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Review Article

Feral Deer in the Suburbs: An Emerging Issue for Australia?

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Deer are not endemic to Australia, but were introduced for game and aesthetics between the early 18th and 20th centuries. Until recent decades, most deer descended from these introductions. Before the 1970s when deer numbers and distribution expanded dramatically, farming was a modest enterprise. With the collapse of farming in the 1990s, large numbers of deer were deliberately released and translocated. Feral numbers and herds have subsequently expanded, and are increasingly encroaching on urban areas. As a new issue in Australia, views toward feral deer are polarized and span "welcome guest" to "major pest." The emerging urban deer issues need greater acknowledgment and strategic management. This will require more emphasis on raising awareness, engagement with stakeholders, and development of legislative instruments to provide better strategic management of urban deer. This article reviews the potential increase in urban deer in Australia, considers the associated issues, and provides recommendations for management.

Keywords urban deer, community attitudes, deer–vehicle collision, feral management, emerging urban pest

Introduction

Australia is the only inhabited continent without endemic deer. This species was introduced in the 18th century (Hall & Gill, 2005) by acclimatization societies, and releases continued into the 20th century for game and aesthetics (Frith, 1973). Six species became established as feral populations: chital (*Axis axis*), hog (*Axis porcinus*), red (*Cervus elaphus*), rusa (*Cervus timoriensis*), sambar (*Rusa unicolor*), and fallow (*Dama dama*) (Bentley, 1978). These species have transitioned from small isolated herds of 500 to more than 10,000 individuals (Moriarty, 2004a, 2004b).

Deer have also been farmed in Australia since 1803. Throughout most of the intervening period, they have supported a modest-sized venison industry. However, deer farming

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became popular in the 1970s and 1980s with an associated dramatic expansion of the industry, and captive numbers (Moriarty, 2004b). Throughout the history of deer farming, animals have escaped, but with a slump in demand during the 1990s coinciding with severe drought, many were released and escapes continue. These escapees join existing feral herds or form the basis of new ones (Low, 1999). Moriarty (2004b) estimated that farm releases resulted in 77 new feral herds of up to 500 deer. Although some farmed species (e.g., chital, red, rusa, sambar, fallow) have well-established feral populations, others including white-tailed deer (*Odocoileus virginianus*), sika (*Cervus nippon*), and wapiti/elk (*Cervus canadensis*) could become established (Moriarty, 2004b), thus increasing feral deer and herd numbers.

Anecdotal evidence suggests that translocations of deer occurred historically, although until the 1980s this practice was limited by a lack of available stock (Harrison & Slee, 1995). In the 1990s, however, translocations of stock from defunct farms increased dramatically and the practice became widespread (Low, 1999). In 2004, Moriarty (2004b) identified 128 deer herds of upward of 500 animals that originated from these translocations.

In Australia, deer have historically represented a minor component of the fauna, but feral populations are now widespread. The alarming increase in numbers during recent decades (Moriarty, 2004a) has paralleled an increase in the human population in urban areas (Raik, Lauber, Decker, & Brown, 2005). By 2011, for example, approximately 90% of Australians lived in urban areas, with a predicted continual rise in population (ABS, 2013). With the continuance of this trajectory and the associated expansion of urban areas, road density, and traffic volume (Ramp & Roger, 2008), inevitably the associated issues with managing urban deer into the future will increase (Moriarty, 2004a).

As observed elsewhere (e.g., New Zealand; McShea, Underwood, & Rappole, 1997), feral deer can lead to conflict among stakeholders (Moriarty, 2004b). Compared to their management in rural areas, however, there is limited information on deer management in urban areas (defined to include peri-urban and semi-rural matrices) of Australia (McLeod, 2009). This article reviews the current status and potential increased habitation of urban deer in Australia, considers the associated issues, and makes recommendations for management of urban deer.

Feral Urban Deer Dilemma

Feral deer management in Australia has resulted in an intense debate among stakeholders, including landowners, recreational hunters, animal welfare groups, conservation organizations, and health authorities. As already apparent in Royal National Park (between Southern Sydney and the Wollongong Region), extremes in conflict occur between those who view deer as game and an aesthetic addition to the landscape versus those who perceive deer as pests (Hall & Gill, 2005). The current legislative approach to deer management in Australia is, however, predominantly geared toward game hunting, with limited consideration of other values and impacts (Forsyth, 2009).

Forsyth (2009) concluded that, in Australia, even research on the management of deer as game was scant, and available data largely consisted on an *ad hoc* collection of studies based on researcher interest. The literature on deer–human interaction in urban areas is also limited. Recent publications on Australian urban wildlife (e.g., Lunney & Burgin, 2004; Lunney, Munn, & Meikle, 2008) or pests (Lunney, Eby, Hutchings, & Burgin, 2007) included a single paper focusing on deer (Moriarty, 2004a), and one other paper on urban deer (Ramp, Wilson, & Croft, 2006). This paucity of research on deer suggests that the associated issues have not become significant. However, given parallel increases in deer

numbers and range extension, coupled with increases in human populations, there will be more conflict. To underpin the future management of urban deer, there is a need to investigate the current level of awareness within communities, deer–vehicle collisions, damage to the urban landscape and associated damage to property (Kilpatrick & Walter, 1997; Stout, Knuth, & Curtis, 1997), transmission of disease (Kilpatrick & Walter, 1997; Stout et al., 1997) such as Lyme disease (Hayes & Piesman, 2003), and social distress (e.g., vocalizing, fighting at night, barking dogs; Connelly, Decker, & Wear, 1987; Moriarty, 2004a).

Although not yet identified as a significant issue in many urban areas of Australia, there is no dispute that numbers of deer and herds are increasing. Of the 218 feral herds reported by Moriarty (2004b), 14 with an estimated 170,000 deer originated from early releases more than 100 years ago. The other 203 extant herds had an average herd age of less than one decade. At least some of these herds will continue increasing in size and new ones will develop due to natural processes and deliberate translocations. Given that many recent herds have established in the more populated areas (Victoria, New South Wales [NSW], Queensland), deer will inevitably continue encroaching into urban areas, particularly under adverse conditions (e.g., drought, fire, overgrazing; Moriarty, 2004a). One aspect of managing the increasing deer numbers that are already encroaching on urban areas, or have the potential to do so, is for governments to engage with recreational hunters (Finch, Murray, Hoy, & Baxter, 2014).

Deer Hunting in Australia

The Sporting Shooters' Association of Australia (SSAA) records that they have 150,000 members of which 80% hunt regularly (SSAA, 2013), although Finch et al. (2014) estimated that there were between 200,000 and 300,000 recreational hunters in Australia in 2011–2012. In late 2004, 4,000 applications had been lodged in NSW for recreational deer hunting licenses (Tsang, 2005), and by 2012 there were 20,000 "conservation hunters" in the State (Melham, undated). In Queensland, the two deer associations (Australian Deer Association, Research into Deer Genetics and Environment) had approximately 250 members each with some being members of both societies. In 2005, there were 40,000 Queensland members of SSAA, and an estimated 90% claimed some interest in recreational deer hunting (Jesser, 2005). These numbers have, however, subsequently remained static (SSAA, 2014).

In the Victorian 2011–2012 hunting season, an estimated 41,600 deer were shot by licensed hunters (Gray, 2012) and, subsequently (2012–2013), the estimated number culled was over 50,000, an increase of more than 20% above the previous year (Gray, 2013). It was also estimated in 2012 that the State's feral deer population was between 200,000 and 350,000 (Gray, 2012). More recently, Gray (2013) suggested that these numbers could be "hundreds of thousands." This 2012 lower estimate of feral deer is equivalent to Moriarty's (2004b) lower estimate Australia-wide. There has, therefore, been an explosive growth in deer numbers at least in Victoria, or at least one of the estimates was inaccurate.

Despite the claim that recreational hunters of Australia serve to control feral deer (Jesser, 2005), deer numbers are increasing, at least near major urban centers such as Brisbane (McCarthy, 2013), Melbourne (Gray, 2012, 2013), and Sydney (Moriarty, 2004a, 2004b). The spread of this species is undoubtedly exacerbated by translocation for recreational hunting (Moriarty, 2004b) and thus, presumably, more regional urban centers will become affected.

Community Attitudes Toward Deer

Most Australians live within urban areas (ABS, 2013) and typically have limited contact with wildlife or rural industry. Despite this lack of direct exposure, many residents will develop an opinion on deer management and these often uninformed views influence management. Within this context, Jesser (2005) suggested that it was essential that information be available to assist individuals in developing a balanced view of relationships among rural stakeholders (e.g., primary producers, deer hunters), deer, and the environment. There is, however, only one published paper (Finch & Baxter, 2007) on non-urban stakeholder attitudes toward feral deer in Australia, and none on urban stakeholders' views.

Finch and Baxter (2007) surveyed Queensland primary producers in areas where feral deer were established and found that, although approximately 50% of respondents were positive about deer on their land, 64% considered them a game species and 39% viewed them as a feral pest. As with wolves in the United States, management will be problematic because such conflicting attitudes are often evoked without reasonable or logical bases. Scarce (1998) suggested that the scale of such attitudes was diametrically extreme on both sides and they may be established early in life. For example, Gray (1993) found children's attitudes to mammals that were furry, mobile, and/or those with humanoid features, were popular. Other vertebrates that are readily anthropomorphized (e.g., penguins, pandas) or the subjects of popular stories could also evoke positive attitudes (Woods, 2000). Positive attitudes toward deer have been attributed to the "Bambi syndrome" (Hastings, 1996; Nietschmann, 1977). In contrast to the development of positive attitudes toward Australia's feral deer, there is also a negative view of them as pests and/or a hunting resource (Hall & Gill, 2005). These polarized views emerge repeatedly in deer management. Some people have an ethical reluctance to see deer killed, whereas others focus on risks that deer may pose to human health and safety (Stout et al., 1997), and there is a strong recreational hunting lobby. One attitude that has not been widely tested in urban Australia, however, is attitudes toward the most widespread and obvious outcome of increasing encroachment of deer into urban areas—deer–vehicle collisions.

Deer–Vehicle Collisions

A major issue associated with deer encroachment into urban areas is that they can be traffic hazards (Brockie & Sadleir, 2009). In 2004 in Michigan (USA), for example, one deer–vehicle collision occurred approximately every eight minutes (Havlick, 2004). Outcomes include vehicle damage and injury or death to humans and/or the deer involved (Bissonette, Kassar, & Cook, 2008; Hobday & Minstrell, 2008). In Australia, data on the number of deer–vehicle collisions are unavailable. Accidents are not officially recorded; instead deer are recorded as "animal," together with other taxa that are not required to be explicitly named (Ng, Nielsen, & St Clair, 2008; Ramp, Caldwell, Edwards, Warton, & Croft, 2005). In addition, reporting procedures vary among jurisdictions and underreporting of animal-related crashes also occurs. Within these caveats, and generally using data collected between 2001 and 2005, there were probably substantially more than 11,600 wildlife–vehicle collisions in Australia (Rowden, Steinhardt, & Sheehan, 2008).

To obtain an indication of the taxa involved in these collisions, roadkill data, either taxon-specific (e.g., kangaroo/wallaby [*Macropus* spp.; Lee, Klöcker, Croft, & Ramp, 2004]; easternquoll [*Dasyurus viverrinus*] and Tasmanian devil [*Sarcophilus harrisii;* Jones, 2000]; eastern barred bandicoot [*Perameles gunnii*; Mallick, Hocking, & Driessen, 1998]) or generic (e.g., Burgin & Brainwood, 2008; Taylor & Goldingay, 2004) counts

of roadkill animals have been accessed. Typically, the common victims are native species (Hobday & Minstrell, 2008; Rowden et al., 2008), although taxa vary dependent on characteristics such as region (Burgin & Brainwood, 2008), season (Hobday & Minstrell, 2008), and/or climatic conditions (e.g., drought; Coulson, 1989; Lee et al., 2004).

Despite a lack of quantitative information on deer–vehicle collisions in Australia, such collisions are of concern because of their magnitude and the size of deer (Geist, 1999). Increased human population, urban sprawl and associated infrastructure, coupled with increased deer numbers and range extension, will increase the risk of deer–vehicle collisions in urban areas. The greatest risk will be where there are high densities of resident deer in natural areas that are close to major urban populations. Currently, such areas in Australia occur in association with Royal National Park (Moriarty, 2004a), in suburban Brisbane (McCarthy, 2013), and in Melbourne adjacent to the Dandenong and Yarra ranges, where the number of feral deer has "surged" in recent years (Gray, 2012). In urban areas associated with Royal National Park, for example, there are increasing numbers of deer crossing roads to forage, particularly in peak hours of vehicle traffic. This has resulted in "substantial numbers of collisions with deer that cause[d] irreparable vehicle damage and serious injury (or death) to the occupants of the vehicle" (Moriarty, 2004a, p. 182).

Ramp and Roger (2008) used the N.S.W. Traffic Accident Database System to investigate animal–vehicle collisions between 1996 and 2005. Of over 5,000 entries, including 2,100 kangaroos, 1,991 stock (cattle, horses), and 177 "other large animal[s]," no deer were recorded. However, given that large animals (kangaroos, horses, cattle, sheep, wombats, emus) were listed separately, the categories "straying stock" and "other large animal[s]" that had approximately 35% of the total number of "objects first impacted in collisions," probably included deer. Even assuming that all unnamed animals were deer, the current level of deer–vehicle collisions in NSW would be lower than for other large species. Based on calculations for a peri-urban reserve (Ramp & Ben-Ami, 2006) and a rural landscape (Klöcker, Croft, & Ramp, 2006), annual roadkill of kangaroos approximated 10% of the local population (Ramp et al., 2006). A cursory review of the estimated deer herd sizes in Moriarty (2004a) indicated that deer fatalities were substantially below 10% of the State's feral deer population. However, underreporting of accidents occurs in Australia (Rowden et al., 2008) and is likely exacerbated for deer because of the lack of a reporting requirement (Jesser, 2005). Even considering these issues, however, deer fatalities as a percentage of the local population are apparently low. Hobday and Minstrell (2008) undertook an extensive road network analysis that overlapped much of the Tasmanian deer range (compare maps from Hobday & Minstrell, 2008, and Moriarty, 2004a) and recorded approximately 6,000 roadkills, none of which were deer.

The only known Australian study that recorded deer roadkills was undertaken in the non-breeding season along a 22 km (approximately 14 miles) stretch of road in Royal National Park. Of the roadkilled mammals, 11% ($n = 36$) were deer. Other roadkill mammals were native species and all relatively small compared to an adult deer. Although deer–vehicle collisions were relatively low, the impact would be greater than most vehicle–animal collisions and, presumably, the deer would be less likely to be killed outright (Ramp et al., 2006).

In common with rapidly increasing numbers of Australian feral deer (Moriarty, 2004b), white-tailed deer in the United States have become overabundant in many urban areas (Cromwell, Warren, & Henderson, 1999), and deer–vehicle collisions are a nationwide problem (Nielsen, Anderson, & Grund, 2003). In 1980, for example, 200,000 deer were killed on U.S. roadways (Danielson & Hubbard, 1998), broadly equivalent to the total number of feral deer estimated for Australia (Moriarty, 2004b). However, annual deaths

on U.S. roads increased significantly by the 1990s (Romin & Bissonette, 1996) and by 1997, an estimated 1.5 million deer–vehicle collisions occurred annually (Mastro, Conover, & Frey, 2008). Consequently, factors influencing deer–vehicle collisions have been widely investigated in the United States, but not in Australia. Understanding issues with urban deer in Australia, therefore, necessarily relies heavily on others' experiences.

In urban Minneapolis (USA), the best predictor of deer–vehicle collisions was the number of buildings and public lands (Nielsen et al., 2003). In Illinois (USA), landscape vegetation was also a factor; the probability of roadkill was reduced with distance from forest cover. Collisions were adjacent to gullies, riparian travel corridors that crossed roads, and public recreation lands within 0.5 miles (0.8 km; i.e., along migration routes; Finder, Roseberry, & Woolf, 1999). These findings are equivalent to the Australian situation where abundant forage, adjacent protective cover, landscape heterogeneity, water sources, and forest and/or agricultural fields increase the risk of deer–vehicle collisions (Jesser, 2005). There is also a higher probability of accidents in higher vehicle speed zones. Collisions also tend to occur in areas of low road densities and poor in-line visibility. Speed limit reductions may, therefore, be effective during peak seasons, particularly in areas of high road densities and where non-forest vegetation occurs adjacent to roadways (Ng et al., 2008).

Pokorny (2006) found that deer–vehicle collisions varied with season and bimodally with most collisions at dawn and dusk. In addition to temporal variation due to season/diurnal patterns in behavior, traffic volume, and driver visibility, Ramp et al. (2006) also suggested that proximity to human habitation, day of the week, driver alertness, and road characteristics also influenced collisions in Australia. Also in Australia, Burgin and Brainwood (2008) found higher wildlife road fatalities in rural (compared to urban) areas and on roads with medium traffic volumes (compared to local traffic roads or major highways). Others (e.g., Klöcker et al., 2006; Ramp et al., 2005) also observed differences in road type influenced patterns of mortality, numbers, and species. Trends in these studies were broadly equivalent and the differences between urban and rural areas were assumed to be due to the size of local animal populations (Burgin & Brainwood, 2008). For example, possums (brushtail *Trichosurus vulpecula*) are habituated to urban environments (Hill, Carbery, & Deane, 2007), whereas rabbits (*Oryctolagus cuniculus*) and foxes (*Vulpes vulpes*; Marks & Bloomfield, 1999) are common in both rural and urban areas. Some species (e.g., foxes) may have higher densities within urban areas (White, Gubiani, Smallman, Snell, & Morton, 2006) and the data of Burgin and Brainwood (2008) reflected such differences.

More roadkills also occur where there is a barrier on one side of the road (rather than none or both), on stretches with slashed edges, and where traffic volume is medium to low (Burgin & Brainwood, 2008). In Australia, many roadside fatalities are nocturnal herbivores, most active at dusk and dawn when most difficult to detect and avoid. Together with kangaroos (Klöcker et al., 2006; Lee et al., 2004), deer exhibit this nocturnal behavior (Moriarty, 2004a). Native herbivores, and presumably deer, move toward forest habitat in response to perceived danger, which may lead them into oncoming traffic and thus collision (Jaarsma, van Langevelde, & Botma, 2006). The reasons why deer are attracted to roadside verges may also be part of the attraction of urban areas.

Urban Environmental Damage

There are limited data on deer impacts in urban open spaces (Putman & Moore, 1998) despite evidence that they are increasingly encroaching into urban areas in many countries such as the United Kingdom (Ward, 2005), United States (Cornicelli, Woolf, & Roseberry,

1996; Rondeau & Conrad, 2003), and Australia (Doherty, 2004; Moriarty, 2004a, 2004b). In Illinois (USA), for example, white-tailed deer are resident herds in some urban areas (Cornicelli et al., 1996). This also occurs in Brisbane, Australia where "thousands of feral deer . . . [have] invaded . . . Brisbane suburbs" (McCarthy, 2013, p. 15).

In urban areas, tolerance of deer decreases both with increasing numbers and the extent of their establishment (Loker, Decker, & Schwager, 1999). Although Sayre, Decker, and Good (1992) reported that damage to vegetation by deer was widespread in areas of the Northwest United States, assessment of impacts is scant. Where such damage has been considered, it is typically combined with the broader economic impact of urban deer. Most estimates would, therefore, be attributable to deer–vehicle collisions. Putman and Moore (1998) suggested that the environmental damage in urban areas was not economically significant, although they acknowledged that this species may be a nuisance because of their penchant for garden plants. Sayre et al. (1992) surveyed homeowners in New York (USA) and found that the median loss to householders in the southern area of the state was $200 annually and in the western areas it was $90 annually. Extrapolated to all homeowners within their study areas, losses could be millions of dollars. Study outcomes were comparable to previous research in the same state (Connelly et al., 1987), but with increased deer numbers since that time in many U.S. urban areas (Nielsen et al., 2003), damage would be greater than Sayre et al. (1992) calculated.

Australian feral deer tend to be generalist grazers (Hart, 2009). In Royal National Park, for example, rusa deer consumed approximately 90% of native plant species (Keith & Pellow, 2005), and rumen contents from the area indicated that 155 native species were consumed (Moriarty, 2009). Foraging damage includes defoliation, shoot removal, stem breakage, loss of reproductive material, bark stripping, and plant mortality. Although the severity of grazing varies spatially, localized soil erosion can be substantial in high use areas. Removal of deer resulted in some recovery, although full recovery would take several seasons, whereas reduced seed production and seedling establishment could impact plant populations long term. The damage to specific plant taxa, however, may vary with deer species. Rusa deer, for example, avoid ferns and sedges (Keith & Pellow, 2005), but other species (e.g., fellow deer) have a preference for this vegetation (Hart, 2009). Garden plants are also targeted. A caravan park in Royal National Park, for example, lost 90% of 1,000 plants to deer grazing (Doherty, 2004). Most other comments on the impact of deer in Australian urban areas have been generic, such as "deer are an increasing nuisance in urban areas, damaging gardens . . ." (Bilney, 2013, p. 1), and "grazing deer may damage parks, residential gardens and fences in outer urban areas . . ." (DAFFB, 2013, p. 2).

Transmission of Disease

In addition to environmental impacts, deer potentially act as vectors in disease transmission (Biosecurity SA, 2013; Vaske, Shelby, & Needham, 2009) including tuberculosis (Daszak, Cunningham, & Hyatt, 2000), epizootic haemorrhagic disease virus (Forster, Breckon, Luedke, & Jones, 1977), and Lyme disease (Hayes & Piesman, 2003). Most of these diseases require close contact with an infected animal for transmission such as respiratory bacterial diseases that are usually transmitted through sneezing and coughing (DeNicola, VerCauteren, Curtis, & Hygnstrom, 2000). Others, such as Lyme disease, are transmitted via an intermediate host (Hayes & Piesman, 2003).

Most diseases in deer, even if present in Australian herds, are unlikely to be transmitted to humans (e.g., tuberculosis, respiratory bacterial diseases) because they need

close association for successful transmission. In contrast, because Lyme disease may be transmitted by ticks, opportunities for transmission between deer and humans may occur in Australia where the disease is present (Schmid, 1985), although the vector remains unconfirmed (Russell et al., 1994).

An alternative form of disease transmission between deer and humans is via the ingestion of parasites, such as *Echinococcus granulosus*, a tapeworm that causes hydatids. This may occur as a secondary infection due to domestic animals ingesting raw deer meat carrying the parasite (Jenkins, 2006). For example, a survey of farm dogs in Southeast Australia by Jenkins, McKinlay, Duolong, Bradshaw, and Craig (2006) revealed that up to 29% of farm dogs carried *E. granulosous* coproantigens, and many farmers "occasionally" feed their dogs raw meat from wildlife. Some animals may also supplement their diet by scavenging. Since hydatids results from the ingestion of the parasite's eggs, humans may be infected by dogs (Jenkins, 2006). They could also obtain the parasites directly from warm blooded species, such as deer, by consuming inadequately cooked meat or by handling infected animal tissue (Gauss et al., 2006).

If introduced, several exotic livestock diseases of deer (e.g., foot-and-mouth, rinderpest, vesicular stomatitis, rabies, blue tongue) may cause major issues for Australian agriculture (DAFF, 2012). Of particular concern is foot-and-mouth, a disease that could have flow-on effects to other industries, even tourism (SCPI, 2012). Deer and other livestock are among the natural hosts of this disease (DAFF, 2012). No outbreaks of foot-and-mouth have been reported in Australia and since 1872 (SCPI, 2012). Australia's closest neighbors are also free of the disease (WHO, 2013). Major outbreaks in the United Kingdom (Knowles, Samuel, Kitching, & Donaldson, 2001), and more recently in North Korea (Valarcher et al., 2009) have, however, raised concern of the disease entering Australia (SCPI, 2012) because even a small-scale outbreak would have substantial economic impacts (Buetre et al., 2013). An outbreak of foot-and-mouth-disease, for example, would result in a major economic downturn to Australian livestock industries in the process of responding to the disease because of associated restrictions on ungulate movement, export market closure, and indirect effects on businesses that directly and indirectly rely on revenue from livestock (SCPI, 2012). In 2009–2010, it was estimated that even a small-scale outbreak could cost between AUD$7.1 (US$6.6) billion for a three-month response to AUD$16 (US$15.07) billion for a 12-month outbreak. However, the direct impact on urban areas would likely be minimal compared to rural areas, although the indirect impacts would be detrimental to the entire economy (SCPI, 2012). The economic fallout would result in social distress countrywide.

Social Distress

Deer encroachment will also cause other, more localised, social distresses in urban areas. Deer tend to be nocturnal, moving to forage in the late afternoon and returning in the early morning. Social distress due to human–deer interaction would thus most likely occur at night. The most widespread cause of distress associated with deer would likely be deer–vehicle collisions. Other potentially deadly encounters include trampling by a frightened deer or being shot by a hunter's stray bullet (Moriarty, 2004a). Deer are also potentially dangerous during the rut when focused on mating (Iverson & Iverson, 1999), particularly if residents attempt to get close. Another interference with deer that may prove detrimental is to attempt to assist a deer caught, for example, in a wire fence. Such encounters are likely to be rare, although Webb (2013) reported that a teenager was charged by a deer on an outer Melbourne suburban street.

Although not deadly to humans, noise may also cause social stress. Arguably, the most stressful would be vocalizations of rutting deer used for deterring rival males and attracting females (Charlton, Reby, & McComb, 2007). Barking dogs, disturbed by deer, may also cause distress (Moriarty, 2004a). Likewise, the sight of wounded or dead deer could be upsetting (Jesser, 2005). With the increase in deer numbers within urban areas, such issues would be exacerbated and add to the challenges of deer management.

Recommendations and Conclusions

Warren (1997) predicted that the overabundance of urban deer in the United States would become a major challenge for wildlife professionals. He further proposed that management would become more complicated with increased human populations and concomitant urban development, together with societal value changes and diversity of those values. Australia is on the same trajectory; both deer and urban human populations are expanding their footprint.

For economic, environmental, and social reasons, further encroachment of deer into urban areas requires increased emphasis on the strategic development of management regimes. However, the current lack of awareness of issues and polarized views of stakeholders differing in their cognitions (e.g., preferences, attitudes, motivations) challenge wildlife management. Efforts to address the associated complex and controversial issues will continue to be fraught with difficulty (Decker & Gavin, 1987). In addition, there cannot be a generic approach to management in all situations or for all deer species. White-tailed deer, for example, may be sedentary and removal of small, localized groups does not result in recolonization from adjacent herds (McNulty, Porter, Mathews, & Hill, 1997). Not all species, however, are sedentary and urban areas are also not preferred habitat of deer due to stresses imposed by cars, people, lights, and dogs. Deer move into these areas because their habitat has become suboptimal. Where deer are overabundant, for example, they may be attracted by the more palatable vegetation of urban gardens and reserves, particularly during winter (WCC, 2013). Subordinate males may also move to new territory, including urban areas, to escape dominant males (WCC, 2013). In Victoria, for example, extensive bushfires since 1997 have changed the landscape to benefit grazing deer and, subsequently, an increase in deer numbers and associated movements into urban areas have occurred (Gray, 2012).

Deer management issues that need further attention in Australia include legislation, policy, population monitoring, compliance and enforcement, and education and awareness. This requires an integrated approach encompassing the source of animals and their presence in urban areas, with the outcome resulting in policy and legislation appropriate to the current and predicted increase in deer numbers. Wildlife management in urban areas has, however, been widely perceived as difficult. Loker et al. (1999) reported that this was due to vocal resistance of some residents and the exponential heightening of concern that occurs with the increased severity of the problem. In addition, the level of community resistance increases with technique involved in deer management (e.g., nonlethal non-invasive, nonlethal invasive, lethal). Management, therefore, requires ingenuity and experimentation with approaches in the context of conflicting social expectations (Decker & Chase, 1997).

In Australia, arguably the strongest voices in deer management are the shooting lobby and animal welfare advocates. Within this context, urban deer management requires community education, management of the source of urban deer, and addressing deer within the confines of urban areas including roadways. Currently, the major debate over deer management in Australia, however, is focused on recreational shooting (e.g., translocation of

deer to form new herds for game hunting; Moriarty, 2004b). Recreational hunting, however, is not currently a successful management tool for feral deer. For example, despite relaxed rules for deer hunting in Victoria in 2012 (Matherson, 2012) and claims that a "massive number" (50,112) of deer were harvested by licensed shooters in 2012–2103 (Gray 2013), the harvest probably did not even maintain feral numbers. This is because, based on the estimate of 200,000–350,000 deer in Victoria (Gray, 2012), the legal harvest of deer was between 14–25% of the State's wild deer in 2012–2013. Data are scant on the rate of increase in deer herds in Australia, but after bushfires in Royal National Park (1994) there were an estimated 125 rusa deer remaining and by 2002 their numbers were estimated at 2,500 (Cox, 2002), an average annual increase of 12.5%. Between 2002 and 2007, 900 deer were harvested (Galvin, 2007), an average of 7% annually, and the numbers and range of deer continues expanding (WCC, 2013). Indications are, therefore, that the current level of legal hunting is not reducing deer numbers and thus the use of recreational hunting to manage deer requires urgent review to determine its costs and benefits.

A first step in extending deer management to all stakeholders may be the provision of stronger penalties for the deliberate release or translocation of deer. If combined with rewards that result in conviction of offenders, this may encourage vigilance within the broader community and a more successful conviction rate. A second community-wide initiative is for deer–vehicle collisions to be formally recorded and not, as Rowden et al. (2008) pointed out, under the vague term "animal." This would allow for better determination of problem sites for remedial attention. Third, actions could also include the introduction of more widespread and informative signs alerting drivers to the presence of deer in the vicinity, and these should be placed in locations where deer–vehicle collisions are likely. Although there are limited signs alerting drivers to the potential presence of deer in urban areas, these typically merely present a silhouette of a deer. Nocturnal speed restrictions should also be introduced similar to those for koalas in Southern Brisbane. In addition, information noticeboards could enhance awareness of local deer issues, and these should be more widely placed in prominent positions (e.g., verge of roadside parks, tourist information centers, school entrances). Fact sheets should also be more readily available and informative. In addition, information on government (local, state) websites and other outlets (e.g., libraries, schools, notice boards) should be freely available as eye-catching fliers. These materials should include information on issues such as the status of deer locally and how to respond when deer are encountered, where and how to report sightings, and tips on coexisting with deer in urban areas.

Another area of deer management requiring additional attention involves roads. Consideration of features to minimize deer–vehicle collisions should be incorporated into designs when new roads are planned or existing roads are upgraded. Although fencing is often the most effective deterrent for deer (Falk, Graves, & Bellis, 1978), even appropriate fencing in good condition does not exclude deer. On the Trans-Canada highway near Banff National Park in Canada, for example, ungulate–vehicle collisions were reduced by 80% with mitigation fencing (Clevenger, Chruszez, & Gunson, 2001). Fence breaches are probably worst in drought when roadside vegetation is more plentiful on road verges than elsewhere (Bellis & Graves, 1978). Burgin and Brainwood (2008) found that most roadkills occurred where there was a barrier on one side of the road rather than where there were no barriers or they occurred on both sides of the road. Although not tested, densely planted roadside vegetation, preferably unpalatable to deer, could act as an alternative barrier to deter deer along roadways and elsewhere in urban areas. This strategy could be achieved through community action. In Australia there are in excess of 4,000 Landcare groups and "many thousands" of volunteers, together with large numbers of additional "care"

groups working toward the slogan "everyone, everywhere, landcare" (Landcare Australia, undated). These groups have planted native vegetation throughout extensive areas of public lands, including along highway verges across much of the country. In some areas such as a section of the Hume Highway south of Sydney, *Acacia* shrubs (wattles) have been planted that are probably sufficiently dense, and in a swath broad enough to deter deer from the motorway. Since the Landcare mantra is to support natural resource management, these activities would fall within the purview of this Australia-wide network of volunteers. In new urban developments, particularly at the interface of urban and natural areas, planting of vegetation barriers against deer may minimize encroachment of feral deer into the urban area. Within established urban areas, fencing and/or such plantings could be used strategically along roadside verges and around wetlands and parks.

Another technique to reduce attraction of deer to roadways is to cease slashing roadside verges wherever practical given that roadkills are most common in areas where roadside vegetation is slashed. When slashed, herbivores browse on regrowth and, in doing so, increase the chance of becoming victim of vehicle collisions (Burgin & Brainwood, 2008). Other techniques such as underpasses and drift fences (Glista, DeVault, & DeWoody, 2009) and right-of-way clearings have been tested and/or used for white-tailed deer in the United States, although their efficacy has seldom been demonstrated (Falk et al., 1978). These types of management techniques should, however, be investigated for Australia.

Frightening devices based on visual, acoustic, or odour are available commercially. Most of these have also not been appropriately evaluated (VerCauteren, Shivik, & Lavelle, 2005) although those that have been examined have generally proved ineffectual, even in the short term (Gilsdorf, Hygnstrom, & VerCauteren, 2003; VerCauteren et al., 2005). Even motion-activated frightening devices (e.g., combined acoustic and visual stimuli) have either proved ineffective or the deer response has diminished over time (Gilsdorf et al., 2003, 2004; VerCauteren et al., 2005). If such devices did deter deer, many would not likely be widely socially acceptable in urban areas. Within this context, and despite the apparent lack of efficacy of a range of frightening devices, a review of the literature would be appropriate to identify effective device(s) for use within Australia's urban areas. It may be that intermittent use of several different approaches could overcome the habituation of deer to any one device.

Finally, monitoring numbers of deer and their spread into urban areas is required to underpin priority management decisions. Taken together, these are just a few possible recommendations for managing urban and feral deer in Australia, but more research is needed to empirically examine the current status and impacts associated with increased habitation of urban deer in Australia.

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