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The eastern grey kangaroo: current management and future directions

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Abstract

The eastern grey kangaroo is a common and iconic species of Australia. Its specialised behaviour and reproduction have evolved as adaptations to the Australian environment, allowing the species to survive and flourish despite wide climatic and seasonal variations in habitat. Across its range, the eastern grey kangaroo is harvested and subjected to population management for a variety of reasons including localised over-abundance, livestock competition, crop grazing, native habitat conservation, animal welfare, and direct threats to human safety. Population management of kangaroos is most commonly undertaken by shooting, although other methods such as reproductive control, translocation and repellents may also contribute successfully to management. Kangaroo harvesting and population control is controversial and divisive, as the kangaroo is perceived as both a national icon and as a pest species. Although a limited number of surveys have been undertaken on attitudes towards kangaroos and their management, the socio-political aspects affecting these issues are yet to be systematically investigated. Within this review we discuss the relevance of culture and language to species management and conservation, as well as the importance of scrutiny of stakeholder perceptions, motivations and values. Future directions should examine human dimensions that influence kangaroo management decisions and conservation. Three key aspects are recommended as research and management priorities: 1. Experimental determination of whether gaps exist between actual and perceived impacts of kangaroo populations, 2. Empirical investigation of how stakeholder language, culture, identity and values influence perceptions of kangaroos and their management, 3. Where population control is determined to be necessary, an incorporation of stakeholder differences within decision making to ensure best outcomes for both species conservation and population management.

Additional keywords: behaviour, pest management, conservation ecology, contraception, ethics, fertility control, habitat management, management strategies, population dynamics

Introduction

Fifty-one macropod species exist within Australia, arising from three taxonomic metatherian families (Richardson 2012; Potter *et al.* 2014). The eastern-grey kangaroo (*Macropus giganteus*) (EGK) is a large and common macropod species that makes a good case study of kangaroo management due to its abundance across the east side of Australia, and its inclusion in management and harvesting programs (Munny *et al.* 2008; Coulson 2009; Miller *et al.*

2010; Descovich *et al.* 2015). This review aims to provide readers with a current overview of kangaroo management frameworks, including a historical outline, and a summary of behaviour, reproduction and physiology relevant to management strategies. The influence of socio-political attitudes towards kangaroo management are examined, and future directions for research and management discussed. The welfare implications of managing kangaroo populations will only be briefly covered due to recent comprehensive reviews on this topic (Ben-Ami *et al.* 2014; Descovich *et al.* 2015; Hampton *et al.* 2015).

Behaviour and ecology

Physical characteristics

The EGK is one of the largest of the macropods, with some males growing to more than two metres tall and over 70 kg in weight (Kaufmann 1975; Miller *et al.* 2010). It is a sexually dimorphic species with adult females being only half the size and weight of adult males (Dawson 1995; Rieucau *et al.* 2012). It bears a resemblance to the western grey kangaroo (*M. fuliginosus*) (WGK), which has an overlapping range and was once considered part of the same species (Kirsch and Poole 1967; Neaves *et al.* 2010). Hybridisation infrequently occurs between EGKs and WGKs (Neaves *et al.* 2010).

Behaviour

Kangaroos have a fission-fusion social structure with overlaps in home range (Best *et al.* 2013). EGKs maintain social hierarchies, particularly amongst males, and this influences reproductive success (Miller *et al*. 2010; Rioux-Paquette *et al.* 2015).

EGKs are crepuscular animals, retiring to shelter under trees and high scrub bushes to rest two to three hours after dawn (Kaufmann 1975; Woodward *et al.* 2006). General movement and grazing resumes approximately four hours before sunset, with most activity two to three hours later (Kaufmann 1975). EGKs preferentially graze in grassy woodland habitats of eastern Australia (Schmidt *et al.* 2010). Feeding and other behaviour is dependent on weather conditions, and in hot, dry conditions, kangaroos feed almost exclusively at night (McCullough and McCullough 2000).

Reproduction

EGKs can reproduce at any time of the year but most births occur during the late spring and summer months (Poole 1973; 1975). Gestation lasts 36 days, and usually results in a single offspring, although twins have been reported (Poole 1975; Jackson 2007). Macropod species have developed two physiological adaptations that increase offspring survival and reproductive rate. Firstly, the gestation length is long in comparison to other marsupial species, producing larger and more developed young at birth (Dawson 1995). Secondly, many macropod marsupials undergo a post-partum oestrus and the newly conceived embryo enters diapause once it reaches the blastocyst stage due to the sucking stimulus of the new pouch young (Poole and Catling 1974; Poole 1983; Herbert *et al.* 2006). Post-partum oestrus is not common in EGKs but, under favourable conditions, a female will mate again once her pouch young reaches 5-7 months old; the resulting embryo then remains in a state of arrested development due to lactational inhibition. The embryo will recommence development to be born after the existing young exits the pouch (Poole and Catling 1974). Embryonic diapause gives macropods a reproductive advantage in the variable Australian environment to allow weaning to occur in optimal conditions (Renfree and Shaw 2000).

Development of pouch young

As for all marsupial species, EGK young are born in a highly altricial state, being hairless with closed eyes and ears, and possessing only rudimentary hind limbs (Shaw and Renfree 2006). After birth, the neonate will make its journey unaided from the urogenital opening to the pouch, where it will attach to one of four teats (Poole 1975). It will continue to develop inside the pouch for around 240 – 330 days, after which it starts emerging (Poole 1975). Once permanently out of the pouch, the young remains partially dependent on the mother for safety, nutrition and skills development until weaning at roughly 18 months of age (Poole 1975). Sexual maturation occurs in females at approximately this age, but later in males, at around 4 years old (Poole and Catling 1974). Males will disperse from their mothers' home range one to two years after weaning, while females may continue to stay in close proximity for their entire lifetime (Russell 1989).

Ecological pressures

Kangaroo numbers are affected by both 'bottom up' (resource availability) and 'top down' challenges (predators such as dingoes), with dependent young and sub-adults most susceptible to both influences (Robertson 1986; Banks *et al.* 2000; Pople *et al.* 2010; Letnic and Crowther 2013). Since European settlement, many macropod species have declined in numbers due to habitat changes, however several of the larger species including EGKs have benefitted from habitat alteration (Archer *et al.* 1985). Population abundance fluctuates annually due to variations in seasonal conditions and the availability of food, shelter and water. Under favourable conditions with abundant resources, EGKs can increase to high densities, although this pattern is suppressed in regions where dingoes are common (Letnic and Crowther 2013). In urban and peri-urban areas with constantly available food and water and a low level of predation, the reproductive rate of kangaroos can be high enough to require local intervention (Adderton Herbert 2004). This situation is becoming common along the east coast of Australia as residential and industrial development lock remaining kangaroo populations into diminishing and isolated areas of remnant bushland and parkland without the ability to move between regions (Adderton Herbert 2004).

Kangaroo abundance is most frequently determined using aerial surveys, which are labour-intensive and expensive (Pople *et al.* 2010). Aerial surveys began in 1975 in New South Wales, 1978 in South Australia and 1980 in Queensland (Pople *et al.* 2010). Survival of juvenile kangaroos is the most influential variable, creating significant fluctuations in populations (Pople *et al.* 2010). While adult mortality can be detected immediately from aerial surveys by a drop in numbers, juveniles are not currently detectable by air and population changes are determined by subsequent shifts in the adult population (Caughley *et al.* 1985; McCarthy 1996). Since surveys began, the EGK has expanded its range and distribution westward into more arid areas (Caughley *et al.* 1984; Pople *et al.* 2010). The EGK is sympatric with several other large macropod species (e.g. WGKs and swamp wallabies *Wallabia bicolor*) but avoids competition due to differentiation in habitat selection at the microhabitat level (Schmidt *et al.* 2010). EGKs have a preference for arboreal habitats with sparse understory (in particular a lack of shrubs) and plentiful grass, open clearings for grazing, and a balance between 'lateral cover' and grassed areas (Caughley 1964; Taylor 1980; Moore *et al.* 2002; Schmidt *et al.* 2010).

Macropod populations are also influenced by their susceptibility to fatalities and injuries from collisions with cars, especially for males, which represent around 65% of EGK roadkill fatalities (Coulson 1997; Lee *et al.* 2010). Kangaroo flight behaviour increases the probability of collision and fatality, with the chance of taking flight being affected by time of day and season, road and vehicle characteristics (Lee *et al.* 2010). EGKs are more likely to take flight at night, in spring, on hinterland roads (non-highways), when cars are travelling at lower speeds, and when the kangaroo is in closer proximity to the car (Lee *et al.* 2010). Lack of adjacent cover also increases the chance of flight, as does group size, with single or paired kangaroos more likely to flee (Lee *et al.* 2010).

Drivers of population management

Active species management is generally undertaken for four main reasons: threats to human life or livelihood, reduced density of the species (e.g. an endangered species requiring positive management to increase abundance), decline of reproduction and condition, or imbalance between vegetation and animal species (Caughley 1981). An additional driver may also be economic, where management of the species results in financial benefits (e.g. employment, tourism) for stakeholders. Management programs may act to promote or discourage species abundance, depending on the identified problem and favoured outcome. The management of EGKs is predominantly suppressive across all states and territories within its range, acting to reduce the population, with the exception of Tasmania, which operates both suppressive and augmenting management practices in different regions (Tanner and Hocking 2001). Primary reasons for EGK management include the actual or perception of over-abundance of populations, human-animal conflict arising from competition with livestock, grazing by kangaroos on agricultural crops, conservation of native environments, welfare of the kangaroos themselves, and direct threats to humans (TAS DPIPWE 2006; ACT TAMS 2010; QLD EHP 2012; SEWPaC 2013). The management of kangaroo populations is controversial and divisive, as kangaroos are viewed both as a national wildlife icon, valuable to tourism and the national identity, and a pest species (Pople and Grigg 1999).

Kangaroo species compete with livestock in extensively managed agricultural production systems and are thought to represent 13 – 36 % of the population of combined cattle-kangaroo herds (Allen 2015). In 2004, the Cooperative Research Centre for Pest Animal Control claimed that kangaroo competition for livestock food sources cost approximately AUD$77 million per year, and more recent estimates suggest that kangaroo competition with cattle may cost an average sized farm tens of thousands of dollars annually (McLeod 2004; Allen 2015). However the level of impact of kangaroos on agriculture is debated, due to fluctuations in effect based on region, habitat and individual kangaroo variables (Dawson and Munn 2007).

Over-grazing by kangaroos can also have a detrimental effect on other native animal and plant species. A cull of WGKs in the Wyperfeld National Park in Victoria resulted in improved vegetation conditions with an increase in grazing-sensitive species cover, the shrub layer and native species cover (Gowans *et al.* 2010). Similarly, a study by Barton *et al.* (2011) found that reducing EGK grazing improved the abundance and diversity of beetle species, although similar improvements could be produced by modifying the landscape in other ways, such as increasing the availability of logs. Comparable results have been demonstrated for reptiles and some bird groups (e.g. aerial insectivores) (Howland et al. 2014; 2016).

In urban areas, the challenges associated with the presence of kangaroos differ from those in rural regions. Increasing urbanisation can confine kangaroo populations into small or isolated pockets of remnant habitat (Adderton Herbert 2004), where they are unchecked by predators, but may be unable to access sufficient food and water. Urban management programmes attempt to both reduce the impacts on surrounding human residents and protect the welfare of the kangaroos themselves (Coulson 1982, 2001; Environmental Protection Agency 2007; ACT TAMS 2010).

History of kangaroo management

There is evidence that indigenous Australians managed kangaroos in pre-settlement times, using firestick farming to provide open grasslands for them to graze, which supported their hunting (Yibarbuk *et al.* 2001; Murphy and Bowman 2007). European settlers initially regarded kangaroos as a sustainable source of food and hides (Calaby and Grigg 1989). However, towards the middle of the 19th Century they were harvested in great numbers and gradually came to be considered vermin, with legislation that encouraged their destruction through a system of government bounties (Hrdina 1997; Poole 1984; Prince 1984). Between 1877 and 1907, approximately eight million macropods were presented to the Queensland Government alone for bounty money, pushing some species to the risk of extinction (Hrdina 1997). Government regulation began in 1954 with Queensland implementing the Fauna Conservation Act 1954-1979, although restrictions were not placed on kangaroo harvest numbers until 1970 (Kirkpatrick and Amos 1985; Pople and Grigg 1999). In 1984, kangaroo management and conservation programs which involved culling or harvesting for export became subject to government approval under the Commonwealth legislation ‘Wildlife Protection (Regulation of Exports and Imports) Act 1982 (Shepherd and Caughley 1987).

Current management strategies

Shooting

In Australia, approximately 3 million macropods are killed annually for commercial and non-commercial purposes, primarily by shooting, although poisoning is also undertaken in Tasmania for control of some wallaby species (TAS DPIPWE 2014; Descovich *et al.* 2015).

Appropriate management actions are reliant on accurate and regular population estimates (Pople 2008). Management practices that are excessively severe can reduce the local populations to the point of quasi-extinction, where the “population falls below an unacceptably low threshold density”, while practices that are not severe enough will not provide the intended benefits, such as reduced grazing pressure and crop damage (Pople 2008). In states and territories where EGKs are actively managed, quotas are set annually as a proportion of the estimated population (Pople 2008; Descovich *et al.* 2015). As populations are continually in flux, and quotas are not always filled, these quotas may not accurately represent the population that is being culled or controlled. This can be problematic when local populations are vulnerable, in drought, for example, when populations may have already significantly decreased. During this period quotas are often filled as kangaroos are more visible due to lack of forage, and graziers may perceive greater competition between stock and kangaroos for remaining forage (Pople 2008). Quotas may be based on population estimates from previous seasons, creating a disconnect between estimated and actual population sizes. Therefore the combined effect of drought plus a high quota relative to current population may be significant. The cost of estimating kangaroo abundance is high, and there has been considerable discussion on the risk of reducing the frequency of population surveys (Pople 2008), which would increase the risk of disparity between historical and current populations. It is recommended that survey frequency be based on habitat type and the intensity of proposed management (Pople 2008). In areas of intensive harvesting, regular (e.g. annual) surveys should be undertaken. In mesic areas where harvesting will be less intensive, survey frequency could be reduced. EGK populations based in arid areas have a higher risk of quasi-extinction, but if combined with a low harvest quota (e.g. less than 10 %) can also be safely surveyed less frequently (Pople 2008).

The legal responsibility for the management of kangaroos lies with both the federal and state governments of Australia. International export of kangaroo products has to be sanctioned by the federal government, through a state-managed Kangaroo Management Plan, which is revised every five years (Pople and Grigg 1999; Kelly 2005). Six species of macropod are approved for commercial export of meat or leather: EGK, WGK, red kangaroo (*M. rufus*), common wallaroo (*M. robustus*), red-necked/Bennett's wallaby (*M. rufogriseus*) and the Tasmanian pademelon (*Thylogale billardierii*) (Descovich *et al.* 2015). All commercial hunting of kangaroos for international export or the domestic market must meet the National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Commercial Purposes (SEWPaC 2008a). The main tenets of the Code are:

1. Where doubt exists that a sudden and humane death can be achieved, as defined by instantaneous loss of consciousness and rapid death, shooting should not be attempted.
2. The shooter must ensure the target animal is dead before attempting to shoot another animal, even if an animal has escaped after being injured.
3. Female macropods with obvious dependent young should not be shot unless extenuating circumstances apply, such as when the animal is sick or injured.
4. Shooters must search the pouch of any females which have been shot, and young that are found must be killed with the recommended method for the size of the young. Where the mother of a dependent young-at-foot has been killed, the dependant should be shot. Each animal should be examined to confirm death.
5. Shooters must only aim to hit the target animal in the brain.
6. Should a macropod need to be euthanased to alleviate suffering, this must be carried out via a shot to the brain, unless impractical or unsafe in which case a shot to the heart is an acceptable alternative. When neither option is possible, a heavy blow to the base of the skull is permissible.

7. The National Code of Practice does not override state or territory legislation

Kangaroos are also managed non-commercially across Australia due to conflict with agricultural industries, human-animal conflict, isolation of unsustainable populations, conservation of sympatric plant and animal species, and for welfare reasons. More than two million macropods are affected annually, although accurate numbers are difficult to obtain as some states (e.g. NSW) do not collect destruction statistics (Descovich *et al.* 2015). Across its distribution, the EGK is protected fauna under the relevant state nature conservation acts, which in QLD is the Nature Conservation Act 1992 (Queensland Parliamentary Counsel 2015), NSW, the National Parks and Wildlife Act 1974 (New South Wales Government 2015); TAS the Nature Conservation Act 2002 (Tasmanian Government 2015); VIC, the Wildlife Act 1975 (State Government of Victoria 2015) and ACT, the Nature Conservation Act 2014 (ACT Parliamentary Counsel 2015). However, landowners can obtain destruction permits to destroy EGKs on their properties in order to reduce damage by the animals, and each state or territory differs in the process and conditions of applying for a destruction permit. Queensland also allows recreational hunting of EGKs. (QLD EHP 2014) Tasmania allows recreational shooting of some other abundant macropods but not EGKs (TAS DPIPWE 2003). Shooting is the most common lethal means of controlling kangaroos. Non-commercial shooting of macropods should be practised in accordance with the National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Non-commercial Purposes, which is similar in many regards to the code of practice for commercial harvesting (SEWPaC 2008b; Descovich *et al.* 2015).

Where the primary purpose of management is to reduce kangaroo presence in particular regions, several non-lethal options exist, or are in development (Descovich *et al*. 2015).

While many have their own associated welfare concerns, they may provide some assistance either in isolation, or in combination with lethal methods.

Reproductive control

Where the abundance of kangaroos is considered to be undesirably high, fertility control is an alternative population management option to lethal measures. Fertility control results in the contraception and/or sterilisation of target animals and has been used in both sexes in macropodidae (Herbert *et al.* 2004a,b, Woodward *et al.* 2006). Three main methods of reproductive control exist: surgical sterilisation, hormonal manipulation and immuno-contraception (Hinds and Tyndale-Biscoe 1994; Nave *et al.* 2002; Asquith *et al.* 2006; Kitchener *et al.* 2009; Tribe *et al.* 2014).

Reproduction in female kangaroos can be temporarily arrested using the implantation of a long-acting contraceptive containing the synthetic progestin, levonorgestrel, or the gonadotrophin-releasing hormone agonist deslorelin (Suprelorin®) (Herbert *et al.* 2010). In EGKs these have been successfully used for long-term fertility control without apparent adverse side effects (Nave *et al.* 2002; Coulson *et al.* 2008; Herbert *et al.* 2010; Wilson *et al.* 2013; Wilson and Coulson 2016). Levonorgestrel inhibits ovulation by suppressing the luteinising hormone surge, but has no effect on follicular development, while deslorelin inhibits both luteinising hormone and follicle-stimulating hormone, resulting in the suppression of both ovulation and follicular development (Herbert *et al.* 2010). In a small sample of female EGKs, levonorgesterel implants produced contraceptive effects in 87 % of the population, with around 50 % of responding animals remaining infertile five years post-implantation (Herbert *et al.* 2010). Levonorgestrel appears to have a minimal effect on the normal behaviour of EGK, such as feeding, scanning, grooming, and moving, although males prefer to associate with untreated females, suggesting some effect on social dynamics (Poiaini *et al.* 2002). Suprelorin implants produce contraceptive effects in EGKs for at least 17 months, with a response rate of approximately 96 % (Herbert *et al.* 2006; Woodward *et al.* 2006). As with levonorgestrol, suprelorin has no obvious effect on normal activity, with feeding, vigilance, grooming and social interaction unaffected, however treatment can induce a behavioural oestrus, which stimulates mating, albeit unsuccessful (Herbert and Trigg 2005; Woodward *et al.* 2006). The application of contraception to female EGKs should consider several factors, including the duration of effect, the relationship with reproductive life-cycle when determining reapplication needs, methods and ease of delivery, cost-effectiveness, and goals for the population (Herbert *et al.* 2010). In a recent comparative study of levonorgestrol and suprelorin use in EGKs, levonorgestrol was superior in both efficacy and duration of action (Wilson and Coulson 2016).

While fertility control is commonly suggested as an alternative to lethal population control, it has associated welfare issues (Descovich *et al.* 2015; Hampton *et al.* 2015). The most important arise from the need for capture and restraint, usually with chemical immobilisation, which requires specialist expertise, expense and carries a significant risk of injury or death (Tribe *et al.* 2014; Descovich *et al.* 2015). Suprelorin implants are yet to be trialled in male EGKs, but are ineffective in male tammar wallabies (*M. eugenii*) (Herbert *et al.* 2004b). Behavioural impacts of reproductive treatments, particularly those influencing hormonal mechanisms, are poorly understood (Hampton *et al.* 2015).

In contrast to chemical contraception, immunological control acts by vaccinating against hormones and proteins that are required for successful conception, and three treatments have been trialled in macropods: sperm antigen, zonae pellucidae vaccines and GnRH vaccines

(Kitchener *et al.* 2002; Asquith *et al.* 2006; Kitchener *et al.* 2009; Snape et al. 2011). Delivery of these vaccines is via injection, and some success has been found in trials using female EGKs, with reproductive function arrested for more than one year after a single vaccination of ZP (Kitchener et al. 2009) and several years in tammar wallabies after a single injection of GonaconTM (Snape et al. 2011).

Surgical sterilisation is permanently achievable in both sexes but is an impractical solution to kangaroo overabundance due to the cost and expertise required and the welfare issues from peri and post-operative complications (Mosley and Gunkel 2007; Bauquier and Golder 2010; Tribe *et al.* 2014). Surgical sterilisation can suppress sexual and agonistic behaviour, which may alter social structure (ACT TAMS 2010; Tribe *et al.* 2014).

For practical implementation of reproductive control resulting in effective management, many questions remain unanswered (Herbert *et al.* 2010): how many animals must be included in a contraceptive program in order to have the desired effect on the population (extinction, reduction or stability); how reapplication to individuals will affect genetic diversity; how the contraception of some individuals affects population demography, survivorship or immigration / emigration (Herbert *et al.* 2010)? Reproductive control cannot immediately reduce an EGK population, and is most likely to be useful in combination with other methods of control, such as culling. Research in another marsupial (brushtail possums, *Trichosurus vulpecula*) demonstrates that an initial severe reduction of population, in combination with strategies that maintain a low abundance, minimises the total number of animals adversely affected (Warburton *et al.* 2012), which is desirable in terms of overall welfare impact (Yeates 2010; Warburton *et al.* 2012).

Translocation

The translocation of a species, i.e. the "intentional movement by humans of an animal or a population of animals from one location to another" (Fischer and Lindenmayer 2000), has been widely used as a conservation strategy, and may be valuable for the management of vulnerable species, or those with limited range (Clayton *et al.* 2014; Rout *et al.* 2007). However, this option has associated welfare challenges, as the capture, handling and transportation can lead to significant risk of injury and death (Higginbottom and Page 2010; Tribe *et al.* 2014; Descovich *et al.* 2015). Furthermore, the strategy is generally inappropriate for management of abundant species, due to the cost and expertise required for successful translocation, and the challenge of identifying appropriate release sites (Higginbottom and Page 2010; Clayton *et al.* 2014). As most kangaroo management programs are implemented in order to harvest products, or to reduce the impact on human livelihood or for safety reasons, the use of translocation as a management strategy for abundant species, such as EGKs*,* remains largely inappropriate.

Deterrents

An alternative strategy to active population management where the aim is to reduce numbers in a specific area (e.g. crops or livestock grazing areas) is the use of deterrents. A variety of deterrents have been investigated as a method of kangaroo control, and some may be useful under specific circumstances.

Auditory devices based on ultra-sonic frequency outputs have been proposed as methods for deterring wildlife, however in kangaroos this has been found to be ineffective (Bender 2003). Playback experiments with red-necked wallabies and red-necked pademelons (*Thylogale thetis*) investigated their behavioural responses to conspecific, heterospecific, and predator vocalisations and novel sounds (Ramp et al. 2011). Pademelons responded initially to all sounds but showed habituation to predator noises, and sensitisation to novel noises after repeated exposure. Wallabies responded most strongly to conspecific distress noises and did not habituate during the short study period (Ramp et al. 2011). This suggests that auditory deterrents may have a role to play in managing the undesirable presence of macropods, although in-situ studies are still required (Ramp et al. 2011).

Odour repellents are an alternative to auditory deterrents. A recent study by Cox *et al.* (2015) investigated the use of faecal odour repellents from three predators [lion (*Panthera leo*), Sumatran tiger (*P. tigris sumatrae*) and dingo (*Canis lupus dingo*)] as deterrents for two macropod species (EGK and WGK) from eating odour-laced food sources. This was found to be highly effective over a twenty-day period. A similar study that included red kangaroos, WGKs and agile wallabies (*M. agilis*) found that after ten days of dingo odour treatment (using both urine and faeces) many macropods avoided the area entirely, despite the provisioning of attractive food items (Parsons and Blumstein 2010). These studies provide evidence that predator odours deter kangaroos, however practically implementing repellents remains problematic. Repellents may be an effective strategy for excluding kangaroos from crop areas, if placed at access points, and in conjunction with exclusion fencing. However, no field trials have been undertaken to our knowledge, and a key aspect of their potential value will be whether they are effective over the long term.

For the purpose of reducing competition with livestock species, practical implementation of deterrents may also have additional challenges, as non-target species, such as sheep, may find predator cues aversive. Deterrents consisting of faeces or urine of a predator, a caracal (*Felis caracal*), were highly aversive in domestic goats, (Shrader *et al.* 2008), and aversive effects of predator faecal odours have also been found in sheep and cattle (Pfister *et al.* 1990). Therefore, predator odours do not have a species-specific effect on target taxa and may have undesirable effects on domestic herbivores, although field trials should be undertaken to determine on-farm effectiveness.

The presence of predators in areas of kangaroo abundance may be important for controlling competition with livestock species. In the wild, foxes (*Vulpes vulpes*) control kangaroo numbers through predation (Banks *et al.* 2010). Similar patterns have been described for dingoes; which preferentially predate on young kangaroos and females (Robertshaw and Harden 1986; Letnic and Crowther 2013). Where kangaroos share habitat with other potential prey species, such as livestock, dingoes appear to prefer to predate on kangaroos (Corbett 1995). Kangaroo numbers are generally high when there is good food availability (Letnic and Crowther 2013), unless predators are present. Thus the maintenance of kangaroo-livestock herds may be one avenue for reducing attacks on livestock species by dingoes or wild dogs.

Similarly some domestic dog breeds are used as guardian animals for livestock species in order to deter predators, such as wild dogs (van Bommel and Johnson 2012). This technique has been widely and successfully used (Smith *et al.* 2010; van Bommel and Johnson 2012). In areas where dingo populations are maintained as a top-down method of kangaroo control, livestock guardian dogs, or other guardian species, may be an effective and complementary practice to deter attacks on livestock species. Furthermore, kangaroos have a natural aversion to canids (Jarman and Wright 1993), which suggests that livestock guardians may play a dual role in deterring both kangaroos and predators.

Restricted access to water provisions

During periods of drought or low forage abundance, kangaroo populations reduce due to starvation or migrate to other, more productive, areas (Caughley *et al.* 1985; Robertson 1986; Pople *et al.* 2007). It is unclear whether access to an artificial water source increases the abundance of kangaroos, but a recent study that systematically investigated population growth under various environmental variables suggested it did not (Letnic and Crowther 2013). Therefore restriction in water provisioning may not be an effective method of control of kangaroos

Socio-political influences on kangaroo management

Kangaroos and wallabies are iconic Australian animals that are viewed simultaneously as a tourist attraction and pest species (Pople and Grigg 1999; Higginbottom *et al.* 2004). The management of kangaroos is under increasing public scrutiny and socio-political control, encouraging the consideration of alternatives to lethal control methods (Woodward *et al.* 2006). While historically, kangaroo management has been a rural issue, the growing isolation of kangaroo populations in small, isolated areas of remnant bush and parkland as a result of increasing urban and peri-urban development is creating conflict for resources between humans and macropods (Ben-Ami *et al.* 2006; Coulson *et al.* 2014). Consequently, debate about kangaroo populations has turned not only to the rural challenges, but increasingly also the urban ones. This has served to emphasize the socio-political aspects of kangaroo management discussed below.

The eastern seaboard of Australia has witnessed significant recent human population expansion (Bradshaw 2012), with wildlife habitat given over to anthropogenic activity. This usually suppresses the activity of most species (van der Ree and McCarthy 2005; McKinney 2008). The population of EGKs is relatively robust, especially in comparison with many smaller macropod species (e.g. hare-wallabies *Lagorchestes sps.* and bettongs *Bettongia sps.*), which are vulnerable to habitat disturbance and have seriously declined since European settlement (Archer *et al.* 1985; Calaby and Grigg 1989).

As the human population continues to grow and is forced to face many associated development issues, the conflict between wildlife and humans is likely to increase. Knowledge of wild ecosystems is incomplete and anthropogenic influences can result in widespread negative consequences (Ceballos and Ehrlich 2002; Morrison *et al.* 2007). Indeed, when perceived conflict with wildlife is only a symptom of other underlying or broader issues it is likely to remain unaddressed or even compounded by solutions that focus solely on addressing the conflict. Initiatives that address challenges in managing human-wildlife interaction should aim to seek long-term, sustainable solutions that do not result in negative effects for either humans, habitats or wildlife, but attitudes and community perceptions are strong drivers of environmental action.

Institutional attitudes towards kangaroo management

A limited amount of research has been undertaken on public attitudes towards kangaroos, harvesting and management strategies. An early attitudinal survey of a wide range of individuals, industry organisations, and conservation, animal welfare and animal rights groups, found that views are essentially dichotomous (Pople 2004). Farming organisations and lobby groups generally supported the kangaroo harvesting industry and regarded it as economically valuable to rural areas and important for pest control. Groups such as the Ecological Society of Australia, the Royal Zoological Society, the Australasian Wildlife Management Society, other conservation organisations and the RSPCA, all supported sustainable kangaroo harvesting (Pople 2004). However, animal rights groups were philosophically opposed to the killing of kangaroos for either damage mitigation or commercial use (Pople 2004). Tourists and urban residents of Australia often align more closely to the protectionist view of animal rights groups, with many believing that strategies to manage kangaroo populations are unnecessary (Dawson 1995).

Rural attitudes towards kangaroo management

The majority of attitudinal surveys have been undertaken in rural regions. In 1987, Gibson and Young conducted an attitudinal survey on 92 properties in the Longreach area of rural Queensland. Forty-nine percent of property managers ranked kangaroos as the primary major constraint on livestock production, with 20 % ranking kangaroos second and a further 15 %, third. Dawson (1995) found similar concerns amongst farmers, with kangaroos blamed for crop grazing, fence damage and animal-car collisions, especially at dusk and dawn.

A survey of South Australian kangaroo harvesters and processors, and of landholders that allowed shooting of kangaroos on their property, found that landowners had several motivations to allow harvesters onto their property (Thomsen and Davies, 2007). The primary motivation was to manage grazing pressure, while secondary reasons were to provide a source of income to harvesters/processors, to conserve water, to assist in preservation of the environment, or because it was considered a social norm (Thomsen and Davies 2007). The presence of kangaroo harvesters was seen to provide economic benefits to the community, and many harvesters contributed positively to the landholder by undertaking extra duties whilst on the property (e.g. stock movement, equipment checking). Kangaroo harvesters indicated that although they assisted in reducing grazing pressure by removing kangaroos, they also wanted to maintain population numbers so they could continue to shoot in areas of high-density (Thomsen and Davies 2007). This raises questions about whether harvesting lowers grazing pressure and maintains land quality. When asked to predict the outcome of reduced kangaroo harvesting, most respondents thought it would lead to excessive grazing pressure and land degradation, while other suggestions were resource depletion leading to a population crash, lack of food/water for stock, unprofessional/inhumane shooting by landholders and amateur hunters, poisoning of kangaroos, loss of business, negative impact on other native species, and wastage of kangaroo products (Thomsen and Davies 2007). In South Australia, harvesters are allocated tags for harvesting on a property-by-property basis. It was noted that many harvesters engage in tag swapping, an illegal activity where tags allocated for one property are used on another that is also held by the same shooter. It was felt by some respondents that the current tag/property system is ineffective due to temporal constraints on being able to address issues as they arise, and that exclusive rights for harvesting are held by too few individuals, who may choose not to utilise them, causing an inflexible licensing system (Thomsen and Davies 2007).

A survey of the perspectives of indigenous Australians towards kangaroo harvesting has been undertaken in South Australia, incorporating two Aboriginal Australian groups that lie within the commercial harvesting area, the Anangu from the Western Desert region and Adnyamathanha group from the Northern Flinders Ranges region (Thomsen *et al.* 2006). While culture and customary practices varied between the groups, kangaroos were culturally significant for both (Thomsen *et al.* 2006). Some Anangu elders opposed commercial harvest on their land because the culling and processing was not in accordance with their beliefs, while the cultural beliefs of the Adnyamathanha people did not preclude commercial harvest on their land. Culling of kangaroos without utilisation of the carcass afterwards was considered offensive (Thomsen *et al.* 2006). Modern hunting by these groups generally utilises firearms and vehicles, although some respondents indicated that they experienced challenges in obtaining appropriate firearm licenses (Missi 1998; Thomsen *et al.* 2006). Anangu people preferred heart shots when shooting kangaroos, as they believed that shots to the head damaged the spirit of the animal and were therefore cruel (Thomsen *et al.* 2006). In the national codes of practice for the humane shooting of macropods, heart shots are permitted in non-commercial hunting under some circumstances (e.g. when using shot guns), but only headshots are permitted for commercial harvesting (SEWPaC 2008a).

Urban attitudes towards kangaroo management

Human-kangaroo interaction occurs not only in rural areas, but also in urban and peri-urban regions. A survey of Port Macquarie residents in a retirement village, chosen because of the proximity of the housing to rural lands, the high frequency of kangaroos entering the village and documented cases of human injury from this, showed that over half of the residents were concerned about potential human-kangaroo conflict (Ballard 2008). Also 34 % indicated that they had been concerned about leaving the house with a kangaroo present. However, 51 % stated that the presence of the local kangaroos was important to them, with only 19 % opposed; 57 % were in support of allowing the kangaroos to enter, 26 % were not. When asked whether aggressive kangaroos should be controlled, 21 % did not want kangaroos to be managed, 7 % believed that a lethal management strategy should be undertaken, and 67 % had a preference for translocation (Ballard 2008). Most respondents (91 %) believed that people moving into an area populated with kangaroos should be provided with appropriate information on how to co-exist.

Similarly, a series of three surveys on attitudes towards kangaroo management has been conducted in the ACT (Micromex 2015). The most recent of these was in 2015, which indicated that 74 % of people believe kangaroo presence in Canberra Nature Park, where annual kangaroo culling is undertaken via shooting, is important (ACT TAMS 2010; Micromex 2015). Kangaroo culling was supported by 87 % and 85 % of respondents when it was undertaken for animal welfare reasons or conservation, respectively, although support was reduced for culling on farms (77 %) and for harvesting (60 %) (Micromex 2015).

The role of language and culture

Within Australian society, there is a wide diversity of views on kangaroos, management strategies, the desire for co-existence, and the associated challenges with living in proximity to this species. What is yet to be examined, however, is the underlying construction of these views and how they influence both the perception of, and reaction to situations and policies involving kangaroos. As urban development continues to encroach into natural landscapes, ways must be found for humans and macropod species to co-exist. Human-wildlife interaction will be key in successful co-habitation, and correspondingly, the attitudes of people regarding such interaction will determine the perception of conflict and success or failure. Perceived problems with wildlife may only influence a small part of an ecosystem, but efforts to control these problems may have unintended and undesirable effects over ecosystems as a whole, including on humans.

Kangaroo management has usually been addressed from an ecological point of view (e.g. Pople *et al.* 2010), and this review does not attempt to re-examine the questions and issues raised in these studies. However, wildlife management policies (e.g. harvesting, population control) that aim to improve outcomes for society have an essential human element that has to date largely been ignored.

The first question to consider is whether human-macropod conflict is a genuine or perceived problem. The second question is whether it can be resolved by controlling macropod abundance. Considering Human-Wildlife 'Conflict' (HWC), it has been suggested that the term 'conflict' is a misnomer that masks underlying and unrecognised challenges and is further reinforced by language and cultural narratives (Peterson *et al.* 2010; Hill 2015). For example, animals that forage on agricultural crops could be described as 'crop raiding', which creates a negative connotation of theft and malicious intent in contrast to the terms 'feeding' or 'foraging'. The use of HWC creates a barrier to effective mitigation activities, as in many cases HWC is actually conflict between humans on how wildlife should be managed (Peterson *et al*. 2010; Hill 2015). Underlying and unscrutinised motivations can affect how mitigation activities are carried out and whether they are successful (Peterson *et al*. 2010; Hill 2015). Stakeholders who are directly affected by animal activity (e.g. primary producers) may feel anger towards other humans (e.g. governing bodies or conservation groups), and redirected anger towards wildlife can provide a socially-accepted vehicle for expressing concern and avoiding direct conflict (Peterson *et al*. 2010; Hill 2015). Primary stakeholders are also affected by many factors outside of their control (e.g. environmental ones such as drought, or social and political ones such as economic policy) (Vanclay 2003; Edwards *et al.* 2009), and therefore, action over animal activity can represent one variable in which they have a measure of control.

The language used when discussing wildlife management directly reflects, and impacts how these issues are perceived. In Canada, the debate over the management of free-ranging horses is divided along language lines, ether describing them as "wild" or "feral", terms which have some overlap in meaning but are polar opposites in their attached value (Bhattacharyya *et al.* 2011). The term 'wild' is viewed and used as a positive descriptor, while 'feral' is viewed and used as a negative term. In kangaroos, a similar situation exists, with kangaroos described as both ‘icons’ and ‘pests’ by different demographics within Australian society (Higginbottom *et al.* 2004; Kelly 2005). The use of value-laden terms extends to kangaroo product industries within which there is a verbal framework that promotes eating of kangaroo meat to consumers (Craw 2008).

Demographic-based perspectives and values

Different groups or stakeholders can vary in their values and cultures towards wildlife activity. Value orientations are defined as “an expression of basic values and are revealed through the pattern and direction of basic beliefs held by an individual” (Manfredo *et al.* 2003). Some individuals may be “use” orientated, holding a utilitarian view of wildlife, while others may be “protection” oriented. How individuals are placed within this value orientation framework is related to demographic variables, such as age, sex, education and place of residence (Needham 2010; Serenari *et al.* 2015). “Culture”, or “a set of beliefs and assumptions developed by a given group in its efforts to cope with the problems of external adaptation and internal integration” (Barnes 1986 in Bhattacharyya *et al.* 2011) can also be influential. Culturally-derived values are placed on objects, including animals, expression of which is reinforced by social norms, thus legitimising the value of the object (Stephenson 2008). Object value systems are part of a larger, complex environmental value system, which includes culture, attitude, social norms and behaviour. It is therefore critical to note that people attach meaning to their environment, or to objects within that environment such as individual species. These meanings may be shared with other members of the community, creating social norms (Bhattacharyya *et al.* 2011). Some of these values, and their underlying assumptions can be hidden (Bhattacharyya *et al.* 2011). Therefore when different cultural groups within society are affected by, or involved in, decision making of land management practices, they may approach, describe and even conceive situations in diverse ways (Berkes 2004; Mabee and Hoberg 2006). Values may be placed onto ingrained beliefs so that cultural beliefs become “common sense”, and implicit bias can significantly change the discourse and processes around dealing with land management challenges (Stephenson 2008). Such challenges are directly relevant to kangaroo management issues in Australia. The kangaroo debate is polarising but may be progressed using these approaches. What are the values and philosophies that influence whether kangaroos are perceived as a problem, how do they fit in to our general view of land management, and do these views result in long-term sustainable outcomes for affected species, including humans? Furthermore, where stakeholder groups differ in their views of macropod management, how can effective conversations be undertaken to create positive outcomes? Surveys of primary producers suggest that they perceive damage or competition from kangaroos to be of considerable concern (Gibson and Young 1987; Dawson 1995). However, attitudes surrounding wildlife interaction are complex, as demonstrated above, and may under or over-estimate the actual challenge, or mask more profound challenges over which less control is possible. Therefore, broadening our understanding of the human dimensions of macropod control and harvesting is an important aspect of future research.

Future directions for research and management

We recommend three key areas for future research that can inform and improve kangaroo management strategies. The first priority is to advance existing attitudinal surveys by conducting an up-to-date study of the socio-political-demographic elements that contribute to perceptions of kangaroos and their management. This should include an inspection of how involved parties use language to frame elements of the issue, and how this might influence values and attitudes. One relevant framework, which may facilitate such an examination, is the 'Levels of Conflict Model' (discussed below) (adapted from CICR 2000 by Madden and McQuinn 2014). Secondly, an experimental approach should be undertaken to determine whether gaps exist between stakeholder perceptions of kangaroo impact and actual impact. Thirdly where kangaroo management is determined to be necessary, stakeholder conflict could be managed using a relevant model to address both the evident and underlying issues, such as the 'Conflict Intervention Triangle' (discussed below) (Madden and McQuinn 2014).

Examination of socio-political-demographic elements of stakeholders

To date, several attitudinal surveys have been conducted of relevant stakeholders regarding kangaroos and their management (e.g. Pople, 2004; Thomsen *et al.* 2006; Thomsen and Davies, 2007). One model, which may be employed in the context of kangaroo management, is the 'Levels of Conflict' model (adapted from CICR 2000 by Madden and McQuinn 2014).

The Levels of Conflict model defines three potential levels of conflict: dispute, underlying, and identity based (Madden and McQuinn 2014), with greater complexity and challenge involved with each additional level. The dispute level is the superficial manifestation of the conflict. In the case of kangaroo management this may be livestock-macropod competition, population abundance, direct attack by kangaroos, or kangaroo-car collisions. The second underlying level describes the history of the conflict, particularly when unresolved or perceived as such (Madden and McQuinn 2014). The third level represents identity conflict and involves beliefs, values or social-psychological needs of the participants. Parties to the conflict may make assumptions of the other participants based on their perceived group membership, and may assign blame to these participants for past unresolved conflict based on these perceived groupings. Furthermore affected parties may begin to identify themselves and/or their group by their position within the relevant conflict (Lederach, 1997 in Madden and McQuinn, 2014). In the context of kangaroo management, these groupings may be institutional (e.g. government department or scientific institutes), regional (e.g. rural vs. urban dwellers), demographic (e.g. age, sex, employment type, socioeconomic) or philosophical (utilitarian or protectionist value of wildlife). The Levels of Conflict model may assist in understanding complexity in stakeholder contribution to, and perception of, kangaroos and their management.

Perceived versus actual impacts

Kangaroos are primarily subject to management, because stakeholders perceive their impact to be costly and/or their management to be beneficial either economically, ecologically, socially, or physically. However, the accuracy of these perceptions is yet to be challenged empirically. We propose that an experimental approach could be undertaken to assess how measurable impacts/benefits of kangaroo presence or abundance correlate with perceived impacts/benefits. Where gaps exist between perception and reality, the influence of internal and external circumstances can then be assessed.

Addressing stakeholder conflict in kangaroo management

Our third recommendation for future directions is an examination of stakeholder conflict. Where an accurate assessment of kangaroo impacts has been identified and population management has been determined to be beneficial, conflict may occur between different stakeholders, both within the kangaroo management industry, as well as those external to the direct conflict but holding firm views on the necessity of management. Effective conservation conflict management is defined by good outcomes for stakeholders, effective stakeholder consultation, and effective action for both the evident issue and contributing underlying issues.

Stakeholder conflict mitigation could be facilitated using a relevant model such as the Conflict Intervention Triangle (adapted from Moore, 1986 and Walker and Daniels, 1997 by Madden and McQuinn, 2014), which incorporates three dimensions of conflict: substance, process, and relationships. The substance dimension corresponds directly to the dispute level in the Levels of Conflict model and is based on the evident or superficial conflict. The process dimension relates to the decision-making process with the quality of stakeholder consultation (respect, discussion, equity, communication, trust and authority) being a critically influential component (Anderson and Olson, 2003; Leong et al., 2009; Lovallo and Sibony, 2010). The relationship dimension relates to the quality of the relationships amongst stakeholders and can include both personal and group-level conflict (Madden and McQuinn, 2014). The Conflict Intervention Triangle does not offer prescribed advice for mitigating conservation conflict but a strategy for identifying potential areas where conservation strategies can be improved.

In summary, future directions in kangaroo management should be focused on the social, demographic, and perceptual influences of human-kangaroo conflict. To date, these aspects have been largely ignored and potentially underestimated, and their quantification will add significantly to the conservation literature and to the design of effective management strategies that address human-kangaroo conflict at all levels in which it exists.

Conclusions

The eastern grey kangaroo is a large, common, native iconic species of Australia. Its specialised behaviours and reproductive system have evolved as adaptations to the Australian environment, allowing the species to survive and flourish despite the wide climatic and seasonal variations across its range. In both rural and urban regions, kangaroo management may be required for a variety of reasons, including conflict with primary producers, conservation of native areas, threats to human health or livelihood, and animal welfare. Harvesting of kangaroos and most management strategies for damage mitigation are undertaken by shooting. While several other options exist for deterring or removing kangaroos, these strategies are still in the early stages of development or lack practical implementation strategies. Support for kangaroo management and harvesting varies depending on the justification for management and is affected by socio-political influences. Whilst several studies have assessed attitudes towards kangaroo management across demographics, a detailed study of the underlying construct of these attitudes is needed if effective methods for the management of kangaroos are to be identified. Future research priorities should focus on the human dimensions of kangaroo management, with specific investigation on socio-political influences, and whether perceptions of kangaroo impact by stakeholders is a reliable and sensitive indicator of actual impacts.

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