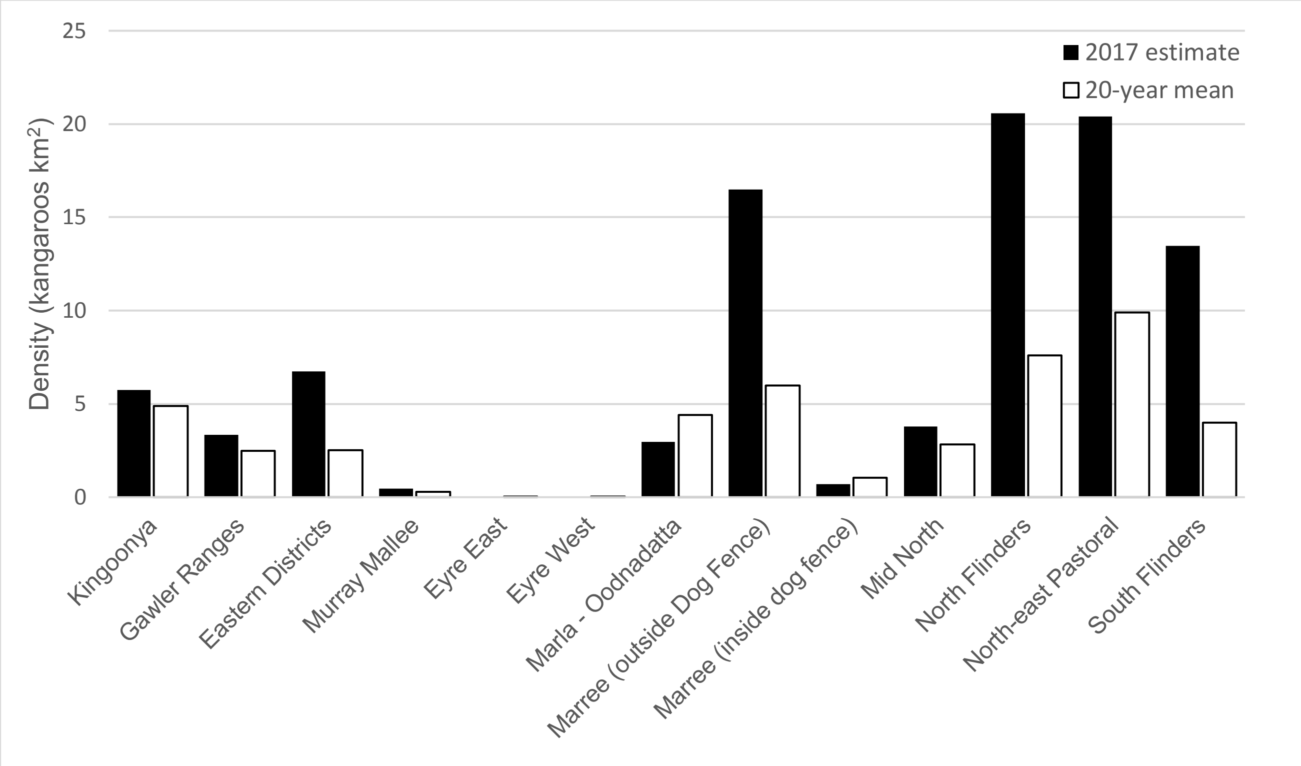
Zichy-Woinarski, J.C., Burbidge, A., & Harrison, P. (2015) Ongoing unraveling of a continental fauna: Decline and extinction of Australian mammals since European settlement. Proceedings of the National Academy of Sciences of the United States of America. 112(15): 4531-4540. DOI: 10.1073/pnas.1417301112

9 Appendices

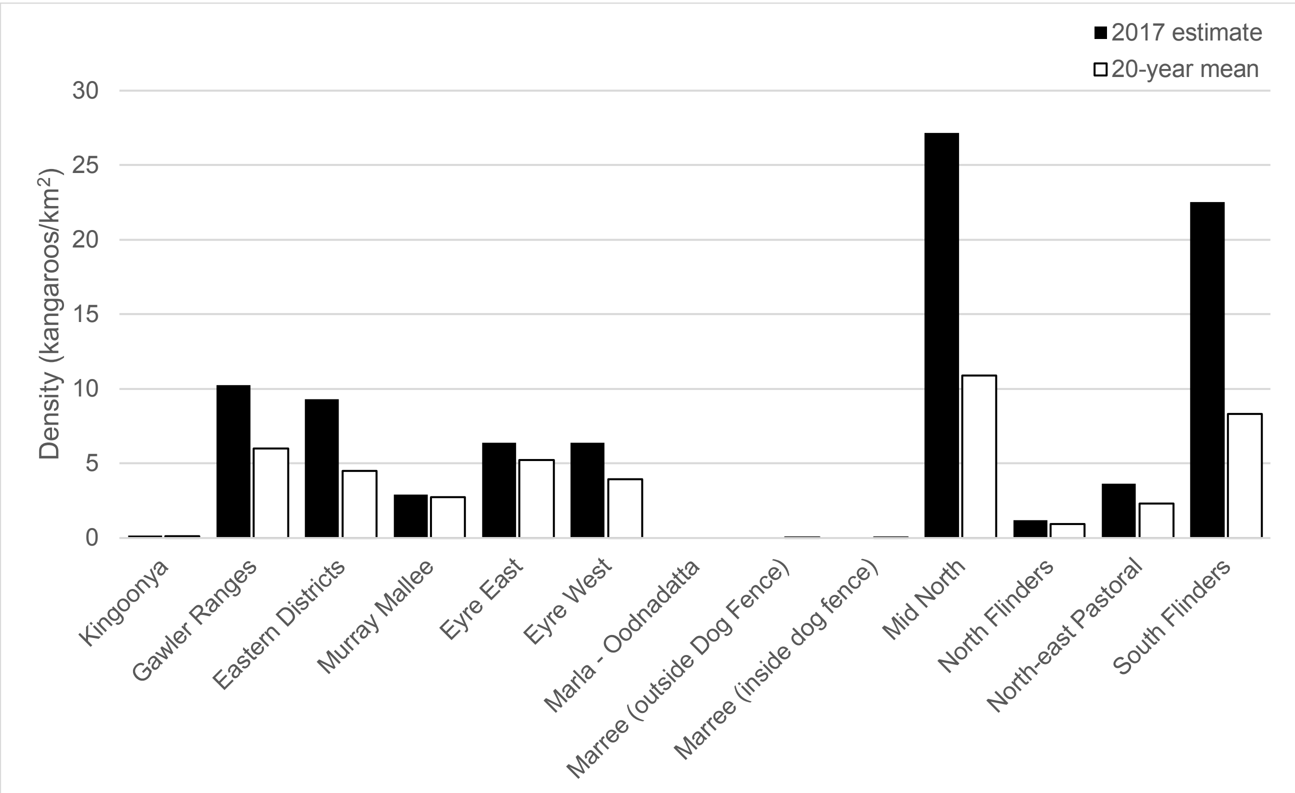
9.1 Appendix 1. Current South Australian Kangaroo Commercial Harvest Management Regions (CHMR). Internal boundaries represent the Commercial Harvest Sub-Regions within each of the four CHMR. Map taken from DEWNR (2018).



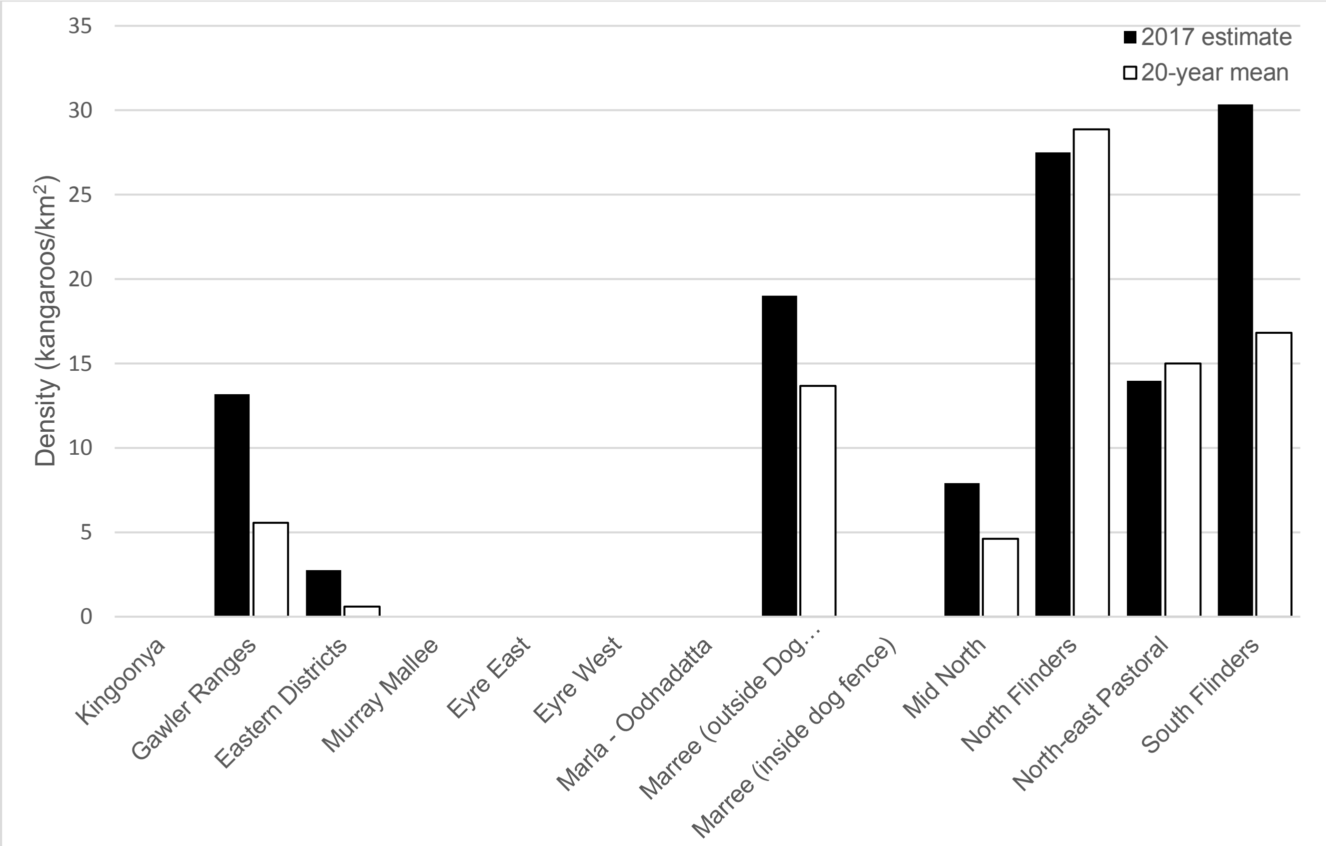
9.2 Appendix 2 Estimated kangaroo densities across survey regions in the commercial harvest zone of SA



Appendix 2a: Estimated average regional densities of Red Kangaroos (kangaroos/km^2)(DEWNR 2017b)

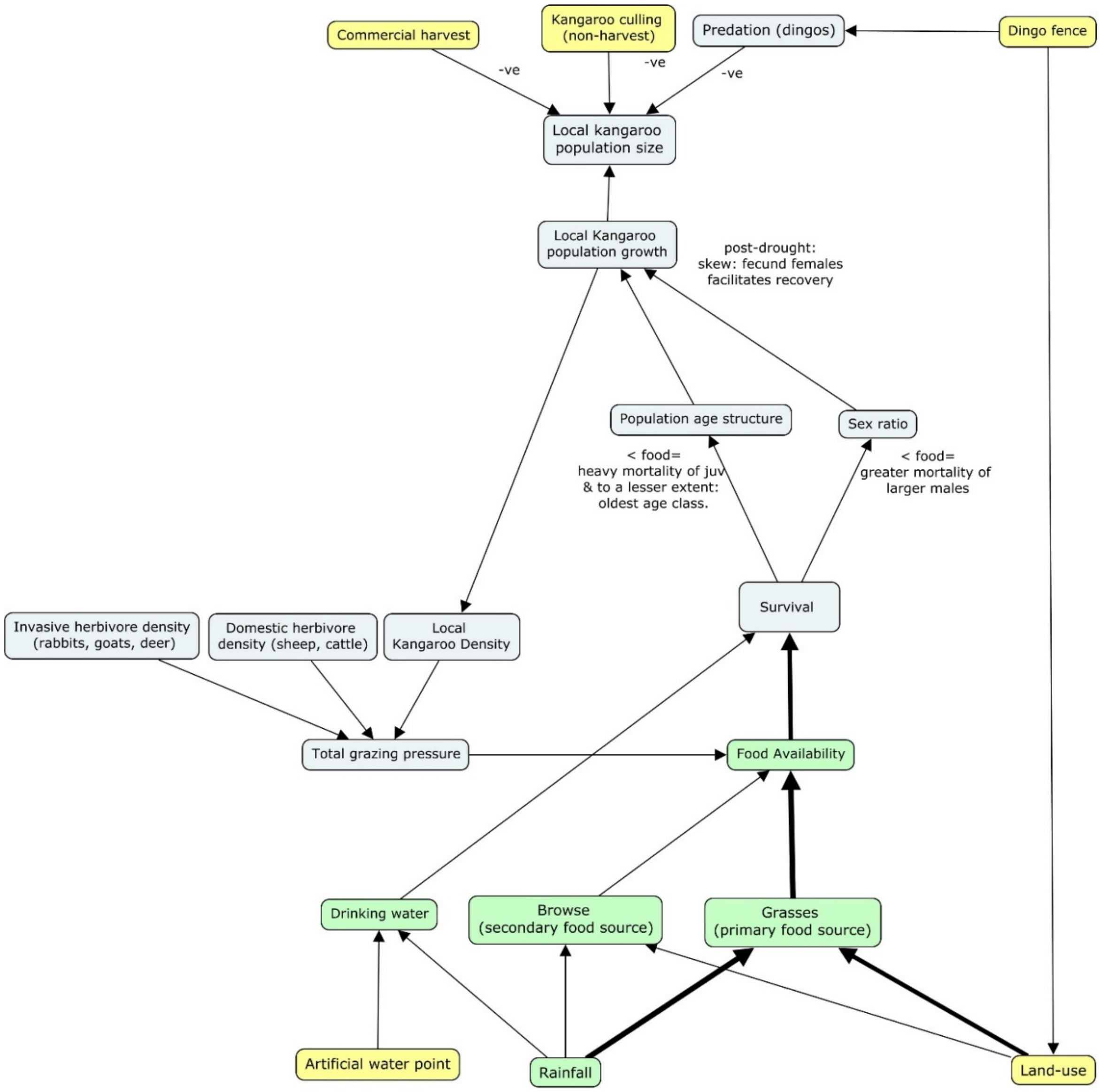


Appendix 2b: Estimated average regional densities of Western Grey Kangaroos (kangaroos/km^2) (DEWNR 2017b)



Appendix 2c: Estimated average regional densities of Euros (kangaroos/km^2) (DEWNR 2017b)

9.3 Appendix 3. Simple conceptual model of kangaroo population dynamics in SA



As described in Section 2 ('kangaroo population dynamics') of this report, a very simple conceptual understanding of kangaroo population dynamics in SA can be briefly summarised as following:

- Local kangaroo population sizes are determined by both bottom-up (i.e. resource availability) and top down (i.e. predation and culling) drivers.
- Land-use and rainfall affect the availability of suitable food sources and water availability. The availability of food is also affected by total grazing pressure from a variety of native and introduced herbivores.
- Survival of kangaroos decreases under conditions of low food and water availability. Under these conditions (i.e. during drought), the larger males and both very young and very old individuals suffer the greatest mortality. This skews the population towards fecund females and facilitates population recovery when resources become available (i.e. post-drought).
- Kangaroo population sizes can be directly reduced by culling, commercial harvest or via predation by dingos. Dingo predation is less frequent south of the dog fence where they are required to be destroyed.

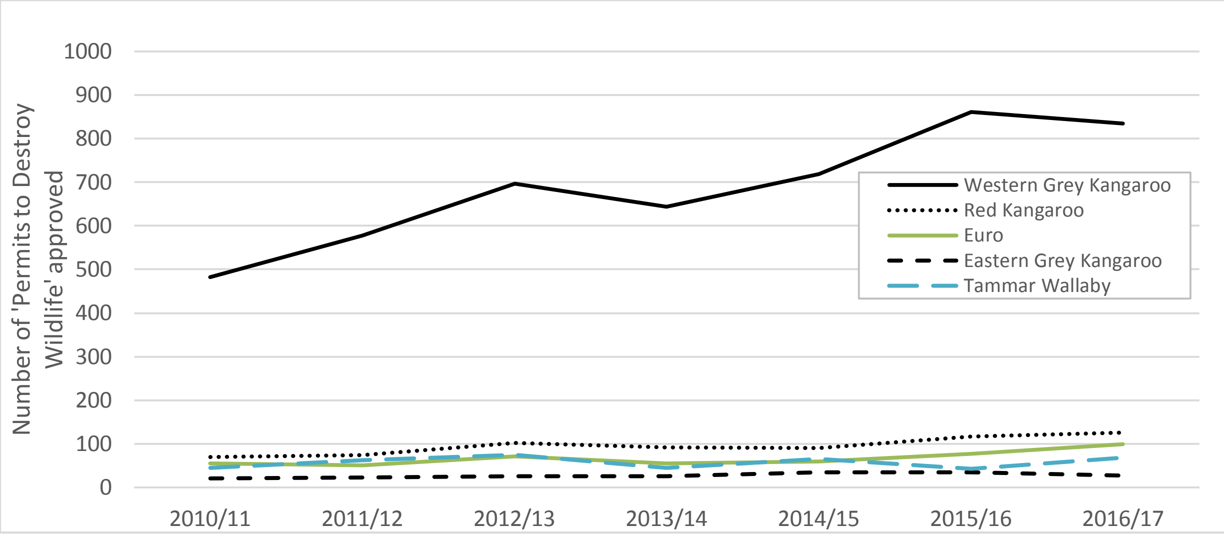
9.4 Appendix 4: Example of grazing impact at Chowilla wetland (Riverland)

Appendix 4a: group of goats grazing around an exclosure at Gum Flat (Chowilla) in July 2017 (captured by motion sensor cameras)

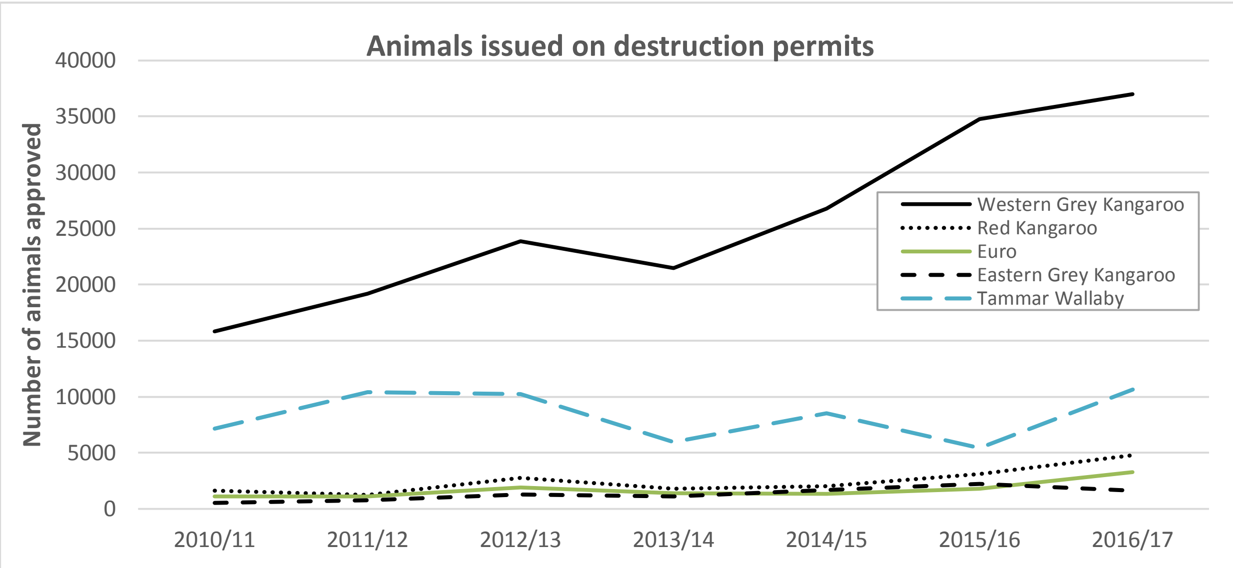
Appendix 4b: kangaroo grazing around an exclosure at Lake Limbra (Chowilla) in July 2017 (captured by motion sensor cameras)

Appendix 4c: 25 m^2 (5 x 5 m) grazing exclosure at Chowilla in February 2015. Originally established 2005–06

9.5 Appendix 5: Issue of destruction permits in SA



Appendix 5a: Number of destruction permits approved in SA from 2010–17



Appendix 5b: Number of animals issued (permitted to be destroyed) via 'Permits to Destroy Wildlife' from 2010–17