Wallabies and Roads: Interactions and Management in an Urbanising Landscape

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Abstract

Understanding the impacts of roads on wildlife and the natural environment is of increasing importance, especially in the context of widespread urbanisation. Macropods (mostly kangaroos and wallabies) are a diverse and widespread taxon in Australia that has been significantly affected by the presence of roads in various ways. Although a moderate volume of research has been conducted on the interactions between macropod species and roads in Australia, this is a fraction of the research effort conducted on large mammals in Europe and North America. Research that encompasses a variety of aspects of interactions between roads and macropods (and wildlife in general) is needed to broaden our perspective on impacts and mitigation.

Patterns of wallaby road mortality were investigated in a per-urban area of South East Queensland. Wallaby road-kill rates varied greatly; between 0.044 and 0.883 road-kills km⁻¹ month⁻¹ at the road or road section scale. Four wallaby mortality hotspots and several other areas of high mortality density were identified from the kernel density spatial analysis. Percent of commercial vehicle traffic (positively correlated) and distance to water (negatively correlated) were important spatial variables for determining the patterns of red-necked wallaby road-kill. Cumulative rainfall over the previous four weeks and maximum wind gust speed (both negatively correlated) were important temporal variables in determining the patterns of red-necked wallaby road-kill. Too few swamp wallaby road-kills were observed to be analysed.
Wildlife warning signs are a common mitigation measure used to reduce the incidence of wildlife-vehicle collisions, yet there is little evidence of their effectiveness. A public opinion survey was conducted primarily to compare the likelihood of driver response to eight wildlife warning sign designs. There were a total of 134 participants in the survey and three sign designs were ranked highly by participants. Animal-activated and vehicle speed-activated signs (not graphically displayed) were also highly likely to produce a response from drivers. Much more research into optimising the design of wildlife warning signs is needed to maximise driver response and improve the effectiveness of a relatively inexpensive road impact mitigation measure.

Little is known of the behaviour of wildlife around roads, yet their behaviour can be a significant contributor to their susceptibility to road mortality. Red-necked wallaby behaviour during road-crossing events (N = 192 adults) and in response to vehicles (N = 166 adults) were investigated. Red-necked wallaby road-crossing behaviour varied greatly among individuals, yet was overall slightly more risky at the road with the highest traffic volume and speed limit. Here more wallabies paused (45%) more frequently (up to 9 times) during crossings and were more likely to emerge directly from the surrounding habitat onto the road without first stopping to assess the traffic condition. Wallabies were more likely to flee from approaching trucks (86% fled), as opposed to smaller vehicles (39% fled), and higher tolerance levels (lower response) to traffic was observed at the road with intermediate traffic volume. The tendency for wallabies to flee from approaching trucks may be a key contributor to their susceptibility to road
mortality, as the percent of commercial vehicle traffic was identified as a contributing factor to patterns of red-necked wallaby road mortality.

The activity budgets of wallabies (N = 186) were affected by the presence of roads. Foraging (mean allocation of time = 39.2-59.6%) and vigilance (mean allocation of time = 30.8-51.1%) were the dominant activities observed. Time allocated to foraging and grooming (mean allocation of time at roads = 2.3-3.0% cf. control = 4.7%) tended to be reduced near roads, with wallabies allocating more time to vigilance and locomotion (mean allocation of time at roads = 2.5-4.1% cf. control = 1.5%) than when they were further away from roads. Variance in time allocated to grooming also tended to be reduced at the road sites, although not significantly so. Vigilance rates were significantly higher near roads than away from roads, potentially increasing stress levels. Again, slightly higher tolerance levels were observed at the road with intermediate traffic volume.

This study contributes to the body of knowledge of the interactions between macropods and roads, particularly in peri-urban landscapes. The contribution of commercial vehicles to wallaby, and possibly other wildlife, road mortality may have significant implications for the management of road mortality in some areas and the construction of new roads that are primarily for the transportation of heavy vehicles. This relationship needs to be explored further, as well as the behavioural contribution to road mortality risk. More research needs to be conducted, especially regarding the impact of roads on macropod population dynamics and viability and optimising mitigation measures that are able to be implemented in a wide range of landscapes. As seen with other wildlife species, declines in road-impacted peri-urban populations can occur relatively quickly, and
thus should be regularly monitored and managed in order to be prevented or at least detected early.
Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

__________________________________

Amy Blacker
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Included in this thesis are published refereed research papers in Chapters 1 and 3 which are co-authored with my principle supervisor. My contribution to each co-authored paper is outlined at the front of the relevant chapter. The bibliographic details/status for these papers including all authors, are:

Chapter 1

Amy Bond ___________________________________________ Date

Supervisor: Darryl Jones ___________________________________________ Date

Chapter 3

Amy Bond ___________________________________________ Date

Supervisor: Darryl Jones ___________________________________________ Date
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Chapter 1

Background and general introduction

The contents of Chapter 1 are based on an article accepted for publication in a peer-reviewed scientific journal. Slight alterations in the text do exist that align more specifically to the areas of research in the remainder of this thesis. I was responsible for reviewing all literature reported and summarised in this article and for writing the body of the text. The co-author was my principle supervisor and was listed in recognition of this contribution and editing of the manuscript.

Chapter 1


____________________________________  _______________________
Amy Bond  Date

____________________________________  _______________________
Supervisor: Darryl Jones  Date
1. Background and general introduction

1.1. Introduction

Roads are now widely accepted as being a major source of environmental change. These changes can include habitat destruction and fragmentation, rerouting and pollution of waterways, erosion and pollution of soils, wildlife mortality, disturbance from sound and light, facilitation of the dispersal of invasive species and the severing of connectivity between previously continuous habitats (Forman et al. 2003). Some of these disturbances can penetrate hundreds of metres, or even over a kilometre, into the adjacent habitat (Forman and Deblinger 2000; Forman et al. 2003; Biglin and Dupigny-Giroux 2006; Beckmann and Hilty 2010).

The level of impact on wildlife associated with these disturbances varies greatly, ranging between little or negligible influence to dramatic and severely detrimental to resident populations. Some species cannot cope with the associated changes to their environment, and so avoid the road entirely, whereas other species can be attracted to the road by resources that may be limited in their habitat (e.g. water, high-quality food, salt - Lee 2006; Barrientos and Bolonio 2009; Grosman et al. 2009). Other species may attempt to cross roads to access favoured resources available in habitat on the other side (e.g. mates, water, quality food, unoccupied territories), thereby increasing the risk of traffic-related mortality (e.g. Gagnon et al. 2007). Terrestrial species that migrate, in particular, are faced with the task of safely crossing numerous roads in order to reach their seasonal breeding grounds (Forman and Deblinger 2000; Sullivan et al. 2004b; Dahle et al.)
Conversely, some non-migratory species can face this risk on an almost daily basis in areas of high road densities, where various resources are located on either side of roads or roads have divided animal home ranges (e.g. Klar et al. 2009; Jones et al. 2012).

A variety of measures have been employed to mitigate the impacts that roads have on wildlife (Forman et al. 2003). The most commonly implemented measures are wildlife warning signs (Forman et al. 2003; Glista et al. 2009; Huijser and McGowen 2010), which are aimed at modifying driver behaviour and, ultimately, reducing road-kill rates. Despite their prevalence and popularity, the effectiveness of such signs is questionable, with mitigation measures such as wildlife-exclusion fencing and road-crossing structures having much more discernible benefits (Huijser and McGowen 2010). Most mitigation measures are implemented to benefit a variety of species, although there is no “one-size-fits-all” approach; in some cases species-specific mitigation will be required (e.g. Mansergh and Scotts 1989).

With about 50 species living in Australia (Coulson and Eldridge 2010), macropods (Macropodidae) are present in most landscapes, whether arid or forested, rural or urban. The general public and tourists are familiar with some macropod species and regard them as iconic and valued wildlife (Tisdell et al. 2005, 2006). However, due to their wide-ranging distributions and high mobility, macropods are often especially vulnerable to the disturbances associated with roads (Ramp 2010). Further, because of their perceived ‘commonness’, macropods in general are not often considered as being of conservation concern (Coulson 2007).
Comparisons can be made between macropods and ungulates indicating the similarity of their ecological roles and relationship with road environments. Many species of both taxa are large-bodied animals that aggregate in open areas to graze (Pays et al. 2007a; Favreau et al. 2010), inhabit a variety of landscapes, can be attracted to roads by resources (Lee 2006; Grosman et al. 2011), can contribute to substantial human injury and vehicle damage in wildlife-vehicle collisions (Seiler 2005; Ramp and Roger 2008), and present similar challenges for widespread road mitigation (Putman 1997; Ramp 2010). Although macropods are not migratory, they often have large home ranges, and road crossings can be frequent, even in areas with low road densities (e.g. Lee 2006).

The perception that high road-kill rates equate to abundant populations remains widespread (see Forman et al. 2003), despite considerable evidence to the contrary (e.g. Coulson 1989; Jones 2000; Vijayakumar et al. 2001; Schwab and Zandbergen 2011). As well as causing severe injury or death to the animals involved, macropod-vehicle collisions, particularly those involving larger species, can also result in severe injury or death to humans and great damage to vehicles (e.g. Abu-Zidan et al. 2002; Ramp and Roger 2008). Some research has been conducted on the impacts of roads on macropods, particularly with regard to macropod-vehicle collisions (e.g. Coulson 1982; Osawa 1989; Buchanan 2005; Chambers et al. 2010; Lee et al. 2010) and current road mitigation measures (e.g. Magnus et al. 2004; Bond and Jones 2008; Hayes and Goldingay 2009), but many crucial aspects remain largely unstudied. This review aims to summarise the body of research conducted to date on the impacts of roads on macropods and mitigation measures used to ease these impacts. Recommendations on the
direction of future research will also be made in order to obtain a better understanding of the interactions between roads and macropod species, whether widely abundant or critically endangered.

First, however, some important terms in road ecology must be defined (see Forman et al. 2003 for further details). The road corridor consists of the road surface and roadsides where road construction and maintenance alter the land. The road verge is the area between the road and adjacent blocks of land that includes the road shoulder, ditches and areas altered by road maintenance. The road-effect zone is the area within which the road impacts on the surrounding environment, with its size being dependent upon the width and traffic volume of the road, the impacts being investigated and the species, taxa or ecological process of concern. Finally, the road barrier effect is when a road corridor forms a partial or complete barrier to water, plant and animal movement and dispersal, effectively separating previously continuous populations.

A web-based search resulted in a total of 60 scientific journal articles, reports and theses that included some study of the impact or interactions between macropods and the road environment (Table 1.1).
Table 1.1 Number of studies that investigate relationships between macropods and roads in Australia from 1973-2013 that were assessed in this review. The studies included were from published journal articles, edited books, unpublished project reports, government reports, theses and conference proceedings.

<table>
<thead>
<tr>
<th>Topic</th>
<th>No. of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadkill</td>
<td></td>
</tr>
<tr>
<td>Macropods only</td>
<td>12</td>
</tr>
<tr>
<td>Include macropods</td>
<td>17</td>
</tr>
<tr>
<td>Roadkill factors</td>
<td></td>
</tr>
<tr>
<td>Traffic volume</td>
<td>4</td>
</tr>
<tr>
<td>Local road attributes</td>
<td>5</td>
</tr>
<tr>
<td>Landscape attributes</td>
<td>3</td>
</tr>
<tr>
<td>Temporal variations</td>
<td>11</td>
</tr>
<tr>
<td>Behavioural factors</td>
<td>2</td>
</tr>
<tr>
<td>Demographic biases</td>
<td>6</td>
</tr>
<tr>
<td>Human aspects</td>
<td>6</td>
</tr>
<tr>
<td>Road movements</td>
<td>1</td>
</tr>
<tr>
<td>Roadside behaviour</td>
<td>2</td>
</tr>
<tr>
<td>Population impacts</td>
<td></td>
</tr>
<tr>
<td>Modelling</td>
<td>5</td>
</tr>
<tr>
<td>No modelling</td>
<td>3</td>
</tr>
<tr>
<td>Mitigation measures</td>
<td></td>
</tr>
<tr>
<td>Overpasses</td>
<td>3</td>
</tr>
<tr>
<td>Underpasses</td>
<td>14</td>
</tr>
<tr>
<td>Acoustic deterrents</td>
<td>3</td>
</tr>
<tr>
<td>Olfactory deterrents</td>
<td>1</td>
</tr>
<tr>
<td>Warning signs</td>
<td>2</td>
</tr>
<tr>
<td>Warning reflectors</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>60</td>
</tr>
</tbody>
</table>

1.2. Patterns of macropod road mortality

By far the most conspicuous impact of roads on wildlife, including macropods, is mortality due to collisions with vehicles (Figure 1.1). This is also the most commonly researched aspect of road impacts. In Australian studies,
macropods sometimes contribute a large percentage of total native mammal road-kills, though low proportions have also been reported (see Table 1.2).

Figure 1.1 A road-killed red-necked wallaby in Redland, south-east Queensland.
Table 1.2 Percentage of road-killed macropods from total road-killed native mammals in Australian road-kill studies.

<table>
<thead>
<tr>
<th>Location</th>
<th>% macropods</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snowy Mountains Highway, NSW</td>
<td>94.3</td>
<td>Ramp et al. (2005)</td>
</tr>
<tr>
<td>Redland City, South East QLD</td>
<td>79.7</td>
<td>Buchanan (2005)</td>
</tr>
<tr>
<td>Various peri-urban and regional locations in NSW</td>
<td>75.0</td>
<td>Burgin &amp; Brainwood (2008)</td>
</tr>
<tr>
<td>Redland City, South East QLD</td>
<td>58.2</td>
<td>Dexter et al. (2009a, b)</td>
</tr>
<tr>
<td>Redland City, South East QLD</td>
<td>49.1</td>
<td>Dexter (2007)</td>
</tr>
<tr>
<td>Royal National Park, NSW</td>
<td>43.8</td>
<td>Ramp et al. (2006b)</td>
</tr>
<tr>
<td>Narrabeen Catchment, Sydney, NSW</td>
<td>40.0</td>
<td>Harris et al. (2008)</td>
</tr>
<tr>
<td>Pacific Highway between Woodburn &amp; Ferry Park, NSW</td>
<td>30.0</td>
<td>Hayes &amp; Goldingay (2009)</td>
</tr>
<tr>
<td>Several highways in eastern Tasmania</td>
<td>27.4</td>
<td>Hobday &amp; Minstrell (2008)</td>
</tr>
<tr>
<td>North-eastern NSW</td>
<td>5.6</td>
<td>Taylor &amp; Goldingay (2004)</td>
</tr>
<tr>
<td>Between Gungahlin &amp; Lake Cowal, NSW</td>
<td>5.5</td>
<td>Vestjens (1973)</td>
</tr>
<tr>
<td>Pacific Highway between Yelgun &amp; Cudgera Creek, NSW</td>
<td>0</td>
<td>Hayes &amp; Goldingay (2009)</td>
</tr>
</tbody>
</table>

1.2.1. Traffic volume

One of the most frequently discussed factors contributing to wildlife-vehicle collision hotspots is that of traffic volume (Taylor and Goldingay 2010). Low levels of traffic are usually of little significance as the risks of collisions for most species are relatively low (Burgin and Brainwood 2008). Medium-level traffic volume roads, on the other hand, have been associated with high incidence of road-kill for many species (not only macropods) (Burgin and Brainwood 2008). It has been suggested that medium traffic volumes are low enough for animals to cope with the disturbance, yet high enough for many animals to become injured or killed.
during crossing attempts (Huijser and McGowen 2010). Very high traffic volumes, however, often result in little wildlife mortality as continuous traffic leads wildlife to avoid the high disturbance associated with these roads. For example, in peri-urban and rural areas of New South Wales, macropod road-kills were significantly more frequent on roads with medium traffic volumes than those with high or low volumes (Burgin and Brainwood 2008). On North Stradbroke Island in Queensland, higher incidence of swamp wallaby (*Wallabia bicolor*) road-kills were aligned with the relatively higher traffic volumes during the school holiday periods (11,295 and 9,712 vehicles per four weeks), compared to the very low levels at other times (6,411 to 7,387 vehicles per four weeks, excluding two periods following a bush fire) (Osawa 1989). Road-kills also increased with average weekly night-time traffic volumes during a drought in north-western New South Wales (NSW) (Lee et al. 2004; Klöcker et al. 2006). These were the only studies to date to specifically investigate the influence of night-time traffic volumes, which is when the majority of macropod-vehicle collisions occur (Osawa 1989), and among the few to include temporal variations in traffic volume. Across these studies there is evidence demonstrating that traffic volume can influence rates of macropod road-kills both spatially and temporally, which emphasises the importance of this variable in predicting and mitigating against road-kills (Taylor and Goldingay 2010).

1.2.2. Local road attributes

Both landscape and local roadside physical features can influence road-kill rates along some roads or sections of roads. For example, visibility of the road verge and the immediate road ahead is known to contribute to the detectability of
animals at the roadside (Mastro *et al.* 2010). Sharp bends or corners in the road reduce the driver’s ability to view the road immediately ahead, and therefore result in potential hotspots for road-kill (Lee *et al.* 2004; Klöcker *et al.* 2006). Obstructions along the roadside can also greatly reduce the visibility of macropods nearby or may temporarily trap macropods on the road. In some cases, dense vegetation, such as shrubs or long grass can be such an obstruction to driver visibility (Lee *et al.* 2004). Additionally, the presence of impermeable or wildlife-unfriendly fencing and road cuttings may cause macropods to panic when faced with an approaching vehicle (Lee *et al.* 2004; Klöcker *et al.* 2006; Burgin and Brainwood 2008).

Vegetation along the roadside verge can also play a role in attracting macropods to the roadside to forage. This is evident during a drought when Klöcker and colleagues (2006) found that pasture cover, height and greenness were greater at locations of road-kill incidents than at locations that were free from kangaroo fatalities. Similarly, Lee (2006) found kangaroos to be killed more often on sections of road where shrubs were present and overall pasture greenness was high. Swamp wallabies on North Stradbroke Island were found to select forage with higher nitrogen content, the preferred grasses of which occurred mostly in roadside verges and nearby areas (Osawa 1990). Another study (Burgin and Brainwood 2008) found more macropod road-kills in areas where the road verge was of mown grass, as opposed to longer unmown grass, although no other parameters relating to verge vegetation were considered.

Chambers and colleagues (2010) addressed two largely ignored localised road factors, road verge width and speed limit. This investigation found a positive
correlation between tammar wallaby (*Macropus eugenii*) road-kills and verge width on Garden Island in Western Australia (WA). Higher road-kill rates were also found on 60 km/h roads than roads with speeds of 50 km/h and 80 km/h. Although these are interesting results, further research with greater replication of road speed limits would be needed to corroborate them. It should also be considered that verge width and speed limit may not always present as independent variables, such as when high-speed roads have wide verges.

1.2.3. **Landscape attributes**

Landscape attributes can also contribute to determining road-kill hotspots. Gullies, creek crossings, drainage lines and the presence of other water bodies can be areas of regular movement for macropods and other wildlife (Lee *et al.* 2004). Land use and the type of habitat on either side of the road can also determine where different species are likely to come into contact with the road environment, and therefore are more likely to be involved in a vehicle collision. For example, in a study of road-kill along the Snowy Mountains Highway in NSW, eastern grey kangaroos (*M. giganteus*) were more likely to be killed in flat areas with little forest, and where the road was closest to a large dam (Ramp *et al.* 2005). Alternatively, swamp wallabies and red-necked wallabies (*M. rufogriseus*) (combined) were far more likely to be killed where there was a high proportion of forest, presumably because these species often browse and prefer the cover of nearby forest (Ramp *et al.* 2005). In a rural-urban area to the south-east of Brisbane, red-necked wallabies were more likely be killed on roads in areas where both forest and rural properties bordered the road (Buchanan 2005). Red-necked
wallabies were also slightly more frequently killed in areas where only rural habitats bordered the road than where only forest bordered the road. Alternatively, swamp wallabies tended to be killed in areas where rural and forest habitats and only forest bordered the road more than in rural habitats (Buchanan 2005). Proximity to forested cover and gullies can likewise influence the location of deer-vehicle collisions (e.g. Finder et al. 1999; Found and Boyce 2011a).

1.2.4. Temporal variations

In general seasonal patterns of macropod road-kills are usually not apparent, although some studies have observed seasonal peaks. Reported macropod-vehicle collisions over a 10 year period (1996-2005) in NSW were highest from April to August (Ramp and Roger 2008). During a five year period (1975-1979) eastern grey kangaroo road-kills peaked in autumn during two separate years (1975 and 1978) in central Victoria (Coulson 1982). Similarly, tammar wallaby road fatalities over five years (2000-2004) on Garden Island, WA were noticeably greater between March and August (Chambers et al. 2010). Further investigation of this pattern showed that day-length (number of daylight hours) was significantly negatively correlated with wallaby road-kill numbers (Chambers et al. 2010).

Peaks in eastern grey kangaroo road deaths have also been related to lunar phase, with significantly higher numbers of deaths around full moon than during any other times (Coulson 1982; Lintermans and Cunningham 1997). In an eight-week study of road-kill patterns in peri-urban landscapes in South East Queensland, Buchanan (2005) initially found no clear relationship between
mammal road mortality and lunar phase. However, when data from this study was combined with 12 months of community and council records, mammal road-kill rates (with 75% of the fatalities being macropods) were significantly higher around full moon (Buchanan 2005). In contrast, however, Osawa (1989) found no evidence of swamp wallaby road-kill occurrence being related to lunar phase.

Preceding rainfall levels appear to influence macropod road-kill rates. Six-month road-kill surveys conducted during and following drought conditions along a section of the Silver City Highway at Fowlers Gap, north-western NSW, found road-kill rates to be significantly higher during the drought (20.8 per month) than after the drought (2.6 per month) (Lee et al. 2004). This increased road-kill rate was attributed to a much higher presence of all species of kangaroos at the roadside during drought, perhaps due to higher quality and quantity of food at the roadside than further from the road (Lee 2006). Eastern and western grey (*M. fuliginosus*) kangaroos were killed in similar proportions to their roadside presence both during and outside drought, yet red kangaroos (*M. rufus*) and euros (*M. robustus erubescens*) were killed at a higher proportion to their presence at the roadside during drought (Lee et al. 2004). Similarly, during a four-year drought in central Victoria, the eastern grey kangaroo road-kill rate increased significantly compared to pre- and post-drought surveys (Coulson 1989). The occurrences of swamp wallaby road-kills also increased but were too few for statistical analysis. Further investigation revealed that low rainfall levels would result in higher kangaroo road-kill incidence in the following season, and high rainfall levels would result in lower incidence (Coulson 1989).
On the Snowy Mountains Highway in NSW, road fatalities of eastern grey kangaroos and swamp and red-necked wallabies (wallaby species pooled) were negatively correlated with rainfall over the previous six months (Ramp et al. 2005). This study also found eastern grey kangaroo fatalities to be negatively correlated with the Southern Oscillation Index (SOI), suggesting that road-kill rates are higher during El Niño periods when eastern Australia experiences reduced rainfall (Ramp et al. 2005). Lintermans and Cunningham (1997) also discovered similar increases in eastern grey kangaroo road-kills around Canberra following months of below average rainfall. These observations further support the contention that periods of low rainfall generally lead to greater road deaths in macropods.

Such patterns suggest that macropods are more susceptible to collisions with vehicles during periods of poor environmental conditions, as they have to travel further in search of sufficient resources (Norbury et al. 1994) and tend to move into more open habitats (Hill 1982). Additionally, water run-off from the road surface can create higher vegetation growth in areas immediately adjacent to the road (Lee 2006) and attract macropods to graze at the roadside. This idea is also supported by increased incidence of road-kill following bushfires. During a study on swamp wallaby road-kill on North Stradbroke Island, Queensland, a bushfire occurring along one section of the main road resulted in small increases in collisions along several sections of the road during the following months (Osawa 1989). Although rainfall has emerged as playing a significant role in the frequency of macropod road-kills, during a study on tammar wallabies living on a small island in Western Australia, it was found that day length was positively correlated with
rainfall (Chambers et al. 2010). Once this was accounted for, rainfall was no longer a significant factor in predicting road fatalities for this location. Shorter day lengths in winter mean that peak traffic times align closer with dawn and dusk, when macropods are most active, and thus increase the probability of animals and vehicles colliding during this period.

Few other climatic conditions have been related to macropod road-kills, although this may be due to the lack of studies including such factors. One study that did include other climatic factors found that high barometric pressure and high speed wind gusts were associated with increased kangaroo road mortalities in north-western NSW (Lee 2006). When considering only red kangaroo road-kills, low night-time temperature and high night-time humidity increased the probability of road-kills (Lee 2006).

1.2.5. Behavioural responses to vehicles

The behavioural response of an animal at the roadside to an approaching vehicle can play a significant role in determining the end result of the encounter. Although this research was limited to a single locality (the Silver City Highway in north-western NSW, Lee 2006; Lee et al. 2010), a relatively strong relationship was found between the generalised level of flightiness of a species and the proportion of road mortalities of that species. These studies showed that red kangaroos and grey kangaroos (eastern and western species combined) had the highest percentages of individuals that fled from an approaching vehicle, took flight at a greater distance from the vehicle and fled the furthest distance (Lee 2006; Lee et al. 2010), respectively. These species also had the highest respective mortality
rates on the highway. Although red and grey kangaroos were also observed in the highest densities at the road, red kangaroos were killed in slightly higher proportions to what was expected, given their roadside densities. The tendency for red kangaroos to flee at greater distances from the vehicle and flee further may have increased their susceptibility to road mortality relative to their densities.

1.2.6. Demographic biases

Numerous studies on macropod road-kills have reported some level of bias towards males being killed on roads. This bias was known initially only for the eastern grey kangaroo (Coulson 1982, 60%; Coulson 1997, 65%), where adult males dominated the data. However, varying levels of male bias has now been reported for western grey kangaroos (70%), swamp wallabies (73%), red-necked wallabies (92%) and red-bellied pademelons (*Thylogale billardierii*, 80%) (Coulson 1997). In contrast, no such bias was found for red kangaroos (42%) (Coulson 1997). Records of eastern grey kangaroo road-kills in Canberra based on adventitious encounters and reports from the public also showed large bias towards males (71%), particularly immature males (39%) (Lintemans and Cunningham 1997). Macropod road-kill surveys in a semi-rural area south-east of Brisbane revealed a strong male bias (94% of 18 sexed carcasses) in red-necked wallaby fatalities, but almost parity of the sexes in swamp wallabies (Buchanan 2005). This study did, however, reveal a strong age bias for swamp wallaby road-kills with 95% of animals being adults, though less pronounced for red-necked wallabies (68% adults) (Buchanan 2005). Lee (2006; Lee et al. 2010) also found male biases in the road-kills of eastern grey kangaroos and euros along the Silver
City Highway in north-western NSW, although sample sizes from these species were very low. However, road-kills of eastern and western grey kangaroos and red kangaroos showed no sex bias along the same section of highway (Lee et al. 2004; Klöcker et al. 2006). In the same studies, male euros were killed more than females and this was attributed to their higher presence at the roadside (Lee et al. 2004; Klöcker et al. 2006). It has been suggested that a likely reason for such consistent bias across macropod species and regions is that males in many species have larger home ranges and often move larger distances than females (Arnold et al. 1992; Evans 1996; Lintermans and Cunningham 1997; Paplinska et al. 2009). This greater travel will result in increased chance of encountering more roads more frequently.

1.2.7. **Human aspects on macropod-vehicle collisions**

It is also critical to discuss the impact of wildlife-vehicle collisions on humans. In the case of medium to large animals, it is almost always in the best interest of drivers to avoid wildlife collisions, as not only is damage caused to the vehicle, but vehicle occupants can be injured and even killed. Indeed, in the USA, wildlife-vehicle collisions – primarily with various species of deer – cause 26,000 human injuries, 200 human deaths and cost an estimated US $8,388 million every year (Huijser et al. 2008).

Similarly, macropod-vehicle collisions, particularly those involving large species, can cause injury and even death to the vehicle occupants (e.g. Abu-Zidan et al. 2002). Despite this, remarkably few data on these incidents are available, apparently as the causes of many crashes are not recorded in detail. The National
Injury Surveillance Unit records report the number of humans injured in motor-vehicle accidents involving the category ‘animals or pedestrians’, but no records of animals alone, or of the species involved, are reported (Berry and Harrison 2007, 2008; Henley and Harrison 2009). The following figures come from a variety of sources giving at best a fragmentary picture.

A sample of 46 patients admitted to Perth Royal Hospital, who had been involved in collisions with a macropod, reported that 19 had actually hit the animal while 27 were able to avoid the animal (Abu-Zidan et al. 2002). For all these incidents, 16 (35%) hit secondary objects and 15 (33%) rolled over. Patients who were in crashes where the macropod was avoided had significantly higher incidence of neck injuries and tended to also have more head injuries, but there was no significant difference in the severity of injuries between those who avoided and those who hit a macropod (Abu-Zidan et al. 2002). One patient of the 46 died as a result of injuries sustained in the collision with a macropod (Abu-Zidan et al. 2002).

Data from the Traffic Accident Database System for NSW (TADS) for 1996-2005, reported high proportions of macropods involved in animal-related accidents (41%) (Ramp and Roger 2008). Additionally, of the 22 animal-related collisions that resulted in human fatality, 13 (59%) of these involved macropods, and of those resulting in human injury, 38% were attributed to macropods (Ramp and Roger 2008). Of all crashes, 57% occurred between 17:00 and 24:00, significantly more crashes occurred from April to August, and on the weekend than on week days, except Friday (Ramp and Roger 2008). Further investigation into the variation across each year revealed that the mean length of natural darkness
(time between sunset an sunrise) was positively correlated with the number of animal-related collisions (at the scale of month) and explained 89\% of variation in crash rate (Ramp and Roger 2008).

Rowden and colleagues (2008) collated data on vehicle collisions with animals in Australia, with data from most states and territories covering the five year period 2001-2005. From the Queensland data (which was the most detailed), the time period when the largest proportion of animal-vehicle collisions occurred was between 18:00 and 23:59 and that most incidents occurred in 100-110 km/h speed zones (Queensland Transport 2007 in Rowden et al. 2008). High proportions of these incidents were reported to involve kangaroos or wallabies: 47\% in New South Wales and 45\% in Queensland (Rowden et al. 2008). Statistics on the type of animal involved from crashes in other states and territories were not reported.

It is clear from these data that kangaroos and wallabies should be of the most concern for Australian motorists. Collisions involving macropods comprised the highest proportion of reported crashes and a high proportion of injury related crashes. Consequently, suitably informed or warned drivers should be motivated to drive more carefully when driving in areas where there is high risk of hitting a kangaroo or wallaby. This also highlights that substantial efforts should be made to enhance the noticeability and impact of driver awareness schemes, such as wildlife warning signs and public education campaigns (Magnus et al. 2004).
1.3. **Movement and behaviour around roads**

There has been very little research conducted on the behaviour and movements of macropods around roads, and some potentially relevant work has focussed mainly on tourism impacts rather than road impacts. Lee (2006) approached these topics by investigating the temporally varying conditions under which road crossings are more likely to occur and the behavioural responses of kangaroos to approaching vehicles. Road crossings by kangaroos were investigated using laser and heat/movement sensor devices attached to a nearby fence, and were influenced by barometric pressure, wind gusts and dew-point temperature (Lee 2006). High-speed wind gusts may create conditions in which kangaroos have more difficulty detecting predators, and thus may travel less during these conditions (Lee 2006).

In response to an approaching vehicle, red kangaroos and grey kangaroos (eastern and western species combined) at the roadside were much more flighty than euros – that is they took flight more often, had greater flight initiation distances and fled further (Lee et al. 2010). In general, kangaroos were more likely to react to an approaching vehicle with flight than with vigilance at night than during the day (Lee et al. 2010). When kangaroos did flee, during both day and night, over 75% of them fled away from the vehicle, with the next most common direction being across the path of the approaching vehicle (Lee 2006). Kangaroos tended to flee across the path of the vehicle more frequently at night, with a negligible proportion fleeing towards the vehicle (Lee 2006). During the day, a small proportion of kangaroos also fled in a parallel direction to the vehicle, but this behaviour was never displayed during the night (Lee 2006). Kangaroos were
also more likely to flee when confronted along a small dirt track (that was used very infrequently) than the highway, during spring and when the vehicle was travelling at low speeds. Grey kangaroos were also significantly less likely to take flight if they were in groups of three or more and if they were partially obscured by cover; these factors did not change the flightiness of red kangaroos and euros (Lee et al. 2010). Similar responses to vehicles have been observed in ungulates (Horejsi 1981; Blackwell and Seamans 2009).

Some studies have also investigated macropod behaviour while being approached by slow-moving tour vehicles in sanctuaries. Bridled nailtail wallabies (Onychogalea fraenata), red-necked wallabies and swamp wallabies all significantly reduced time spent performing maintenance activities, such as feeding, resting, grooming and socialising, when approached by a vehicle (King et al. 2005). Another study found red kangaroos and euros to flee from a slow-moving vehicle 41% of the time, with euros allowing closer approach before flight and fleeing for shorter distances than red kangaroos (Wolf 2009; Wolf and Croft 2010).

Evidence of the spatial extent of the road-effect zone was reported by Pocock and Lawrence (2005) in Bendigo Regional Park, Victoria, where the presence of eastern grey kangaroos and swamp wallabies was found 10m and 25m from a two-lane arterial road, respectively. This suggests that these larger macropod species do not avoid the road, and can even be found in very close proximity to it, potentially increasing their susceptibility to collisions with vehicles.
1.4. **The impact of roads on the viability of macropod populations**

Population viability analyses are often conducted in situations where populations appear to be in decline and are sometimes used to predict the impact of different management strategies on the viability of the population in question (Hanski 2002; Ben-Ami and Ramp 2005). A population viability analysis conducted on a semi-urban swamp wallaby population in the Royal National Park near Sydney revealed that the viability of the population was very sensitive to the number of female deaths (Ramp and Ben-Ami 2006). By reducing female road mortality by only 20%, the model predicted that the population decline could be reversed and carrying capacity restored (Ramp and Ben-Ami 2006). Reducing the wallaby road mortality was by far the most effective management option for this population when compared with high levels of fox control. It must be noted, however, that the population involved in this modelling was assumed to be closed, a condition not necessarily valid given the geography of the site. Thus, the conclusions reached may be less concrete than were articulated in the study.

Conversely, although road-kill was a significant contributor to the mortality of a semi-urban swamp wallaby population in Muogamarra Nature Reserve, also near Sydney, other pressures on the population were found to be more important (Ben-Ami 2005; Ben-Ami *et al.* 2006). This population viability analysis showed that even if all road mortalities were prevented (and no other management action taken), the population would continue to decline (Ben-Ami 2005; Ben-Ami *et al.* 2006). Population modelling conducted on tammar wallabies living near a naval base on Garden Island revealed that road-kill rates significantly decreased the
population growth rate, but not during all years (Chambers 2009; Chambers and Bencini 2010).

Roads can play a significant role in decreasing the viability of vulnerable and endangered populations (e.g. Hayward et al. 2005; Hazlitt et al. 2006; Ramp and Ben-Ami 2006). The Proserpine rock-wallaby (*Petrogale persephone*) is listed as endangered by the IUCN, Commonwealth and in Queensland, and is one such species where roads contribute to its decline. In the national recovery plan for the species (Department of Environment and Resource Management 2010) road mortality is listed as a moderate threat, and in the previous recovery plan (2000-2004, Nolan and Johnson 2001) reduction of road mortality was listed as the second threat management priority. Road mortalities in some areas have been attributed to guinea grass (*Panicum maximum*) attracting the wallabies to graze in road verges and wallabies crossing a road to access irrigated grass in a picnic area (Department of Environment and Resource Management 2010). Efforts to reduce guinea grass in road verges and provide alternative irrigated grazing areas appeared to reduce road-kill rates, although further monitoring has not yet been reported.

The brush-tailed rock-wallaby (*Petrogale penicillata*) is listed as vulnerable by the IUCN and in Queensland, where its populations are the most stable in Australia (Hazlitt et al. 2006). On a road near one population of ~20-25 individuals in South East Queensland, at least seven individuals were killed from collisions with vehicles during a single year (2004) (Hazlitt et al. 2006). Despite this apparently low number of road-kills, they represented a substantial proportion
(~28-35%) of the small and genetically constrained population of the species (Hazlitt et al. 2006).

The quokka (*Setonix brachyurus*) is also listed as vulnerable by the IUCN, and although it has a stable population on Rottnest Island, Western Australia, the small surviving metapopulations on the mainland are subject to much greater threats (Hayward 2002; Hayward *et al.* 2003; Hayward *et al.* 2005; Hayward *et al.* 2007). In a study of survivorship in the northern jarrah forests, eight of 58 radio-collared individuals died, with two of these being attributed to collisions with vehicles (Hayward *et al.* 2005). The risk of mortality of quokkas from vehicle collisions was high at two of the remaining populations where roads with high traffic volumes and speeds bisect the swamp habitat of the quokkas (Hayward *et al.* 2005). Road mortalities of Lumholtz’s tree-kangaroo (*Dendrolagus lumholtzi*), which is listed as near-threatened in Queensland, have also been recognised as a significant threat to their populations in the wet tropics (Newell 1999; Goosem *et al.* 2005).

1.5. **Road crossing structures and other mitigation devices for macropods and other wildlife**

Many approaches have been used to attempt to mitigate the impacts that roads have on wildlife, including: wildlife warning road signs, road markings, ultrasonic devices, roadside reflectors, wildlife-exclusion fencing, wildlife underpasses and retro-fitted culverts, and wildlife overpasses (e.g. Magnus *et al.* 2004). Mitigation structures and devices aim to change either, the behaviour and movements of the wildlife near roads, or the behaviour of drivers. Their
effectiveness, however, has been shown to be highly variable and dependant on the location of the measure, strategic implementation for the targeted wildlife and continued maintenance (see Huijser and McGowen 2010 for North American review).

1.5.1. *Wildlife warning signs*

Wildlife warning signs are the most commonly implemented approach to mitigation of wildlife road-kills (Huijser and McGowen 2010). Typically they depict a silhouette of the species of concern on a yellow background, although larger and more conspicuous signs also exist. On some occasions these images are deployed in conjunction with signs indicating reduced speed limits during the times when animals are most susceptible to collisions (Gleeson and Gleeson 2012). The main aim of such signage is to alert drivers to the possibility of encountering wildlife on or near the road and thus make the driver more vigilant and reduce speed.

Despite wildlife warning signs being commonly used, there is little evidence that they significantly change driver behaviour and reduce road-kill rates (Dique et al. 2003; Al-Ghamdi and AlGadhi 2004). Standard kangaroo warning signs were ineffective at reducing macropod road-kill rates immediately following erection along the Northern Highway in central Victoria in 1978 (Coulson 1982). On a Wyoming highway (speed limit 105 km/h), USA, the use of deer signs with flashing lights when deer were detected near the road succeeded in reducing vehicle speeds, but only by an average of 6% without lights and 7% when lights were flashing (Gordon et al. 2004). Magnus and colleagues (2004) developed and installed a new wildlife warning sign design that included a greatly reduced
recommended speed from dusk to dawn. Unfortunately, the vehicle speed data collected were incompatible with pre-sign data, though anecdotally, speeds were thought to be reduced at least in the short-term. Magnus and colleagues (2004) did, however, highlight the importance of investigating alternative sign designs that may be more informative and meaningful to drivers.

1.5.2. *Road crossing structures and wildlife-exclusion fencing*

Underpasses and overpasses that are purpose-built or retro-fitted for wildlife can be successful in providing safe movement across roads. These structures, however, typically only function well when used in conjunction with wildlife-exclusion fencing and are designed so that wildlife are not deterred from using them (Figure 1.2). Table 1.3 summarises reported evidence of macropod species using underpasses and overpasses. Kangaroos and wallabies have used underpasses with a wide range of dimensions. Although wallabies and kangaroos have used fauna culverts as small as 1.2m high x 2.4m wide (Taylor and Goldingay 2003), a minimum of 3m in height should be recommended to allow animals to stand upright and hop unimpeded (Figure 1.3 and Figure 1.4). The influence of the length of underpasses has only been assessed in a few occasions, but one culvert 62.5m in length has been used, suggesting that wallabies and kangaroos may not be deterred by long structures (Hayes and Goldingay 2009). Unidentified kangaroos or wallabies have also been detected using viaducts and culverts for creek and drainage flow on the Gold Coast, Queensland, although no dimensions for these structures were reported (Leopold-Wooldridge 2008). The three overpasses used by wallabies and kangaroos varied in minimum width, but wider
overpasses with continuous habitat will limit disturbance from the traffic and encourage regular use. Smaller macropods such as pademelons, potoroos and bettongs, have been recorded less commonly than large macropods (AMBS 2001a, b, d, 2002a), while overseas studies have suggested that smaller animals tend to prefer shorter structures (e.g. Yanes et al. 1995; Ascensão and Mira 2007). Underpass length, however, does not appear to constrain use by these smaller macropods, as pademelons, potoroos and bettongs all used structures of least 52m in length (AMBS 2001b, d, 2002a). To date, there has been no evidence of potoroos and bettongs using overpasses, although there is potential for overpasses to be used by smaller macropods if continuous dense vegetation covers the structures. Wildlife-exclusion fencing associated with most of these structures was integral in encouraging macropods to use such road crossing structures, particularly for larger wallabies and kangaroos which readily make direct road crossings (Buchanan 2005; Bond and Jones 2008).
Figure 1.2 An example of a forested fauna overpass (land bridge), with wildlife-exclusion fencing, connecting habitat across Compton Road in Brisbane, Queensland.
<table>
<thead>
<tr>
<th>Species</th>
<th>Structure Type</th>
<th>Dimensions</th>
<th>Exclusion</th>
<th>Location</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGK</td>
<td>Forested bridge</td>
<td>20m base, 15m mid width, 70m long</td>
<td>yes</td>
<td>Karawatha Forest, Kuraby, south-east QLD</td>
<td>12, 13</td>
</tr>
<tr>
<td>RNW</td>
<td>Arch underpass</td>
<td>2.8m diameter, 47.8m long</td>
<td>yes</td>
<td>Taree Bypass, NSW</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Forested bridge</td>
<td>20m base, 15m mid width, 70m long</td>
<td>yes</td>
<td>Karawatha Forest, Kuraby, south-east QLD</td>
<td>12, 13</td>
</tr>
<tr>
<td>SW</td>
<td>Fauna underpass</td>
<td>4m high, 3.2m wide, 20m long</td>
<td>unknown</td>
<td>Wollongong, NSW</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Underpass</td>
<td>10m diameter, unknown length</td>
<td>yes</td>
<td>Brisbane Water National Park, NSW</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Fauna underpasses</td>
<td>3m high, 3m wide, 40-52m long</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>4, 6</td>
</tr>
<tr>
<td></td>
<td>Span bridge underpass</td>
<td>5.5m high, 75m wide, 21m long</td>
<td>yes</td>
<td>Petrie, south-east QLD</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Span bridge underpass</td>
<td>3m high, 12m wide, 14m long</td>
<td>yes</td>
<td>Victoria Point, south-east QLD</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Culvert</td>
<td>3.7m high, 3m wide, unknown length</td>
<td>yes</td>
<td>Capalaba, south-east QLD</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Fauna underpasses</td>
<td>3-3.1m high, 3-3.1m wide, 55m long</td>
<td>yes</td>
<td>Gateway Mwy, Mackenzie, south-east QLD</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Forested bridge</td>
<td>20m base, 15m mid width, 70m long</td>
<td>yes</td>
<td>Karawatha Forest, Kuraby, south-east QLD</td>
<td>12, 13</td>
</tr>
<tr>
<td>UWK</td>
<td>Fauna underpasses</td>
<td>3m high, 3m wide, 40-52m long</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>4, 6, 8</td>
</tr>
<tr>
<td></td>
<td>Arch underpasses</td>
<td>18.3m diameter, unknown length</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Arch underpass</td>
<td>2.8m diameter, 47.8m long</td>
<td>yes</td>
<td>Taree Bypass, NSW</td>
<td>7, 9</td>
</tr>
<tr>
<td></td>
<td>Fauna underpasses</td>
<td>1.2m high, 2.4m wide, 18m long</td>
<td>yes</td>
<td>Brunswick Heads, NSW</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Span bridge underpasses</td>
<td>3m high, 10m wide, unknown length</td>
<td>yes</td>
<td>Brunswick Heads, NSW</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Span bridge underpass</td>
<td>Unknown dimensions</td>
<td>yes</td>
<td>Herons Creek Deviation, NSW</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Fauna underpasses</td>
<td>1.2m high, 2.4m wide, 18m long</td>
<td>yes</td>
<td>Brunswick Heads, NSW</td>
<td>10</td>
</tr>
<tr>
<td>Fauna underpasses</td>
<td>2.4m high, 2.5m wide, 48m long with raised cement level 1.6m wide, 2m clearance</td>
<td>yes</td>
<td>Karawatha Forest, Kuraby, south-east QLD</td>
<td>12, 13</td>
<td></td>
</tr>
<tr>
<td>Fauna underpass</td>
<td>3m high, 3m wide, 42.3m long</td>
<td>yes</td>
<td>Marshall’s Ridges, Yelgun, NSW</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Fauna underpass</td>
<td>3m high, 3m wide, 62.5m long</td>
<td>yes</td>
<td>Tagget’s Hill, Cudgera Creek, NSW</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Span bridge underpass</td>
<td>1.5m high, 8m wide, 12m long</td>
<td>Yes</td>
<td>Gold Coast Hwy, Arundel, south-east QLD</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Forested bridge</td>
<td>20m base, 15m mid width, 70m long</td>
<td>yes</td>
<td>Karawatha Forest, Kuraby, south-east QLD</td>
<td>12, 13</td>
<td></td>
</tr>
<tr>
<td>Forested bridge</td>
<td>9.4-37m wide, unknown length</td>
<td>yes</td>
<td>Marshall’s Ridges, Yelgun, NSW</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Forested bridge</td>
<td>35m wide, unknown length</td>
<td>yes</td>
<td>Tagget’s Hill, Cudgera Creek, NSW</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>RLP</td>
<td>Arch underpasses</td>
<td>3.4m high, 3.7m wide, unknown length</td>
<td>unknown</td>
<td>Wet Tropics World Heritage Area, north QLD</td>
<td>11</td>
</tr>
<tr>
<td>UPa</td>
<td>Fauna underpass</td>
<td>3m high, 3m wide, 40-52m long</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>4, 6</td>
</tr>
<tr>
<td>Arch underpasses</td>
<td>18.3m diameter, unknown length</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>LNP</td>
<td>Fauna underpass</td>
<td>3m high, 3m wide, 40-52m long</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>8</td>
</tr>
<tr>
<td>UPo</td>
<td>Fauna underpasses</td>
<td>1.2m high, 2.4m wide, 18m long</td>
<td>yes</td>
<td>Brunswick Heads, NSW</td>
<td>3</td>
</tr>
<tr>
<td>UB</td>
<td>Fauna underpass</td>
<td>3m high, 3m wide, 40-52m long</td>
<td>yes</td>
<td>Pacific Hwy, Bulahdelah to Coolongolook, NSW</td>
<td>8</td>
</tr>
<tr>
<td>LTK</td>
<td>Arch underpasses</td>
<td>3.4m high, 3.7m wide, unknown length</td>
<td>unknown</td>
<td>Wet Tropics World Heritage Area, north QLD</td>
<td>11</td>
</tr>
</tbody>
</table>


*A forested bridge is a wildlife bridge that has forest growing on it. A culvert is a drainage culvert that is also used by wildlife. An underpass is a structure that was undefined by the authors; whereas a fauna underpass is purposed for both drainage and fauna use. A span bridge underpass is a bridge that spans a creek through which wildlife can also move. An arch underpass is a fauna underpass with an arched entrance.*


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Figure 1.3 Swamp wallaby using a 3m x 3m fauna underpass under the Gateway Motorway in Brisbane, Queensland. (Photo: Applied Road Ecology Group, Environmental Futures Centre)

Figure 1.4 Entrance of a fauna underpass used by swamp wallabies under the Gateway Motorway in Brisbane, Queensland. (Photo: Applied Road Ecology Group, Environmental Futures Centre)
Fauna-exclusion fences aim to prevent animals from entering the roadway and have different specialised features, depending on what taxa are being targeted and their ability to breach a standard fence. In some fence designs, animals are prevented from climbing over the fence by having a ‘floppy top’ that flops back towards a climbing animal, or by running metal sheeting along the top that is wider than the species’ reach (Department of Transport and Main Roads 2010; Gleeson and Gleeson 2012). Similarly, animals can be prevented from digging under the fence by a thick plastic strip that is dug slightly into the ground, or the bottom of the fence mesh being attached to a block of cement running under the fence (Department of Transport and Main Roads 2010). When well designed and maintained, such fencing along roads has been proven to reduce road-kill rates of many taxa (Clevenger et al. 2001b; Jaeger and Farhig 2004; Dodd et al. 2007; Leblond et al. 2007; Bond and Jones 2008). Not only does wildlife-exclusion fencing reduce wildlife-vehicle collisions, it can also be strategically placed to funnel wildlife to road crossing structures and increase successful road crossings via these structures (Dodd et al. 2007).

The use of fencing alone is often cautioned against, however, as it also creates an impermeable barrier to most animals, thus inhibiting animal movement across the road and creating smaller isolated populations without the possibility of gene flow (Jaeger and Farhig 2004). Although fauna-exclusion fencing will reduce wildlife-vehicle collisions where it is present on both sides of the road, they can also cause road-kill hotspots at the fence ends (Clevenger et al. 2001a). Additionally, on occasion when an animal may breach the fence, they then become
trapped on the roadway unless one-way escape gates or ramps are installed at regular intervals in the fence (Department of Transport and Main Roads 2010).

1.5.3. **Warning reflectors, acoustic repellents and scent repellents**

Studies on other mitigation devices such as wildlife warning reflectors and vehicle-mounted acoustic repellent devices have shown varying results. In some studies, wildlife warning reflectors were found to have little effect on the roadside behaviour of deer, with little change in the rates of road-kill (Waring et al. 1991; D'Angelo et al. 2006), while in others, deer-vehicle collisions were reduced dramatically (Putnam 1997). For macropods, the effectiveness of both red and white reflectors from two brands (Strieter-Lite and Swareflex) were assessed on captive red kangaroos and red-necked wallabies (Ramp and Croft 2006). The red Strieter-Lite reflectors elicited significantly increased vigilance in red kangaroos and increased flight from the road in red-necked wallabies (Ramp and Croft 2006). However, despite these results being statistically significant, overall responses to the wildlife warning reflectors were very low, and therefore were deemed ineffective (Ramp and Croft 2006). Roadside reflectors were installed in northern Queensland where endangered Proserpine rock-wallabies were at risk from being hit by vehicles. Initially the reflectors were thought to be reducing road-kills of the species (Nolan and Johnson 2001; Johnson et al. 2003), but were later assessed and revealed to be ineffective (Department of Environment and Resource Management 2010). Swareflex wildlife warning reflectors were also installed with a range of other mitigation measures in Cradle Mountain – Lake St. Clair National Park in Tasmania (Jones 2000). Road-kill rates were reduced along the road, but the
various mitigation measures installed were not independently tested from one another (Jones 2000), so the reduction in road-kill rates cannot be attributed to the reflectors alone.

Vehicle-mounted acoustic repellent devices claim to repel animals by emitting a high-frequency sound (Bender 2003; Magnus et al. 2004; Muirhead et al. 2006). Such devices have been tested to assess their effectiveness in Australia, generally resulting in little or no response from animals (Bender 2003; Magnus et al. 2004; Muirhead et al. 2006). The electronic Roo-Guard® sound emitter was tested on captive and free-ranging eastern grey kangaroos, captive red kangaroos (Bender 2003) and temporarily captive tammar wallabies (Muirhead et al. 2006). Exposure to the sound emitted from the Roo-Guard® elicited no significant response from all species, including free-ranging eastern grey kangaroos (Bender 2003; Muirhead et al. 2006).

Another device, the Hobi ultrasonic animal alert whistle, an air-driven vehicle-mounted whistle, was tested for its ability to change wildlife roadside behaviour and reduce the number of animals hit (Magnus et al. 2004). During the tests, the driver was unaware as to if the device was turned on or off, in order not to bias drive behaviour. This device did not alter animal roadside behaviour and failed to significantly reduce the number of animals hit (Magnus et al. 2004). Additionally, the whistle sound emitted was found to be only slightly louder than the sound of the vehicle, suggesting that the sound produced was insufficient (Magnus et al. 2004).

Scent repellents have not been well researched with regard to deterring macropods from roads. Gibson (2008), however, investigated the reaction of red-
necked wallabies to various scent repellents under captive conditions. First, four different scent repellents were compared in their effectiveness in deterring the wallabies from a food source, with two performing well: Plant Plus (based on chemistry of dog urine) and an egg formulation (Gibson 2008). Captive trials revealed that Plant Plus was the most effective repellent (from a limited food source). Furthermore, wallaby habituation to the scent over a period of six weeks was minimal and Plant Plus continued to persist and be effective for up to 10 weeks after application (Gibson 2008). Field trials of the repellent were attempted, but failed due to unavoidable and unpredicted site disturbance and lack of interest by free-ranging macropods in artificial food sources (Gibson 2008).

1.6. Research gaps

From the material summarised in this review, it is evident that there are numerous areas of research that need to be investigated further with regards to the relationship between macropods and roads, and in road ecology in general. First, although many road-kill studies have been conducted, some of which include modelling, there is a lack of species-specific road-kill modelling. Both spatial and temporal modelling has been conducted on species-pooled road-kill data (e.g. Ramp et al. 2005), but this often fails to consider species differences in habitat preferences, behavioural responses to roads and general ecology of the various species recorded (Teixeira et al. 2013b). By conducting species-specific road-kill modelling, more accurate predictions and conclusions can be drawn. Additionally, more research that includes seasonal variation and investigation of daylight length
on road-kill rates would be beneficial to concentrating mitigation efforts when resources are limited.

In general, behavioural and animal movement studies relating to roads have been rare in Australia (although see King et al. 2005; Lee 2006; Wolf 2009), but these are very important in developing a profile on how different species perceive roads and vehicles and the contributing impact of roads on a day-to-day basis. Such behavioural studies also have the potential to contribute significantly to understanding road-kill risks and to the design and location of mitigation measures. Data on animal movements around roads in particular are lacking, and should be prioritised, as this can potentially reveal road avoidance and/or attraction, road permeability, regular road crossing locations (where road-kills may not be prevalent, e.g. Lewis et al. 2011; Neumann et al. 2012), and quantification of road exposure (using time budgets).

Research on the overall impact of roads on the viability of species populations in Australia is also lacking (see Taylor and Goldingay 2010). Population viability analyses can be a useful tool for quantifying and prioritising the pressures on populations, particularly in urban landscapes, where there are numerous pressures from human sources (Ben-Ami and Ramp 2005; Ben-Ami et al. 2006). To date, population modelling has been performed on only three macropod populations where the impact of roads has been investigated (Ben-Ami et al. 2006; Ramp and Ben-Ami 2006; Chambers and Bencini 2010). Two of these studies were conducted on swamp wallaby populations; similar studies need to be conducted on other macropod species, particularly where declines in the populations may easily go unnoticed. Further research needs to be conducted on
population impacts, particularly on species of conservation concern where severe road impacts may be occurring, for example, as has been conducted for a squirrel glider (*Petaurus norfolcensis*) metapopulation (Taylor and Goldingay 2012). Additionally, however, preventing population decline in currently abundant road-impacted species should also be a management goal through ongoing long-term research.

Wildlife use of road crossing structures (both drainage and wildlife-dedicated structures) has only been explored in recent decades in Australia. To date, research has mostly been limited to documenting use by various taxa and not actual effectiveness in creating pathways for movement between populations (van der Ree *et al.* 2007). Ideally, efforts need to be invested in long-term BACI (Before-After-Control-Impact) studies that involve investigating metapopulation dynamics through population genetics (Lesbarrères and Fahrig 2012). Unfortunately, such research is both time and financially expensive, and so is rarely conducted. Even so, smaller short-term (approx. three to five years) research in this area would highly valuable (e.g. van der Ree *et al.* 2009; Taylor 2010; Torres *et al.* 2011).

Another poorly researched area is that of identifying the road crossing structure preferences and tolerance limits of different species. It is vitally important that when road crossing structures are being designed, that the target taxon's preferences for using structures of varying design are considered. This should include structures of various dimensions (an openness index is often used), vegetation type and proximity, light penetration (for underpasses), and ground substrates (e.g. Woltz *et al.* 2008). Such research could then be used to design appropriate and targeted (whether to one species or many) road crossing
structures that are likely to be more successful than the generic structures commonly deployed as part of road upgrades.

Further research on other road mitigation measures is also needed. As mentioned above, wildlife warning signs are the most commonly implemented mitigation measure, yet the limited research on their effectiveness is far from clear, with little evidence of a reduction in wildlife road-kill rates in the long-term (e.g. Dique et al. 2003). Despite this, it is likely that signage will continue to be frequently employed due to their relatively minor cost. With this in mind, research into alternative sign designs that may be more effective at eliciting desired responses from drivers is required (Magnus et al. 2004). Additionally, scent repellents may be appropriate to use in some small areas of particularly high road mortality, although field tests on a variety of species are needed before this approach can be seriously considered as a mitigation option (Gibson 2008).

Genetic studies investigating the potential barrier effects of roads have been completely deficient on macropods, to the best of my knowledge. Such research would be highly informative in quantifying the permeability of roads to wildlife populations, whether limited gene flow caused by road barrier effects is likely to cause population collapse and evaluate the facilitation of gene flow by road crossing structures (Simmons et al. 2010).

1.7. Conclusion

Research in the field of road ecology is still in its relative infancy in Australia (see Taylor and Goldingay 2010), and much more attention is needed in many areas to be comparable to Europe and North America. Although a moderate
volume of research has been conducted on the interactions between macropod species and roads in Australia, this a fraction of the research effort conducted on large mammals in Europe and North America (Seiler 2001; Forman et al. 2003; Fahrig and Rytwinski 2009; Beckmann et al. 2010). Research that encompasses a variety of aspects of interactions between roads and macropods (and wildlife in general) is needed to broaden our perspective on impacts and mitigation. Not only is the Australian research effort limited in volume and variety, but it is mainly comprised of short-term studies. Road ecology research in Australia needs to be significantly broadened to include longer-term studies that assess a higher level of complexity and impact.

1.8. Research aims and thesis structure

Given the important research gaps outlined above, considerable effort was made to investigate the movement patterns of wallabies around roads and the population viability of a peri-urban red-necked wallaby population. Upon commencement of field investigations, severe problems were encountered during attempts to capture wallabies for attachment of GPS collars. Multiple methods of capture were attempted over an extended period, but, due to uncontrollable environmental circumstances, these efforts were unsuccessful. Therefore, these aspects of the research were abandoned and replaced with investigations that were able to be conducted in a timely manner and expanded upon other areas of the study.

The overall objectives of this research project were to investigate interactions between wallabies and the road environment in an urbanising
landscape to the south-east of Brisbane and to explore a practical and inexpensive strategy to improve the effectiveness of broad-scale road mitigation. More specifically, the research aims were to:

1. investigate local and landscape spatial and temporal patterns of red-necked wallaby and swamp wallaby road mortalities;
2. explore alternative wildlife warning sign designs and their potential effectiveness on driver response;
3. investigate the road-crossing behaviours of red-necked wallabies;
4. investigate the behavioural response of red-necked wallabies to passing vehicles; and
5. investigate the changes in red-necked wallaby activity budgets at three roads with varying traffic volumes and speeds compared to a local control area.

The following five chapters consist of four data chapters based on field and survey investigations and a final synthesis chapter that discusses the contribution of this research to our understanding, management implications and priorities for future research. Chapter 2 describes the spatial and temporal patterns of wallaby road mortality in an urbanising landscape and examines influence of several variables on these patterns. Chapter 3 presents a series of potential alternative wildlife warning sign designs and then assesses the likely responses of drivers to the signs and describes the prominent aspects and messages conveyed by these signs through a public opinion survey. This chapter also assesses the impact of certain sign elements and placement on driver responses. Chapters 4 and 5 investigate aspects of red-necked wallaby behaviour near roads and behavioural
changes caused by the presence of roads and traffic. Chapter 4 looks specifically at red-necked wallaby road-crossing behaviours and their responses to approaching vehicles at three roads with varying traffic volumes and speeds. Alternatively, chapter 5 compares the activity budgets of red-necked wallabies near the same three roads with those in a similar control area away from roads. Finally, chapter 6 concludes by synthesising the contributions of the previous chapters to our knowledge of the interactions between macropods and roads and outlines the directions of future research in this area and in peri-urban landscapes in general.

This research was conducted under the approval of the Griffith Animal Ethics and Human Research Ethics Committees (ENV/16/10/AEC, ENV/09/12/AEC, ENV/10/12/AEC and ENV/18/13/HREC). Permission was also granted by the Department of Environment and Resource Management (formerly the Environmental Protection Agency; permit numbers WISP08102210 and WITK11327212), Brisbane City Council, Redland City Council, Logan City Council and the Department of Transport and Main Roads.
Chapter 2

Characterising the occurrence of wallaby road mortality in an urbanising landscape
2. Characterising the occurrence of wallaby road mortality in an urbanising landscape

2.1. Introduction

Expanding urban areas are a primary cause of habitat loss, fragmentation and degradation (Department of the Environment Water Heritage and the Arts 2009; State of the Environment 2011 Committee 2011). Although environmental issues associated with urbanisation are problems globally, it is of particular concern in Australia, as our urban footprint continues to rapidly expand. Due to the large land area and relatively small population of Australia, urban centres in this country tend to grow through urban sprawl, while maintaining relatively low population densities in inner cities, compared to cities in other countries (State of the Environment 2011 Committee 2011). The road networks associated with such urbanising areas are often continuously expanded and upgraded in order to support the increasing demands of increasing population densities. As a result, road-kill rates in urban and urbanising (peri-urban) areas are a growing issue in Australia.

Wildlife mortalities from collisions with vehicles can represent significant proportions of some populations and contribute to reducing wildlife populations in all landscapes where roads are present. In some circumstances, road mortality rates can be severe enough to even cause local population extinctions (Jones 2000; Carr and Fahrig 2001; Department of Environment and Resource Management 2009). Additionally, skewed population demographics can result when risk of road mortality is biased towards a particular sex or age (Mumme et al. 2000; Aresco
2005a). In expanding urban areas, population declines from road mortalities, coupled with increasing habitat loss, fragmentation, and predation from domestic cats and dogs (for small species and juveniles of larger species), can create a major synergistic effect on peri-urban wildlife populations. This is exemplified by the relatively recent and rapid decline in koala (*Phascolarctos cinereus*) populations along the ‘Koala Coast’ in South East Queensland (Department of Environment and Resource Management 2012), where vehicle strikes were identified as a key contributing factor (Preece 2007; Natural Resource Management Ministerial Council 2009). This region was previously regarded as a stronghold for koalas, as it held high densities of natural koala populations (Dique *et al.* 2004; Preece 2007). Today, however, these populations are threatened with immanent local extinction (Natural Resource Management Ministerial Council 2009; Department of Environment and Resource Management 2012).

Of a total of 14 macropod species (Department of Sustainability Environment Water Population and Communities 2011), eastern grey kangaroos, *Macropus giganteus*, red-necked wallabies, *Macropus rufogriseus*, and swamp wallabies, *Wallabia bicolor*, are likely the most common and widely distributed in South East Queensland. In some areas within this region, however, eastern grey kangaroos have slowly disappeared, most likely due to loss of large, connected tracts of habitat. With the increasing pressures from urbanisation, there is significant risk of the remaining macropod species progressively disappearing from much of the region. This has occurred in the areas surrounding Sydney and in the Blue Mountains in New South Wales (NSW), where eastern grey kangaroos, common wallaroos, *Macropus robustus*, and red-necked wallabies have
disappeared or are rarely observed in urban and peri-urban areas (Ben-Ami 2005; Zusi 2010).

Avoiding building roads in areas that are sensitive and/or have high environmental risk must be the first priority when considering where to place a new road. When environmental impacts cannot be avoided, they then need to be minimised and mitigated against or, as a last resort, compensated for through offsets. In order to mitigate the impact of wildlife road mortality on current roads, road-kill hotspots need to be identified so that mitigation measures can be introduced in locations where they are likely to have the greatest effect. Identifying temporal patterns of mortality is also important to target public awareness campaigns around these times.

Many studies of wildlife road mortality have investigated environmental predictors of road-kill frequency or hotspots, whether of a single species or taxa, or across multiple species and taxa groups (Clevenger et al. 2003; Burgin and Brainwood 2008; Cureton and Deaton 2012; Russell et al. 2013). A range of spatial and temporal variables have been found to be associated with wildlife road mortality, yet there is little consistency in the variables found to be influential, as well as high variability among species and locations. Many studies have reported the influence of road-related variables on road-kill rates, such as traffic volume (e.g. Burgin and Brainwood 2008; Litvaitis and Tash 2008; Orlowski 2008; Gunson et al. 2011) and traffic speed or speed limit (e.g. Barrientos and Bolonio 2009; Chambers et al. 2010; Found and Boyce 2011a; Farmer and Brooks 2012). Road topography, alignment and width, as well as road verge width and vegetation have also been found to influence where wildlife-vehicle collisions occur (e.g. Clevenger
et al. 2003; Grilo et al. 2009; Chambers et al. 2010). Road verge vegetation can affect the presence of wildlife-vehicle collisions in three ways: by attracting animals to the vegetation at the roadside and, if dense enough, may conceal animals from the view of drivers and cars from the view of animals entering the roadway (Lee 2006; Department of Environment and Resource Management 2010).

Temporal patterns of wildlife road mortality are also often evident, although generally such mortality occurs year round. Seasonal road mortality is perhaps most obvious in migratory (Ng et al. 2008) and seasonally active species (Cureton and Deaton 2012). Some species are more mobile at certain times (e.g. mating season, dispersal of young) and thus are more likely to encounter roads and collide with vehicles (Grilo et al. 2009; da Rosa and Bager 2012). The influence of other temporally varying conditions, including moon phase, temporal changes in traffic volume, rainfall and other weather variables can also determine road-kill patterns (Coulson 1982; da Rosa and Bager 2012).

Some research has been conducted on the patterns of road-kill to the south-east of Brisbane (Buchanan 2005; Dexter 2007), although these studies have been habitat focussed and did not include many other variables that many influence patterns of road-kill. Although both of these studies included road-kill of other species and taxa, some analyses were conducted on the macropod species. Both Buchanan (2005) and Dexter (2007) found habitat associations, with red-necked wallaby road-kills being more prevalent in rural habitats, whereas swamp wallabies tended to be associated with forest habitats. Buchanan (2005) also found a severe bias toward male red-necked wallabies being killed (94%) and found
significantly more road-kills during full moon, however this analysis was performed on all mammal data. Dexter (2007) also found that red-necked wallabies tended to have slightly higher mortality rates in winter, though not significantly so. No other variables were investigated by these studies, and so it is warranted to further investigate the possible influence of other spatial and temporal variables on wallaby road-kills in the area.

The objective of this chapter was to identify patterns of macropod road mortality in a peri-urban area of South East Queensland. More specifically, this study aims to (1) identify wallaby road-kill hotspots; (2) investigate possible demographic biases in wallaby road-kills; (3) investigate spatial patterns of wallaby road mortality using multiple local-scale and landscape-scale variables; and (4) investigate temporal patterns of wallaby road mortality using lunar, weather and seasonal variables. These investigations treated red-necked wallabies and swamp wallabies separately, as the behaviour and habitat use of these two species differ substantially (Johnson and Jarman 1987; Johnson 1989; Ben-Ami 2005; Zusi 2010).

2.2. Methods

2.2.1. Study area

The study area was centred over the southern half of mainland Redland City in South East Queensland, and extended slightly westward into the bordering areas of Brisbane and Logan cities (27°36’S, 153°13’E, Figure 2.1). The southern half of mainland Redland comprises a matrix of suburban, agricultural and remnant
bushland land uses, and has lower human population densities than the northern half of mainland Redland (Table 2.1).

Figure 2.1 Location of the study area (green star) in South East Queensland. The pink suburbs are those inside and bordering the study area (see Table 2.1).
Table 2.1 Human population density of suburbs in mainland Redland city and suburbs included in the study in Brisbane and Logan (Source: Australian Bureau of Statistics 2006; Australian Bureau of Statistics 2011a, b).

<table>
<thead>
<tr>
<th>Suburb</th>
<th>Land area (ha)</th>
<th>Population density (persons ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inside study area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burbank (Brisbane)</td>
<td>3,002</td>
<td>0.38</td>
</tr>
<tr>
<td>Carbrook (Logan)</td>
<td>2,288</td>
<td>0.51</td>
</tr>
<tr>
<td>Sheldon</td>
<td>2,283</td>
<td>0.74</td>
</tr>
<tr>
<td>Mount Cotton</td>
<td>4,273</td>
<td>1.12</td>
</tr>
<tr>
<td>Redland Bay</td>
<td>4,661</td>
<td>2.93</td>
</tr>
<tr>
<td>Thornlands</td>
<td>2,171</td>
<td>5.90</td>
</tr>
<tr>
<td><strong>Bordering study area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capalaba</td>
<td>1,879</td>
<td>8.85</td>
</tr>
<tr>
<td>Victoria Point</td>
<td>1,340</td>
<td>11.04</td>
</tr>
<tr>
<td><strong>Outside study area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ormiston</td>
<td>496</td>
<td>11.36</td>
</tr>
<tr>
<td>Wellington Point</td>
<td>973</td>
<td>12.07</td>
</tr>
<tr>
<td>Alexandra Hills</td>
<td>1,374</td>
<td>12.16</td>
</tr>
<tr>
<td>Cleveland</td>
<td>1,185</td>
<td>12.17</td>
</tr>
<tr>
<td>Birkdale</td>
<td>1,131</td>
<td>12.26</td>
</tr>
<tr>
<td>Thorneside</td>
<td>257</td>
<td>13.87</td>
</tr>
</tbody>
</table>

The study area has expanding suburban areas, particularly housing estates, but still contains large bushland remnants, including Venman Bushland National Park, Don and Christine Burnett Conservation Area, Ford Road Conservation Area, Buhot Creek Reserve, Brisbane Koala Bushlands, Sandy Creek Conservation Area, Bayview Conservation Park, Days Road Conservation Area, Serpentine Creek Conservation Park, Carbrook Wetlands Conservation Area and other remnant bushland. Importantly, Venman Bushland National Park, Don and Christine Burnett
Conservation Area, Buhot Creek Reserve, Ford Road Conservation Area, and Brisbane Koala Bushlands (Tingalpa Creek and JC Trotter Memorial Park sections) link to Neville Lawrie Reserve and Daisy Hill Conservation Park, forming a large, relatively connected tract of bushland.

The vegetation in these areas is primarily eucalyptus-dominated forest. Some local vegetation alliances include mixed eucalypt open forest and woodland, brush box open forest, melaleuca open forest and woodland, and scribbly gum open forest and woodland (Brisbane City Council 2000, Map 7). These vegetation alliances are dominated by *Eucalypt tereticornis*, *E. siderophloia*, *E. seeana*, *E. propinqua*, *E. acmenoides*, *E. crebra*, *E. microcorys*, *E. planchoniana*, *E. tindaliae*, *E. robusta*, *E. racemosa*, *Melaleuca quinquenervia*, *Callistemon salignus*, *Corymbia intermedia*, *C. citriodora*, *Lophostemon suaveolens*, *L. confertus*, *Angophora leiocarpa*, and *A. woodsiana* (Department of Environment 1998; Brisbane City Council 2000).

Redland City is home to 46 native species of terrestrial mammals, ~350 species of birds, 54 native species of reptiles (excluding marine turtles) and 26 native species of frogs (Redland City Council 2008). Eight introduced mammals, one introduced reptile and one introduced frog are also present (Redland City Council 2008).

In the study area only two species of large macropod persist: the red-necked wallaby and the swamp wallaby. Eastern grey kangaroos remain present in other areas of South East Queensland (including one offshore island of Redland), but have disappeared from mainland Redland and the study area (L. Bailey,
personal communication, 25 October 2013). This is likely due to increasing fragmentation and the absence of large tracts of suitable habitat.

2.2.2. Road-kill route

Road-kill surveys were conducted along selected roads within Redland, Brisbane and Logan cities in South East Queensland. Survey routes were selected on the basis of personal and colleague knowledge of wallaby road-kill presence and included roads that linked these routes to survey areas that were likely to have a range of wallaby road-kill rates. These roads were Beenleigh-Redland Bay Road, Serpentine Creek Road / Cleveland-Redland Bay Road, Double Jump Road, Mt Cotton Road (Double Jump Road to Valley Way), Sanctuary Drive, Valley Way, Heinemann Road, Kingfisher Road / Springacre Road, Eprapah Road, Duncan Road / Mt Cotton Road / Broadwater Road (Redland Bay Road to Alperton Road), Mt Cotton Road (Duncan Road to West Mt Cotton Road), West Mt Cotton Road, Cherbon Street and Alperton Road / Kloske Road (Figure 2.2).
The road-kill survey route (red line) through the study area in South East Queensland.

The most southern road is Beenleigh-Redland Bay Rd, Carbrook and marks the beginning of the road-kill survey route (travelling east). The most western road is Alperton/Kloske Rd, Burbank and marks the end of the road-kill survey route.

2.2.3. Data collection

Surveys were conducted every third day for approximately one month every second month between July 2010 and July 2012 (excluding May to August 2011 due to prioritisation of other field work). A total of 100 surveys were
conducted. A route of 78.68 km was driven between 05:00 and 10:00 hours at speeds between 40 km h\(^{-1}\) and 80 km h\(^{-1}\), driving in the lower range when traffic conditions allowed. At each wallaby road-kill incident, the date, species, sex, maturity, location and roadside variables were recorded. Roadside variables included road width, verge width, verge vegetation, topography (hill crest, dip, slope or flat) and the immediate habitat/land use. Additionally, opportunistic wallaby road-kill incidents outside of the survey periods and zones were recorded.

Due to the high detectability of road-killed large-bodied mammals from a vehicle (Taylor and Goldingay 2004; Teixeira et al. 2013a), it was deemed unnecessary to conduct a detectability study to account for animals that may have been missed during surveys. Due to the frequency of surveys (every three days) and detailed location notes, it was easy to determine whether a carcass had previously been counted in the data. Wallaby carcasses rarely remained present between bi-monthly survey periods, and, if they did, were substantially decayed to determine that the carcasses were old and not relevant to the current survey.

Other road and landscape attributes were obtained using ArcGIS 10.1 (Environmental Systems Research Institute (ESRI) 1999-2012). Road-kill incident data was entered into ArcGIS and variables such as distance to nearest body of water (Euclidean), distance to nearest road bend (following the road surface), and road sinuosity were measured. Where available, the average daily traffic volume, percent commercial vehicles and average speed were obtained for roads (or road sections) from either the Department of Transport and Main Roads or the relevant local council.
Daily weather variables were obtained from the Bureau of Meteorology’s Archerfield Airport weather station for the day previous to the survey day. Although this was not the closest weather station to the study area (located ~14.5km west of the edge of the study area), it provided the most consistent weather data and observations for more variables. Weather variables used included atmospheric pressure, relative humidity, wind speed, and maximum wind gust speed. Available weather data was recorded at 09:00 and 15:00 hours; therefore the average of the two daily measurements was used for atmospheric pressure, relative humidity and wind speed. Cumulative rainfall for the previous two-week and four-week periods was also obtained. Daily moon illumination for Brisbane was obtained from the Time and Date website (Time and Date AS 1995-2013).

2.2.4. Data analyses

All wallaby road-kill incidents were imported into ArcGIS 10.1 (Environmental Systems Research Institute (ESRI) 1999-2012) and a kernel density analysis was run from spatial analyst. A bandwidth of 300 m was used in the analysis. The road-kill incidents were grouped at the scale of 300 m road sections. The frequency of incidents within each road section was used as the dependent variable in all spatial statistical analyses.

A series of Chi-squared tests were conducted on the categorical variables of verge vegetation, habitat, road curvature, and road topography. Road sections were labelled as ‘low’ road-kill frequency if one or two road-kills occurred during
the survey period or as ‘high’ road-kill frequency if three or more road-kills occurred.

Poisson multiple regression was used to reveal influence in the distribution of road-kill incidents from the continuous spatial variables of traffic volume, percent commercial vehicles, average speed, road width, verge width, distance to nearest water body, distance to nearest road bend and road sinuosity. The final model was obtained by sequentially removing insignificant variables according to the greatest improvement in the Akaike’s Information Criterion (AIC), until the model could no longer be improved upon.

Poisson multiple regression was also used to reveal influence in the distribution of road-kill incidents from the continuous temporal variables of day length, moon illumination, rainfall over previous four weeks, atmospheric pressure, relative humidity, and maximum wind gust speed. Rainfall over the previous four weeks and maximum wind gust speed were used in preference to rainfall over the previous two weeks and average wind speed respectively, as they contributed more to the initial model. The final model was obtained by sequentially removing insignificant variables according to improvement in the AIC, until the model could no longer be improved upon.

2.3. Results

A total of 164 wallaby road-kills were recorded during surveys, with an additional 23 road-kills recorded opportunistically. Of these, 139 (84.8%) were red-necked wallabies and 25 (15.2%) were swamp wallabies. The maturity of one red-necked wallaby and the sex of 28 red-necked wallabies and two swamp
wallabies were not able to be determined due to severe disfiguration of the carcasses. There was no evidence of sex bias in red-necked wallaby road-kills, with 49 (44.1% of sexed individuals) females and 62 (55.9% of sexed individuals) males being recorded \( (\chi^2 = 1.5225, \text{df} = 1, p = 0.2172) \). Most red-necked wallabies were adults (60.1%), with 24 (17.4%) being subadults, 31 (22.5%) being juveniles. There was also no bias in maturity between the sexes in red-necked wallabies \( (\chi^2 = 1.0229, \text{df} = 2, p = 0.5996, \text{Table 2.2}) \).

**Table 2.2** The distribution of maturity between the sexes in road-killed red-necked wallabies and swamp wallabies in the study area.

<table>
<thead>
<tr>
<th></th>
<th>Red-necked wallabies</th>
<th>Swamp wallabies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Adult</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>Subadult</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Juvenile</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

There was similarly no evidence of sex bias in swamp wallaby road-kills, with 9 (39.1% of sexed individuals) females and 14 (60.9% of sexed individuals) males being recorded \( (\chi^2 = 1.087, \text{df} = 1, p = 0.2971) \). Most swamp wallabies were adults (80%), with four (16%) being subadults and one (4%) being a juvenile. A Chi-squared test for maturity bias between the sexes was not able to be conducted due to low numbers of subadult and juvenile swamp wallabies, even when subadults and juveniles were pooled. There was, however, a trend of higher proportions of adult males (Table 2.2). Due to low numbers of swamp wallaby road-kills, no further statistical analyses were able to be performed on this data, except where road-kill from both species are pooled.
2.3.1. Spatial patterns

Pooled wallaby road-kill rates were calculated for each road or road section (Table 2.3). These rates varied from 0.044 road-kills km$^{-1}$ month$^{-1}$ to 0.883 road-kills km$^{-1}$ month$^{-1}$. Heinemann Road had the highest road-kill rate, 1.5 times that of the second highest road, Mt Cotton Road between Double Jump Road and Valley Way. Four very high wallaby road-kill hotspots can be identified from the kernel density spatial analysis (Figure 2.3). These hotspots were located at two points along Heinemann Road, Broadwater Road near Stockyard Creek and Springacre Road north of Eprapah Road (two red sections in circled area 1, and areas 2 and 3 respectively in Figure 2.3). Other road sections of high wallaby mortality were the rest of Heinemann Road south of Giles Road, Alperton Road north of Leacroft Road, Mount Cotton Road near Sanctuary Drive, Cleveland-Redland Bay Road north of Serpentine Creek Road, West Mount Cotton Road south of the nursery, Mount Cotton Road north of Valley Way, and Mount Cotton Road east of Ney Road (remaining orange section in circled area 1, and areas 4-9 respectively in Figure 2.3).
Table 2.3 Wallaby road-kill rates for surveyed roads or road sections (red-necked wallabies and swamp wallabies pooled). In the calculations a month was defined as 30 days.

<table>
<thead>
<tr>
<th>Road section</th>
<th>Road section length km</th>
<th>Road-kills km(^{-1}) month(^{-1})</th>
<th>Estimated road-kills year(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heinemann Rd</td>
<td>3.85</td>
<td>0.883</td>
<td>41.4</td>
</tr>
<tr>
<td>Mt Cotton Rd (Double Jump Rd - Valley Way)</td>
<td>2.92</td>
<td>0.582</td>
<td>20.7</td>
</tr>
<tr>
<td>Broadwater Rd (Cherbon St - Alperton Rd)</td>
<td>1.36</td>
<td>0.515</td>
<td>8.5</td>
</tr>
<tr>
<td>Eprapah Rd</td>
<td>1.21</td>
<td>0.492</td>
<td>7.2</td>
</tr>
<tr>
<td>Kingfisher Rd / Springacre Rd</td>
<td>3.32</td>
<td>0.452</td>
<td>18.3</td>
</tr>
<tr>
<td>Double Jump Rd (eastern section)</td>
<td>2.99</td>
<td>0.356</td>
<td>12.9</td>
</tr>
<tr>
<td>West Mt Cotton Rd</td>
<td>5.10</td>
<td>0.350</td>
<td>21.7</td>
</tr>
<tr>
<td>Double Jump Rd (western section)</td>
<td>2.67</td>
<td>0.300</td>
<td>9.7</td>
</tr>
<tr>
<td>Mt Cotton Rd (Lyndon Rd - Ney Rd)</td>
<td>1.74</td>
<td>0.287</td>
<td>6.1</td>
</tr>
<tr>
<td>Alperton Rd / Kloske Rd</td>
<td>3.84</td>
<td>0.286</td>
<td>13.4</td>
</tr>
<tr>
<td>Duncan Rd (Redland Bay Rd - Lyndon Rd)</td>
<td>1.91</td>
<td>0.262</td>
<td>6.1</td>
</tr>
<tr>
<td>Valley Way</td>
<td>2.35</td>
<td>0.213</td>
<td>6.1</td>
</tr>
<tr>
<td>Sanctuary Dr</td>
<td>2.64</td>
<td>0.180</td>
<td>5.8</td>
</tr>
<tr>
<td>Mt Cotton Rd / Broadwater Rd (Ney Rd - Cherbon St)</td>
<td>2.25</td>
<td>0.178</td>
<td>4.9</td>
</tr>
<tr>
<td>Cleveland-Redland Bay Rd / Serpentine Creek Rd</td>
<td>9.32</td>
<td>0.129</td>
<td>14.6</td>
</tr>
<tr>
<td>Mt Cotton Rd (Duncan Rd - West Mt Cotton Rd)</td>
<td>1.89</td>
<td>0.126</td>
<td>2.9</td>
</tr>
<tr>
<td>Cherbon St</td>
<td>1.18</td>
<td>0.085</td>
<td>1.2</td>
</tr>
<tr>
<td>Beenleigh-Redland Bay Rd</td>
<td>9.11</td>
<td>0.044</td>
<td>4.9</td>
</tr>
</tbody>
</table>
Figure 2.3 Kernel density of pooled red-necked wallaby and swamp wallaby road-kills (pooled).

Bandwidth = 300m. Areas in pink circles are 1 Heinemann Road, 2 Broadwater Road near Stockyard Creek, 3 Springacre Road north of Eprapah Road, 4 Alperton Road north of Leacroft Road, 5 Mount Cotton Road near Sanctuary Drive, 6 Cleveland-Redland Bay Road north of Serpentine Creek Road, 7 West Mount Cotton Road south of the nursery, 8 Mount Cotton Road north of Valley Way, and 9 Mount Cotton Road east of Ney Road. Hot spots with very high road-kill densities were the two red sections within area 1, and areas 2 and 3. Areas 4-9 and the remaining orange sections of area 1 had high road-kill densities.
A Chi-squared test on road curvature was insignificant, revealing a lack of influence on road-kill frequencies ($\chi^2 = 1.5061$, df = 1, $p = 0.2197$). Chi-squared tests for all other categorical variables were unable to be conducted due to low values in some cells. The distribution of road-kills among these categorical variables would have been more appropriately tested between road-kill presences and absences, where absences were represented by an equal number of random points along the survey route where no road-kills occurred. This method was not employed due to time constraints to gather data on random points where wallaby road-kills were absent.

The final spatial Poisson multiple regression model included the variables percent commercial vehicles and distance to nearest water body (Table 2.4). Some variables were significantly correlated with percent commercial vehicles and each other, and thus average speed and traffic volume were not used in the model. Sinuosity was correlated with distance to nearest road bend and so was not used in the model. Red-necked wallaby road mortality was positively related to percent of commercial vehicles, but negatively related to distance to nearest water body. Even though neither variable in the model was statistically significant at the 5% level, the Chi-squared goodness of fit test was insignificant (residual deviance = 48.446, df = 57, $p = 0.783$), indicating that the data fit the model reasonably well. The resulting spatial model equation was

$$\log(\text{rnwrk}) = 0.914 + 0.019(\text{CV}) - 0.002(\text{water})$$

where rnwrk is the number of road-killed red-necked wallabies, CV is the percent of commercial vehicles and water is the distance to the nearest water body.
Table 2.4 Summary table of final Poisson multiple regression model of the spatial pattern of red-necked wallaby road-kills. CV = percent commercial vehicles, water = distance to nearest water body. AIC = 211.08, log-likelihood = -102.54. *** significant at 0.1% level, ~ significant at 10% level.

| Parameter | Estimate | Std. Error | 95% CI Lower | 95% CI Upper | z value | P(>|z|) |
|-----------|----------|------------|--------------|--------------|---------|---------|
| Intercept | 0.914    | 0.1940     | 0.5266       | 1.2877       | 4.714   | 2.43 x 10^{-6} *** |
| CV        | 0.019    | 0.0100     | -0.0015      | 0.0378       | 1.864   | 0.0624 ~ |
| water     | -0.002   | 0.0009     | -0.0033      | 6.953 x 10^{-5} | -1.835 | 0.0666 ~ |

2.3.2. Temporal patterns

The monthly road-kill rate across the survey period peaked in April, May, July and September (Figure 2.4). This trend suggests that red-necked wallaby road-kill rates peak in the cooler months, although this could not be confirmed due to the absence of surveys conducted in June and August.

![Figure 2.4 Mean number of red-necked wallaby road-kills per survey across months surveyed. The number of surveys conducted in each month is shown above each bar.](image_url)
The final temporal Poisson multiple regression model included maximum wind gust speed and cumulative rainfall over the previous four weeks (Table 2.5). Many variables were intercorrelated, and thus day length, atmospheric pressure, and humidity were not able to be used in the model. Red-necked wallaby road mortality was negatively related to both maximum wind gust speed and rainfall over the previous four weeks. The Chi-squared goodness of fit test was insignificant (residual deviance = 105.678, df = 91, p = 0.139), indicating that the data fit the model reasonably well. The resulting temporal model equation was

\[
\log(\text{rnwrk}) = 1.678 - 0.030(\text{windgust}) - 0.003(\text{rain4w})
\]

where rnwrk is the number of road-killed red-necked wallabies, windgust is the maximum wind gust speed and rain4w is the rainfall over the previous four weeks.

**Table 2.5** Summary table of final Poisson multiple regression model of the temporal pattern of red-necked wallaby road-kills. windgust = maximum wind gust speed, rain4w = rainfall over the previous four weeks. AIC = 275.06, log-likelihood = -134.53. *** significant at 0.1% level, ** significant at 1% level, * significant at 5% level.

| Parameter | Estimate | Std. Error | 95% CI | z value | P(>|z|) |
|-----------|----------|------------|--------|---------|--------|
| Intercept | 1.678    | 0.3961     | 0.9045 | 2.4560  | 4.236  |
| windgust  | -0.030   | 0.0100     | -0.0498| -0.0105 | -2.967 |
| rain4w    | -0.003   | 0.0016     | -0.0065| -0.0004 | -2.122 |

**2.4. Discussion**

The wallaby road-kill rates investigated in the study varied greatly, with Heinemann Road experiencing a rate 20 times that of Beenleigh-Redland Bay Road,
although both were within the range of macropod road-kill rates reported in the literature. The wallaby road-kill rate at Heinemann Road was similar to that reported for kangaroos (red kangaroos, *Macropus rufus*, euros, *M. robustus erubescens*, and grey kangaroos, *M. giganteus* and *M. fuliginosus*) along the Silver City Highway in north-western NSW (0.88 c.f. 1.05 road-kills per km per month, Lee et al. 2004; Klöcker et al. 2006). This rate, however, occurred during drought conditions, when kangaroo road-kill rates were much elevated compared to post-drought conditions in the same area (0.13 road-kills per km per month, Lee et al. 2004; 0.21 road-kills per km per month, Lee and Croft 2008). In comparison, this emphasises the exceptionally high rate of wallaby road-kill detected during the present study, as this was conducted during normal conditions and involved only two species of macropod. This study was, however, conducted in a very different environment, where the influences on macropod road-kill frequencies may be very different. A previous road-kill survey conducted in the same area (but including some different roads) also identified Heinemann Road as a site of high road mortality for red-necked wallabies and found more red-necked wallaby road-kill in rural habitats (Dexter 2007). Conversely, however, numbers swamp wallaby road-kill were greater in forested habitats. Unfortunately the road-kill rates reported by Dexter (2007) could not be directly compared due to the varying temporal method of data collection.

The road-kill rates observed along other roads in the current study fall within or close to rates reported in the literature. Ramp and colleagues (2006a) recorded a swamp wallaby road-kill rate of 0.13 road-kills km\(^{-1}\) month\(^{-1}\) in the Royal National Park in NSW, while Osawa (1989) recorded a rate of approximately
0.08 swamp wallaby road-kills km\(^{-1}\) month\(^{-1}\) on North Stradbroke Island in Queensland. In a suburban area of Sydney, swamp wallabies were killed along two road sections at rates of 0.19 and 0.45 road-kills km\(^{-1}\) month\(^{-1}\) (Harris et al. 2008). Along three major roads in eastern NSW, swamp wallabies were killed at a rate of 0.05 road-kills km\(^{-1}\) month\(^{-1}\) (Taylor and Goldingay 2004).

The wallaby road-kill rates observed by Buchanan (2005) along different roads in the same area as the present study were much higher during this eight-week survey. For example, along the same 2 km section of Mt Cotton Road (Buchanan 2005, site 6), a road-kill rate of 0.6 road-kills km\(^{-1}\) month\(^{-1}\) was recorded in the current study. This compares to Buchanan’s rate of 2.14 road-kills km\(^{-1}\) month\(^{-1}\). Similarly, Buchanan recorded a road-kill rate of 0.80 road-kills km\(^{-1}\) month\(^{-1}\) along West Mount Cotton Road (Buchanan 2005, site 2), compared to only 0.15 road-kills km\(^{-1}\) month\(^{-1}\) in the current study. During the five years between these studies and during the surveys in the current study, these two road sections did not change significantly in alignment or speed limit, except for a small section (~100m) of West Mount Cotton Road where road works occurred to add a round-a-bout outside the entrance of a quarry. The eight-week survey conducted by Buchanan (2005) may have coincidentally occurred during a particularly high period of road-kills, or it is possible that the wallaby populations have declined during the period between the studies. Reduced or low road-kill rates in areas with suitable habitat can indicate a possible decline in wildlife populations that may have been driven by previous high road-kill rates and/or combined pressures from the surrounding peri-urban environment (Eberhardt et al. 2013; Jones et al. 2013b).
Traffic volume is a commonly used variable in road-kill models (Burgin and Brainwood 2008), although, to my knowledge, the percent of traffic that were commercial vehicles has not been used previously. Despite these variables being slightly negatively correlated in this study, percent commercial vehicles was a much better predictor of red-necked wallaby road-kill frequency. It is plausible that heavy vehicles contribute to a large proportion of the wallaby mortalities in the area. Because hitting a wallaby may cause damage to standard vehicles (and possibly human injury), it is possible that car drivers drive more cautiously where they are perceived to be at risk of hitting wallabies than do drivers of large commercial-sized vehicles. Additionally, wallabies were more likely to flee in response to trucks than they were to passenger vehicles (see Chapter 4), and this flightiness may increase their susceptibility to collisions (Lee et al. 2010).

The negative influence of distance to water suggests that wallabies follow creek lines in landscapes or cross roads to access water in dams or lakes. This relationship was also found for eastern grey kangaroo road-kills along the Snowy Mountains Highway in NSW (Ramp et al. 2005). Kangaroo (eastern and western grey kangaroos, red kangaroos and euros) road-kill incidents were also associated with creeks, drainage areas and artificial water sources during a drought in north-western NSW (Lee et al. 2004).

Previous reports of temporal peaks in macropod road-kills have roughly centred around the cooler months (Dexter 2007: winter months; Ramp and Roger 2008: April to August 1996-2005; Chambers et al. 2010: March to August 2000-2004). The results of this study align with these findings, which recorded increased road-kill rates of red-necked wallabies in April, May, July and September.
Chambers and colleagues (2010) also found road-kill frequency to be negatively correlated with day length, however due to day length being positively correlated with both maximum wind gust speed and rainfall over the previous four weeks, it was not able to be included in the regression model in the current study. The negative influence of these two variables on road-kill frequency does, therefore, reflect a possible negative relationship with day length. This possible relationship is plausible given that in winter, when day length is shorter, peak traffic periods align closer to dawn and dusk, when wallabies are most active.

Several studies have recorded a relationship of increasing macropod road-kill frequencies with decreased preceding rainfall levels. This pattern is most expected in arid areas and/or during periods of drought, as water run-off from roads increases grass growth at roadsides, thus attracting macropods to forage at the roadside (Lee 2006). This was the case in along the Silver City Highway in north-western NSW, where kangaroo road-kill frequency was negatively associated with cumulative rainfall over the previous 30 days during a drought (Lee et al. 2004). Lee (2006) also found kangaroo road crossing rates across the arid-zone highway tended to be greater when no rain had fallen over the preceding two weeks. Outside the arid-zone, eastern grey kangaroos and wallabies (red-necked and swamp, pooled) were positively associated with rainfall over the previous six months on the Snowy Mountains Highway, NSW (Ramp et al. 2005). Furthermore, increases in eastern grey kangaroo road mortality were observed following months of below average rainfall in urban Canberra, Australian Capital Territory (ACT) (Lintermans and Cunningham 1997). The current study, therefore, reaffirms this relationship between rainfall and macropod road-kills, giving
support to the idea that macropods may utilise road verges for foraging more when there is less quality forage available away from roads due to lower rainfall levels.

Very few road-kill studies included other daily weather variables in their models, although Lee (2006) did incorporate several, including maximum wind gust speed. In Lee’s (2006) study, maximum wind gust speed was positively related to eastern grey kangaroo road-kills and the density of red kangaroos, eastern and western grey kangaroos and euros at the roadside. This is the opposite relationship found in the current study, perhaps highlighting differences in environments or species. More specifically, these conflicting results may be the result of differing predatory avoidance strategies among the study species and/or environments during windy conditions.

It is possible that, in an arid, sparsely vegetated environment, kangaroos tend to use large group sizes, early detection and flight as an anti-predatory strategy, which is likely to be heightened during windy conditions that may interfere with visual and acoustic predatory detection (e.g. McGowan et al. 2002). Lee (2006) reported that kangaroo species’ flight response to approaching vehicles was positively correlated with road-kill rates; thus if flightiness increases in windy weather, kangaroos may be more susceptible to road mortality during these conditions. Conversely, in areas where remnant forest is present, such as in the current study area, macropods may avoid moving into open areas to graze due to the decrease in detectability of approaching predators in windy conditions (Hayes and Huntly 2005). This would lead to fewer macropods grazing in the open road verges, thereby reducing their probability of encountering roads and subsequently
being hit by vehicles. Additionally, red-necked wallabies tend to rely more heavily on crypsis as an anti-predatory strategy than do kangaroos, which tend to reply on early detection and large numbers (Southwell 1987; Jarman and Wright 1993; Coulson 1999).

2.5. **Conclusion**

High rates of wallaby road mortality were observed in some areas, particularly along Heinemann Road, and some form of mitigation should be implemented in these areas. The influence of the percent of commercial vehicles on red-necked wallaby road mortality in this study appears to be the first reported case of such a relationship on macropod (or any other wildlife) road mortality. Because of this positive relationship, a novel local mitigation option may be to divert heavy vehicles away from these hotspot areas (and other areas of high wallaby presence), with continued monitoring to assess the effect of the diversion. This finding potentially also has major implications for new roads to be built through natural areas that are primarily intended for the use of heavy commercial-sized vehicles. Such roads should be avoided, especially where wildlife populations are already declining and/or susceptible to other major population threats that may exacerbate these impacts.

There is some evidence (although minor) to suggest that the wallaby populations may have declined in the study area in recent years. Population studies and modelling need to be conducted to assess the viability of the red-necked wallaby and swamp wallaby populations in the study area to avoid possible decline, similar to that experienced by koalas in the region.
It is recommended that future studies of road-kill patterns consider including the percent of commercial vehicles as a possible contributing factor, not only traffic volume. This same recommendation also applies to weather variables.
Chapter 3

Wildlife warning signs: public assessment of sign components, placement and designs to optimise driver response

The contents of Chapter 3 are an article that has been accepted for publication in a peer-reviewed scientific journal. I was responsible for conducting all research reported in this article and for writing the body of the text. The co-author was my principle supervisor and was listed in recognition of this contribution and editing of the manuscript.

Chapter 3


Amy Bond

Date

Supervisor: Darryl Jones

Date
3. **Wildlife warning signs: public assessment of components, placement and designs to optimise driver response**

### 3.1. Introduction

Wildlife-human interactions can occur frequently in urban environments, particularly at the front of urban sprawl expansion (Kretser *et al.* 2008). One such interaction that is particularly conspicuous is the wildlife-vehicle collisions that often occur in urban areas, especially where habitat remnants are still present in the landscape or the urbanised edge is expanding into rural or natural landscapes (Ng *et al.* 2008). Compared to more natural landscapes, peri-urban areas often have higher human densities coupled with higher traffic volumes and road densities, which increase the likelihood of wildlife coming into contact with roads and vehicles, and therefore the risk of wildlife-vehicle collisions (Ng *et al.* 2008). This can be seen in a state-wide spatial analysis of wildlife-vehicle collisions in New South Wales (NSW) that revealed several hotspots concentrated around urban centres, such as Canberra, Newcastle and Byron Bay (Ramp and Roger 2008).

High incidence of wildlife-vehicle collisions can have significant impacts: increasing wildlife mortality rates, influencing population demographics if there are age or sex biases in road mortality, reducing wildlife dispersal success, reducing gene flow between populations, animal welfare issues, causing human injury and occasionally fatalities, and the financial costs to society associated with human injury, vehicle damage, wildlife rehabilitation (for those that survive), and removal of animal carcasses (Forman *et al.* 2003; Huijser *et al.* 2009). Mitigating
these impacts of wildlife-vehicle collisions is, therefore, very important in urban areas, for both the wildlife and the humans involved. Additionally, societies where wildlife-vehicle collisions are reduced will benefit from the reduced financial burden of such interactions (Huijser et al. 2009).

Wildlife warning signs are the most commonly used and widespread form of road mitigation (Forman et al. 2003; Huijser and McGowen 2010). These signs are aimed at reducing the incidence of wildlife-vehicle collisions, and therefore reducing injuries and fatalities to wildlife and drivers, as well as vehicle damage (Huijser and McGowen 2010). It may also be viewed that wildlife warning signs are a way of reducing the liability risk of wildlife-vehicle collisions from road agencies. Despite their common use, however, evidence of their effectiveness is inconsistent; most often, sign effectiveness has not been evaluated (Romin and Bissonette 1996; Al-Kaisy et al. 2008). For example, a lighted, animated deer crossing sign on State Highway 82 in Colorado, USA was reported to reduce vehicle speeds, but this was minimal and, hence, ineffective at reducing the deer-vehicle collision rate (Pojar et al. 1975). In contrast, temporary flashing deer warning signs reduced deer-vehicle collisions by 51% during deer migrations and reduced the number of vehicles recorded to be speeding by at least 8km/h, but this effect did not last to the second year of the trial (Sullivan et al. 2004a).

Al-Ghamdi and AlGadhi (2004) compared seven camel warning signs of different designs and size, using the reduction in vehicle speed at night in response to the sign as the measure of effectiveness. The assessed signs included the standard warning sign design, both with and without diamond reflective material, and an alternative sign that included the words “camel-crossing” and an advisory
speed; the three sign designs were also tested at various sizes (Al-Ghamdi and AlGadhi 2004). Two of the signs did not elicit a reduction in vehicle speed, with the other signs significantly reducing speed by between 1.93km/h and 6.51km/h. Both sign designs were deemed effective at producing a relatively small, yet statistically significant, reduction in vehicle speed, with the larger signs that used diamond reflective material being the most effective (Al-Ghamdi and AlGadhi 2004). However, when a series of similar large signs for moose-vehicle collisions were installed in conjunction with a public awareness campaign, records indicated a 41% drop in collisions with urban moose in Prince George, British Colombia, Canada (Rea 2012).

Dique and colleagues (2003) trialled differential speed wildlife warning signs that aimed to reduce koala-vehicle collisions during the breeding season. Although the number of incidents detected on trial roads was less than on control roads, there was no reduction of incidents during the trial periods when compared to the control periods (Dique et al. 2003). In a recent trial of 16 wildlife (koala) warning signs with vehicle-activated flashing lights, speed reductions ranging from 0.49 km/h to 8.33 km/h were recorded when the vehicle-activated lights were turned on (Sullivan et al. 2013). The vehicle speed at which the flashing lights were activated was altered experimentally, with vehicle speeds being consistently lower when lights were activated at 19km/h, the lowest recommended speed for the radar units. Unfortunately, however, vehicle speeds before and after the signs were not recorded, and thus speeds were only compared with those when the signs were covered and no information on koala-vehicle collisions was available at the time of the study at the study sites (Sullivan et al. 2013).
Despite the limited evidence of their effectiveness, wildlife warning signs are likely to continue to be the most commonly implemented mitigation measure of wildlife-vehicle collisions due to their relatively low cost (Huijser et al. 2009). Therefore, improving the potential effectiveness of this inexpensive option may aid in reducing the impacts of road mortality on macropod populations, as well as other wildlife populations. This may be particularly important in locations where road mortalities to wildlife contribute to local population declines, if the landscape is unsuitable for other mitigation options, or funds for more effective mitigation are not available. Additionally, by improving the effectiveness of wildlife warning signs, the cost of macropod-vehicle collisions to society, through both human injuries and fatalities and vehicle damage, would be reduced (Huijser et al. 2009).

In Australia, the most commonly used wildlife warning signs are static, and very little research has been conducted on alternative sign designs and the potential to improve driver response. One exception was a study of an alternative wildlife warning sign designed and installed in Coles Bay and Bruny Island in Tasmania (Magnus et al. 2004). This design included an image of a car hitting a kangaroo, an advisory speed limit and the words “DUSK TO DAWN”. This sign was designed by the Tasmanian Wildlife Roadkill Collective that was made up of representatives from the Tasmanian Environment Centre, the University of Tasmania, three State agencies (Department of Primary Industries, Water and Environment, Department of Infrastructure, Energy and Resources, Department of Tourism, Parks, Heritage and the Arts) and three local councils (Kingborough Council, Brighton Council, Hobart City Council). While the design process involved the input of a comprehensive suite of perspectives, the opinions of drivers were
not researched. As it is the behaviour of drivers that wildlife warning signs are attempting to influence, we suggest that drivers should be consulted as to what sign designs they would be more likely to respond.

Improving the design and placement of wildlife warning signs to increase the likelihood of driver response has the potential to reduce the incidence of wildlife-vehicle collisions. Additionally, including sign elements, such as time period specifications and updated road-kill counts for message reinforcement, may be deemed as important for increasing driver response. Not only may the likelihood of driver response be increased with optimal sign design, but the type, extent and duration of driver response may also change to reduce the risk of collision with wildlife. To achieve this, several steps must be taken, the first of which is to examine and assess the opinions of drivers on wildlife warning sign designs through a comprehensive public opinion survey. In doing this, a range of sign designs should be provided alongside currently used signs, so that sign designs are presented equally and bias towards either current or alternative designs is avoided. More than one such public opinion survey study may need to be conducted in order to refine the sign designs. This is a crucial precursor to the process of assessing, approving, producing and experimentally field-testing those wildlife warning sign designs with the best likelihood, type, extent and duration of response and/or include features deemed as important to eliciting a response by drivers. The objective of the present study was to initiate this process and conduct the first public opinion survey on wildlife warning sign designs. More specifically, the project aimed to (1) evaluate the importance of sign elements (i.e. time period specifications and updated road-kill counts); (2) evaluate the importance of sign
temporal and spatial placement; (3) design alternative wildlife warning signs; (4) evaluate and rank current and alternative sign designs by assessing the relative likelihood of driver response; (5) identify the messages conveyed by the top ranking signs; and (6) identify key features of the top ranking signs that may increase their noticeability, and therefore driver response.

3.2. Methods

3.2.1. Alternative sign designs

There is a variety of currently used wildlife warning signs in Australia (Department of Transport and Main Roads 2012), the design of which does not vary greatly. To our knowledge, there has been no attempt to assess the effectiveness of these standard designs or to use alternative designs. The most commonly used wildlife warning sign in Australia consists of a reflective yellow diamond with a black animal silhouette (e.g. Figure 3.1a). The wildlife signage guidelines for the Queensland Department of Transport and Main Roads (Department of Transport and Main Roads 2012) stipulate that this style of sign is only to be used for animals large enough to potentially cause human injury and/or vehicle damage. The koala (Phascolarctos cinereus) is one exception to this rule, as it is thought that drivers are likely to avoid hitting a koala, as it is an “endeared national symbol of Australia” (Department of Transport and Main Roads 2012), and in doing so potentially risk danger to themselves and/or occupants of other vehicles. For smaller animals that are unlikely to cause harm to the vehicle occupants and/or vehicle damage, wildlife information signs (e.g. Figure 3.1b) are used to inform of the presence of these animals. Due to the small potential for
human injury and vehicle damage to result from collisions with small wildlife, some road agencies do not expect these signs to elicit a response from drivers (Department of Transport and Main Roads 2012). High impact wildlife warning signs (e.g. Figure 3.1c) are very selectively used in areas where the risk of hitting an animal that may cause human injury and/or vehicle damage is significant (Department of Transport and Main Roads 2012).

In a collaborative effort to produce alternative wildlife warning sign designs, a group of ecologists from various backgrounds met on 14 March 2013 at Griffith University, Brisbane, and discussed possible features that may elicit greater responsiveness from drivers (personal communication D. Jones, C. Dexter, K. Sullivan, R. Appleby, M. S. O’Keefe, L. Bernede, M. McGregor, P. Lewis, A. Gorring, M. Kunde, M. Casella). Some of the ideas produced from this meeting and used to design alternative sign designs are summarised in Table 3.1.

A Google image search for “wildlife warning road signs” was also conducted to assist in designing signs that vary from those commonly used in Australia. Alternative signs were designed and selected by the researchers, as funds for a graphic designer were not available.
Table 3.1 Ideas for alternative wildlife warning sign designs produced from discussions held on 14 March 2013 at Griffith University, Brisbane. Persons who contributed to this discussion were D. Jones, C. Dexter, K. Sullivan, R. Appleby, M. S. O’Keefe, L. Bernede, M. McGregor, P. Lewis, A. Gorrying, M. Kunde and M. Casella.

<table>
<thead>
<tr>
<th><strong>Sign design features</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signage with animal-activated flashing lights or electronic message</td>
</tr>
<tr>
<td>Vehicle speed-activated flashing lights or message &quot;SLOW DOWN PLEASE&quot;, and then, if the vehicle slows &quot;THANK YOU&quot; – positive reinforcement</td>
</tr>
<tr>
<td>Display cute images of wildlife to appeal to people’s sense of protection for animals</td>
</tr>
<tr>
<td>Take a more anthropocentric approach – display images or messages that allude to human injury and vehicle damage from colliding with large wildlife</td>
</tr>
<tr>
<td>Use more realistic and graphic images of wildlife-vehicle collisions (e.g. a car after hitting a kangaroo)</td>
</tr>
<tr>
<td>Display &quot;HIGH WILDLIFE COLLISION ZONE&quot; instead of &quot;WILDLIFE&quot; or &quot;WILDLIFE ZONE&quot; – more specifically descriptive of potential danger</td>
</tr>
<tr>
<td>Include words to encourage drivers to be more vigilant e.g. &quot;LOOK FOR WILDLIFE ON ROADSIDES&quot;</td>
</tr>
<tr>
<td>Display the number of animals killed on that road over the previous year (or other time period)</td>
</tr>
</tbody>
</table>

3.2.2. Public opinion survey

The public opinion survey was primarily designed to enable the comparison of the likelihood of responses to each sign and determine the value of sign components. The sign component and placement questions discussed here were:

“Are you more or less likely to respond to a sign with specified time periods with increased alertness and reduced driving speed if you are driving during this period (6pm – 6am, Aug – Dec)? e.g. 8pm in November” (answer options: “more
likely”, “less likely”, and “I am equally likely to respond to signs in this way, whether or not time specifications are displayed”); 

“Are you more or less likely to respond to a sign with specified time periods with increased alertness and reduced driving speed if you are driving outside this period (6pm – 6am, Aug – Dec)? e.g. 10am in April” (answer options: “more likely”, “less likely”, and “I am equally likely to respond to signs in this way, whether or not time specifications are displayed”); 

“Are you more or less likely to respond to a sign that displays the number of road-killed animals that have occurred on that road over the previous year with increased alertness and reduced driving speed?” (answer options: “more likely”, “less likely”, and “I am equally likely to respond to signs in this way, whether or not road-kill numbers are displayed”); 

“Are you more likely to respond with increased alertness and reduced driving speed to a permanent, periodic or temporary wildlife warning sign?” (answer options: “permanent”, “periodic”, “temporary”, and “I am equally likely to respond to a sign whether it is permanent, periodic or temporary”); and 

“Are you more likely to notice a wildlife warning sign if it is positioned on the roadside or in the median strip (where available)?” (answer options: “roadside”, “median strip”, and “I am equally likely to notice both”). 

Three standard wildlife warning signs (approved by the Department of Transport and Main Roads, Figure 3.1a-c) and five alternative signs (Figure 3.1d-h) were included in the survey. Each sign was graphically presented in the survey and the participants asked a series of questions. The main question used to compare sign designs was “Please indicate the likelihood that you would respond to this
sign by increasing alertness and reducing driving speed when driving at the following speeds”. Here a five-part Likert-type scale (5 - highly likely, 4 - likely, 3 - unsure, 2 - unlikely, 1 - highly unlikely) was used to determine the likelihood of response to each sign at 60km/h, 80km/h and 100km/h. This same question was asked separately regarding an animal-activated sign and a vehicle speed-activated sign, neither of which were displayed graphically. For each sign, participants were also asked “Please explain the message that is conveyed to you by this sign” and “What part or aspect of this sign stands out the most to you?” in open form answers. Smaller images of all the sign designs were then displayed together and participants were then asked “Of all of the signs displayed above, which one are you most likely to respond to by increasing alertness and reducing driving speed?”. In addition, participants were asked about their general driver experience, whether they had previously been involved in collisions with animals and their age, gender and state of residence, however participant demographics and experience are irrelevant at this stage of assessing driver response to wildlife warning signs, as signs are targeted at all drivers. Therefore, for the purposes of this study, responses to questions were not compared among participant demographics and experiences. If further research is conducted in this area, as outlined above, and developments are made, it may then be appropriate to separate responses from participants in different regions (i.e. urban centres, peri-urban areas, rural areas, etc.) to produce the most optimal design and outcome for drivers in different settings. The survey was delivered through the online survey tool SurveyMonkey. See Appendix A for the complete survey.
**Figure 3.1** The eight signs included in the survey.  

- **a)** sign #1, W5-29, source: DTMR;  
- **b)** sign #2, TC1588, source: DTMR;  
- **c)** sign #3, TC1621, source: DTMR;  
- **d)** sign #4, W5-29 (modified), sign image source: DTMR;  
- **e)** sign #5, wildlife images source: Phillip Martin;  
- **f)** sign #6;  
- **g)** sign #7, photo source: A. Blacker;  
- **h)** sign #8, photo source: Western Australia Police.  

The following note accompanied sign #4: "A single sign is displayed; the electronic message that is displayed above the sign is variable. The first message is activated when a speeding vehicle is detected and the second message is activated if the speeding vehicle slows down."
3.2.3. **Participant recruitment**

The survey was aimed at persons 18 years or older who held a licence that enabled them to drive in Australia. Participants to the survey were recruited mainly by emailing and Facebook posts to existing networks of colleagues, associates, friends and family, and encouraging the forwarding on through subsequent networks. Although this method of recruitment was not random, it ensured that the survey was at least distributed to people with a range of backgrounds, education and values. A webpage dedicated to the survey was also created on the My Roadkill website (myroadkill.com.au) to assist in recruiting participants. The survey was also posted to the My Roadkill Facebook page. The Royal Automobile Club of Queensland (RACQ), the Royal Automobile Club of Victoria (RACV) and the National Roads and Motorists’ Association (NRMA) were approached to assist in focusing recruitment to drivers and to reach a broader audience, but all declined. RACV declined to participate because the alternative sign designs were not approved by any road agency; RACQ and NRMA did not give reasons for declining to participate. Due to the limited funds and time in which survey responses were required, the survey could not be advertised or distributed using any other methods.

From here onwards, the animal-activated and vehicle speed-activated signs will be referred to as the A-A and VS-A signs, respectively. Additionally, for conciseness, the terms ‘appropriate response’, ‘to respond appropriately’ and ‘to respond’ are used when referring to drivers increasing alertness and decreasing driving speed in response to signs.
3.2.4. Data analyses

Separate Chi-square tests were conducted on the likelihood of participants to respond to signs displaying time specifications, both within and outside the specified time period, and to signs displaying the number of animals previously killed along the road. Chi-square tests were also conducted on the likelihood of participants to respond to permanent, periodic and temporary signs and signs placed on the roadside or median strip. Periodic signs were defined as being displayed for a two-week period every three months and temporary signs were defined as being displayed for a one month period every year.

Chi-square tests were conducted comparing participant answers to the question “Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds” for each of the signs (including the A-A and VS-A signs). Separate tests were conducted for participant answers at 60km/h, 80km/h and 100km/h. To reduce the occurrence of values less than five in the contingency tables, the categorical answers of “highly likely” and “likely”, and “highly unlikely” and “unlikely” were pooled. This resulted in a 10 (signs) x 3 (answers) contingency table being analysed for each speed.

Additionally, the signs were ranked using the Likert-type scale responses to the above question by summing the scores for the three speed items for each participant, and then averaging these across all participants. This gave a minimum possible score of 3 and a maximum possible score of 15, with higher scores relating to higher likelihood of response. Signs were then ranked according to their mean score. One participant did not answer this question for sign #3 at all three
speeds and was excluded from the calculations for this sign. Scored data from Likert-type scales are ordinal (unless distances between the scale options can be justified as equal), and as such parametric statistics and the use of means are inappropriate (Jamieson 2004). Here, however, mean sign scores were not compared directly; mean values were only obtained in order to rank the signs based on answers given on the Likert-type scale. Such ranking would not be possible using median or mode values.

Separate Chi-square tests were conducted to test for even distribution of participant answers to the two questions “Of all of the signs displayed above, which one are you most likely to respond to by increasing alertness and reducing driving speed?” and “Of all of the signs displayed above, which one do you think drivers in general are most likely to respond to by increasing alertness and reducing driving speed?”.

All statistical analyses were performed in the statistical program R (The R Foundation for Statistical Computing 2011).

3.3. Results

3.3.1. Public survey participants

A total of 134 complete survey responses were received. The majority of these participants held an Australian drivers' licence (98.5%), resided in Queensland (70.1%), and were female (69.4%). A range of ages and length of driving experience of participants were included in the survey. Most participants drove daily (76.1%) or one to a few times per week (17.2%) and regularly drove in areas that displayed wildlife warning signs (69.4%). Two participants (1.5%) held
an international drivers’ licence or other licence that allowed them to drive in Australia. See Appendix B for further details.

3.3.2. **Sign elements and placement**

The presence of season and time indicators on wildlife warning signs altered the likelihood that participants would react to signs inside and outside the specified periods. During the specified time period, 56.0% of participants were more likely, 38.8% were equally likely, and 5.2% were less likely to respond appropriately ($\chi^2 = 53.567$, df = 2, $p = 2.334 \times 10^{-12}$, Figure 3.2a). Outside the specified time period, 49.3% of participants were less likely, 46.3% were equally likely, and 4.5% were more likely to respond appropriately ($\chi^2 = 50.388$, df = 2, $p = 1.144 \times 10^{-11}$, Figure 3.2b). The addition of a count of the number of animals killed by vehicles over the previous year (or other time period) significantly increased the likelihood that participants would react to the wildlife warning sign (72.4% more likely to respond, $\chi^2 = 102.731$, df = 2, $p = 2.2 \times 10^{-16}$, Figure 3.3).
Figure 3.2 The proportion of participants that were more likely, less likely and equally likely to respond to a sign displaying specified time periods a) inside and b) outside the specified time period. N = 134.

Figure 3.3 The proportion of participants that were more likely, less likely and equally likely to respond to a sign displaying the number of road-killed animals over the previous year (or other time period) for the section of road. N = 134.
When questioned about the temporal and spatial placement of signs, the majority of participants were equally likely to respond (55.2% and 59.7%, respectively), regardless of how frequently or where the sign was placed. Permanent, periodic and temporary placements of signs were more likely to produce a response in 23.1%, 13.4% and 8.2% of participants, respectively. The placement of signs on the roadside was more likely to produce a response in 31.3% of participants, whereas this was true for only 9.0% of participants for a sign placed in the median strip.

3.3.3. **Sign design comparisons**

The likelihood that participants would respond to signs with reduced driving speed and increased vigilance was significantly different among the ten signs at all three speeds (60km/h: \( \chi^2 = 126.105, \text{df} = 18, p < 2.2 \times 10^{-16} \); 80km/h: \( \chi^2 = 152.771, \text{df} = 18, p < 2.2 \times 10^{-16} \); 100km/h: \( \chi^2 = 187.429, \text{df} = 18, p < 2.2 \times 10^{-16} \)). At 60km/h, the A-A sign, VS-A sign, sign #4, sign #3 and sign #7 were more likely to produce an appropriate response than the other signs (Figure 3.4a). At 80km/h and 100km/h, the A-A sign, VS-A sign, sign #4, sign #3 and sign #6 were more likely to produce an appropriate response than the other signs (Figure 3.4b and c).
Figure 3.4 Participant likelihood to respond appropriately to the signs at a) 60km/h, b) 80km/h, and c) 100km/h. For sign #3 N = 133; for all other signs N = 134. See Figure 3.1 for sign images.
The sign most likely to produce an appropriate response from participants was unevenly distributed among the signs ($\chi^2 = 79.2537$, df = 7, p-value = $1.955 \times 10^{-14}$). Sign #3 (30.6%), sign #4 (22.4%) and sign #6 (19.4%) were the most frequently preferred signs by participants (Figure 3.5).

**Figure 3.5** The proportion of participants that selected each sign as the most likely to produce the response of increased alertness and reduced driving speed. N = 134.

Using the ranking from the mean scores (from the Likert-type scale) for each sign and the preference ranking, sign #3, sign #4 and sign #6 were the three highest ranked signs using both methods (Table 3.2). Despite this, the sign
placement in the top three signs varied between the rankings; the scored and preference ranks align for only the three lowest ranked signs. When the A-A and VS-A signs were included in the scored rankings, they were the highest ranked signs, respectively.

A variety of messages were conveyed to participants by the three highest ranking signs (Table 3.3). The most consistently conveyed messages were for drivers to slow down, that there is a high animal presence in the area and that there is a crash risk. Participants also mentioned numerous aspects of each sign as the most conspicuous (Table 3.4) with words relating to speed, images, the electronic message and colours being the elements most consistently highlighted. It should also be noted that some participants stated that sign #6 and sign #8 were too cluttered and had too many words to be able to read at speed.
Table 3.2 Sign mean scores (from the Likert-type scale) and ranks based on both scores and participant preferences (see Figure 3.5). The shaded rows represent the three highest ranking signs (not including the A-A and VS-A signs). For sign #3 N = 133; for all other signs N = 134. * The A-A and VS-A signs were ranked separately so that scored and preference ranks could be directly compared, as these signs were not included in the participant preference question. The scored ranks in parentheses are those when A-A and VS-A signs were included in the ranking. Signs are ordered by scored rank, inclusive of A-A and V-A signs.

<table>
<thead>
<tr>
<th>Sign</th>
<th>Sign image</th>
<th>Mean score ± SE</th>
<th>Scored rank*</th>
<th>Preference rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-A</td>
<td>-</td>
<td>14.2±0.16</td>
<td>(1)</td>
<td>-</td>
</tr>
<tr>
<td>VS-A</td>
<td>-</td>
<td>13.6±0.20</td>
<td>(2)</td>
<td>-</td>
</tr>
<tr>
<td>#4</td>
<td><img src="image1.png" alt="Sign image" /></td>
<td>13.3±0.20</td>
<td>1 (3)</td>
<td>2</td>
</tr>
<tr>
<td>#6</td>
<td><img src="image2.png" alt="Sign image" /></td>
<td>12.8±0.24</td>
<td>2 (4)</td>
<td>3</td>
</tr>
<tr>
<td>#3</td>
<td><img src="image3.png" alt="Sign image" /></td>
<td>12.7±0.21</td>
<td>3 (5)</td>
<td>1</td>
</tr>
<tr>
<td>#7</td>
<td><img src="image4.png" alt="Sign image" /></td>
<td>12.2±0.23</td>
<td>4 (6)</td>
<td>5</td>
</tr>
<tr>
<td>#8</td>
<td><img src="image5.png" alt="Sign image" /></td>
<td>12.1±0.25</td>
<td>5 (7)</td>
<td>4</td>
</tr>
<tr>
<td>#1</td>
<td><img src="image6.png" alt="Sign image" /></td>
<td>11.7±0.24</td>
<td>6 (8)</td>
<td>6</td>
</tr>
<tr>
<td>#5</td>
<td><img src="image7.png" alt="Sign image" /></td>
<td>11.0±0.27</td>
<td>7 (9)</td>
<td>7</td>
</tr>
<tr>
<td>#2</td>
<td><img src="image8.png" alt="Sign image" /></td>
<td>10.1±0.30</td>
<td>8 (10)</td>
<td>8</td>
</tr>
</tbody>
</table>
Table 3.3 The percent of participants to which various messages were conveyed by each of the three highest ranking signs. Note that multiple messages were conveyed to some participants, and so the percentages for each sign do not add up to 100%. N = 134 for each sign.

<table>
<thead>
<tr>
<th>Message conveyed</th>
<th>Percent of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sign #3</td>
</tr>
<tr>
<td>Slow down</td>
<td>63.4</td>
</tr>
<tr>
<td>High animal presence</td>
<td>57.5</td>
</tr>
<tr>
<td>Crash risk</td>
<td>21.6</td>
</tr>
<tr>
<td>Be careful/vigilant</td>
<td>23.9</td>
</tr>
<tr>
<td>Personal injury</td>
<td>-</td>
</tr>
<tr>
<td>Animal welfare</td>
<td>-</td>
</tr>
<tr>
<td>Thank you</td>
<td>-</td>
</tr>
<tr>
<td>Limit speed</td>
<td>-</td>
</tr>
<tr>
<td>Urgency</td>
<td>1.5</td>
</tr>
<tr>
<td>Speed enforcement</td>
<td>-</td>
</tr>
<tr>
<td>Important wildlife area</td>
<td>-</td>
</tr>
<tr>
<td>Unusable answer</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Table 3.4 The percent of participants to which various sign features stood out in each of the three highest ranking signs. Note that multiple sign features stood out to some participants, and so the percentages for each sign do not add up to 100%. N = 134 for each sign.

<table>
<thead>
<tr>
<th>Emphasised feature</th>
<th>Percent of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sign #3</td>
</tr>
<tr>
<td>“Slow down” / &quot;speeding kills&quot;</td>
<td>73.1</td>
</tr>
<tr>
<td>Image</td>
<td>29.9</td>
</tr>
<tr>
<td>Electronic message</td>
<td>-</td>
</tr>
<tr>
<td>Colour</td>
<td>11.2</td>
</tr>
<tr>
<td>Yellow/black contrast</td>
<td>8.2</td>
</tr>
<tr>
<td>“High collision area”</td>
<td>-</td>
</tr>
<tr>
<td>Speed detection</td>
<td>-</td>
</tr>
<tr>
<td>“Thank you”</td>
<td>-</td>
</tr>
<tr>
<td>Words</td>
<td>-</td>
</tr>
<tr>
<td>Large size/shape</td>
<td>3.7</td>
</tr>
<tr>
<td>Multiple sign panels</td>
<td>1.5</td>
</tr>
<tr>
<td>“Watch out for wildlife”</td>
<td>-</td>
</tr>
<tr>
<td>Unusable answer</td>
<td>6</td>
</tr>
</tbody>
</table>

3.4. Discussion

3.4.1. Sign elements and placement

Almost three-quarters of participants said that they were more likely to respond to a wildlife warning sign that displayed an updated number of animals killed on the road over some preceding period of time. This was an important finding. The addition of this feature as a separate panel to existing wildlife warning signs would be relatively simple on roads where regular road-kill surveys are already conducted. This information feedback to drivers would provide them with evidence that wildlife-vehicle collisions do occur regularly in that location, especially where the bodies of road-killed animals are removed.
In a series of experiments on methods to reduce driver speed, van Houten and Nau (1983) found that a brief information feedback program was successful in reducing the proportion of drivers speeding. The program involved giving speeders a warning ticket and a flier on the numbers of collisions, injuries and fatalities that had occurred on that specific road in the past. Even though the program only ran for one to four days, it appeared to affect vehicle speeds for several weeks after its conclusion (van Houten and Nau 1983). Some of the participants in the present study expressed that they were much less likely to respond to signs if there was no evidence that wildlife-vehicle collisions occur regularly. This unfortunately is hampered by the regular removal of animal carcasses from roads, usually by local councils, but also occasionally by members of the public (personal observation). The potential importance of road-kill being present has also been supported by studies assessing the effect of various wildlife warning signs in combination with animal decoys or carcasses at the roadside (Pojar et al. 1975; Gordon et al. 2004).

Some wildlife warning signs display specified time periods (e.g. Aug – Dec, 7pm – 5am, Dique et al. 2003) during which drivers are to be aware of the risk of colliding with an animal. Such temporal indications of increased risk of wildlife-vehicle collisions are highly relevant in areas where animals cross roads at predictable times of the year, such as seasonally migratory deer (Gordon et al. 2004; Sullivan et al. 2004a) and amphibians (Aresco 2005b; Sillero 2008) in North America and Europe. In Australia, however, most species that are commonly impacted by road mortality (including all macropod species) are not migratory, and thus are less predictable as to the timing of road crossings (e.g. Taylor and
In the current study, 56% of participants said that they were more likely to respond to a sign that displayed time specifications within the specified time period, although 49.3% of participants also indicated that they were less likely to respond outside the specified time period. This suggests that drivers think there is a much lower likelihood of encountering an animal on the road outside the specified time period, when there may be little difference. This may have the unwanted consequence of drivers being less vigilant for animals around the road during certain times of the year and potentially increasing wildlife-vehicle collisions. Additionally, a small number of participants (5.2%) answered that they were less likely to respond to such a sign within the specified time period, perhaps because they perceived that if animals were only likely to be near the road during a certain time of the year, they were generally less likely to encounter an animal. The relevance and potential benefits and detriments of displaying seasonal specifications on wildlife warning signs need to be carefully considered when proposing to install signs in the future. It is recommended that such time specifications only be used in situations where there is definitive evidence of much higher road-kill rates during certain periods, and not when seasonal variations are only slight. This will ensure that drivers will continue to be vigilant and respond to signs throughout the year.

Wildlife warning signs are usually installed permanently, although in some locations, temporary signs are used when warning of migrating species (e.g. Sullivan et al. 2004a). The use of these temporarily or periodically placed wildlife warning signs in these situations is appropriate where the period of high risk of wildlife-vehicle collisions is highly predictable. It is, however, possible that a
periodic or temporary placement strategy may reduce driver habituation to signs, as this is a significant concern regarding the long-term effectiveness of wildlife warning signs (Sullivan et al. 2013). When queried as to the temporal placement of signs that would more likely produce an appropriate response to wildlife warning signs, the majority of participants to the present study answered that permanent placement would be more effective, or that their response would be equal regardless of temporal placement. However, such a question may be very difficult to answer reliably, as participants may be unaware of whether they are likely to become habituated to signs, and thus their answer may not align with their actions when placed in the real situation. Some indication of participants’ awareness of the potential to habituate to signs is suggested by small proportions of participants answering with periodic and temporary placement. Therefore, field trials comparing the long-term effectiveness of permanent, periodic and temporary warning signs on driver speed and the occurrence of wildlife-vehicle collisions would be highly valuable.

The placement of signs on either the roadside or the median strip may impact on the noticeability of the signs and thus the likelihood that drivers will respond to them. Most wildlife warning signs are currently positioned on the roadside, although the median strip has also been used (e.g. Sullivan et al. 2013), presumably where there are fewer obstructions to the visibility of the sign. The majority of participants indicated that they were equally likely to respond regardless of where the sign was positioned, whereas almost one-third of participants gave preference to the roadside and only 9% gave preference to the median strip. From these results, it would be advisable to only place wildlife
warning signs in the median strip when clear visibility and/or noticeability of the sign on the roadside would be hampered by an obstruction or driver view may be distracted by other signage and/or objects at the roadside.

Many wildlife warning signs also display the distance for which they are applicable. Hardy and colleagues (2006) suggested that a shorter displayed distance may increase driver response to a portable dynamic message sign (displaying “next 2 miles”) compared to the permanent dynamic message signs (displaying “next 20 miles”). This aspect of wildlife warning signs was not addressed by the current study. It would, however, be important to experimentally test the influence of the length of the warning distance displayed on signs to reveal optimal displayed warning distances and therefore a recommended distance for repeated signs along extended areas of wildlife-vehicle collision risk.

3.4.2. Sign Designs

The A-A and VS-A signs had consistently high likelihoods of participants responding appropriately at all three speeds, most likely due to the interactive nature of the signs. This finding was supported by the responses to sign #4 also having consistently high likelihoods of response and the electronic message being the feature of this sign that stood out to most participants. Additionally, when assessing the effectiveness of vehicle-activated signs, Sullivan and colleagues (2013) found that mean vehicle speed was lowest when the associated flashing lights were activated by vehicles traveling at 19km/h (i.e. the lights would have activated for most vehicles, not just speeding vehicles). It is likely that the A-A sign received slightly higher response rates due to the flashing light or message
conveying that there is an immediate risk of collision with an animal. It is highly likely, however, that drivers would become less responsive to A-A signs if false triggers (for example, from moving vegetation) occurred frequently (Gray 2009).

The most consistently conveyed messages associated with the signs used in the present study were for drivers to slow down, that there is high animal presence in the area, that there is a crash risk, and to be careful and/or vigilant. The message of potential human injury and/or vehicle damage was also important for the signs that conveyed this message. These messages should be incorporated into future wildlife warning sign designs as they are likely to be influential to driver behaviour. It is important, however, to keep the design of signs simple, perhaps with fewer words than some of the alternative sign designs used in this study. This would be particularly crucial along high speed roads, where drivers have less time to read and interpret signs.

Wording relating to speed, images, and bright and contrasting colours appeared to attract the attention of participants, and are therefore likely to be important for maximising the noticeability of the sign. Where funds allow for electrical components, flashing lights and/or messages would additionally increase noticeability, even if such elements were not animal- or vehicle-activated. Even if the design of wildlife warning signs is enhanced, it is possible that some drivers will still become habituated to the signs and not always notice or respond to the signs. The incorporation of electronically-activated components in wildlife warning signs is likely to reduce the occurrence of habituation, as the electronic message and/or flashing lights would engage drivers and alert them to the potential risk. Even so, it is recommended that research into driver habituation to
wildlife warning signs be conducted, through either repeated surveys that evaluate driver responses to the same signs over time, or long-term field trials on a variety of static and electronically-activated signs.

3.4.3. **Study concerns and limitations**

Due to the exploratory nature of this study, there are several issues that should be improved upon or explored in more depth in future research. This study primarily used kangaroo/wallaby related images in the sign designs to attempt to standardise the taxa to which drivers were responding, enabling the survey to focus more on design aspects, rather than the species/taxa displayed. The sign type displayed as sign #2 was intended for use where small taxa are more likely to be hit, and as such, a kangaroo image was not available for this sign, thus an echidna image was used (Department of Transport and Main Roads 2012). It should be noted that some drivers are likely to respond differently to different species/taxa displayed on wildlife warning signs (Blacker, unpublished data) and may intentionally hit some species/taxa (Beckmann and Shine 2012); however, this was not the focus of the current study. It would be highly informative for future research to examine the differences in the likelihood, type, extent and duration of driver response to varying taxa displayed on wildlife warning signs, so that in areas where several species/taxa are at risk of being hit by vehicles, the taxon that produces the greatest response from drivers should be displayed. It should be noted that colour-blind drivers were not considered when designing the alternative signs used in the survey, and so the colour combinations used may not be appropriate for use as is. This should be investigated in future studies that
explore alternative wildlife warning sign design. Additionally, the consultation and/or use of a graphics designer is recommended to assist in designing any alternative wildlife warning signs in the future.

When interpreting results from public opinion surveys, researchers must be mindful that participants may not always respond to some questions entirely truthfully (this may be unintentional), and there may be discrepancies between survey results and actual human behaviour (Sheeran 2002; Beckmann and Shine 2012). Because of this, the main section of the survey used in the current study was designed to compare the relative responses of drivers to different signs, so that results are still indicative of true relative responses to the signs. Despite this, it is possible that participants rated the likelihood of their response to the sign that appeared first higher than what would be their actual behaviour, as it may be have been perceived that this was the appropriate behaviour, and therefore the desired answer. On viewing subsequent signs, this perception may have changed, as participants realised the comparative nature of the survey (Perreault 1975; Sheeran 2002). Again, this may not have been intentional. This potential bias may have caused the discrepancies between sign scored and preference ranks. Such potential bias may have been avoided by showing the participants all signs used in the survey before asking questions about any one sign. Additionally, when asking participants of the likelihood of their response to the signs, no option was given for participants to respond by either increasing their alertness without reducing speed, or reducing speed without increasing alertness. These issues should be taken into consideration for any future research that involves similar relative comparisons of sign designs through public opinion surveys.
Generalised interpretations of the results from this study are also limited due to low sample size, dominance of Queensland participants and non-randomised recruitment of participants. Unfortunately due to the limited time available to recruit participants, lack of funds for advertising and unwillingness of RACQ, RACV and NRMA to participate in participant recruitment, these situations were unavoidable.

3.5. Conclusion

High road-kill rates that are experienced in some urban and peri-urban areas may be greatly reduced by optimising the effectiveness of wildlife warning signs, a relatively inexpensive mitigation measure. Additionally, due to the high frequency with which drivers in urban and peri-urban areas repeatedly drive along the same roads, driver habituation to wildlife warning signs may be greater than along highways in more remote areas. Although this research is clearly also relevant to remote areas, repetitive driving along the same stretches of roads is unlikely to occur as regularly in such areas, and thus driver habituation may be less of an issue. Because of this potential for greater habituation in urban and peri-urban areas, use of a variety of sign designs, both spatially and temporally, may be valuable. Research into this possible effect is needed, however.

Much more research needs to be conducted into assessing current and alternative wildlife warning sign designs to optimise their effectiveness. None of the alternative signs designed in this study are recommended for field tests, but modifications to their design could be made and reassessed using a similar method. Eventually field tests should be conducted using optimally designed signs
and currently used signs, as such applied research is likely to produce more definitive and realistic results. The addition of sign elements, such as seasonal and distance specifications and road-kill counts, to wildlife warning signs should also be field tested, however, the use of seasonal specifications on wildlife warning signs is only recommended when highly relevant to the target species/taxa. This and further research into optimising the design of wildlife warning signs will hopefully contribute to reducing the frequency of wildlife-vehicle collisions, particularly in urban and peri-urban landscapes where such wildlife-human conflicts can be frequent.
Chapter 4

Road-crossing behaviours and behavioural responses to vehicles by red-necked wallabies, *Macropus rufogriseus banksianus*
4. Road-crossing behaviours and behavioural responses to vehicles by red-necked wallabies, *Macropus rufogriseus banksianus*

4.1. Introduction

While the scope of research being undertaken in road ecology has diversified greatly over recent decades (Beckmann et al. 2010), some important issues remain poorly understood. Roadside behaviour of animals is one such area with relatively little research having been undertaken (Fahrig and Rytwinski 2009; Taylor and Goldingay 2010), yet knowing how and why animals respond to the road environment and to traffic may be a crucial component of understanding the impacts of roads on wildlife populations (Martin 1998; Caro 2007; Lee et al. 2010).

Investigations of the movements of animals near roads and of road crossing locations and their features have been undertaken for a variety of vertebrate species (e.g. Curatolo and Murphy 1986; Rondinini and Doncaster 2002; Tigas et al. 2002; Bautista et al. 2004; Laurance et al. 2004; Jaarsma et al. 2007; Klar et al. 2009; Lewis et al. 2011; Neumann et al. 2012). Observations of direct animal behaviours in relation to the road environment are, however, far less evident. Some behavioural studies have been conducted on whether animals (mostly ungulates) perceive roads and traffic as a predation risk by comparing activity time budgets at varying distances from roads and at differing traffic intensities (Gavin and Komers 2006; Li et al. 2009; Ge et al. 2011; Lian et al. 2011). These studies indicate that at least some species respond to the road environment as they would in an environment with high predation pressure (Frid and Dill 2002).
Some studies have looked at the specific responses of animals to traffic. Behavioural responses of animals to approaching vehicles have been investigated in some species of mammal (Horejsi 1981; Andersen et al. 1996; Donadio and Buskirk 2006; Stankowich 2008; Blackwell and Seamans 2009; Lee et al. 2010; Vidya and Thuppil 2010; Wolf and Croft 2010; Li et al. 2011), ground-dwelling bird (Blackwell et al. 2009), snake (Andrews and Gibbons 2005) and amphibian (Mazerolle et al. 2005). These studies show that species respond in varying ways to passing vehicles and that even within species, individuals or groups of different sex and/or maturity can respond differently. Most mammals and ground-dwelling birds show flight responses to approaching vehicles, yet species, sex, maturity and some extrinsic factors can influence the distance at which flight is initiated and the length of the response (e.g. Horejsi 1981; Donadio and Buskirk 2006; Blackwell et al. 2009). Even some species of bats, irrespective of approaching flight height, avoided crossing roads when vehicles were present, suggesting some flight response to vehicles (Zurcher et al. 2010). In contrast, snakes and amphibians often became immobilised when approached by a vehicle (Andrews 2004; Andrews and Gibbons 2005; Mazerolle et al. 2005). Even at the level of these taxa, differences in response to vehicles suggest that such behaviour can be influential in determining the outcome of such animal-vehicle encounters.

Relatively few studies to date have investigated the behaviours of animals that regularly cross roads to forage or to reach required habitat. Some exceptions are studies on ungulates (Waring et al. 1991; Qiu and Feng 2004; Baofa et al. 2006), bats (Zurcher et al. 2010), snakes (Andrews 2004; Shine et al. 2004; Andrews and Gibbons 2005), a frog (Bouchard et al. 2009) and dragonflies (Soluk
et al. 2011). Factors such as species, group size and body size, as well as traffic volume, often influence animal road-crossing speed (e.g. Qiu and Feng 2004), and may therefore affect the probability of the animal being hit by a vehicle. Other behavioural attributes, such as road surface avoidance, crossing angle and flight height (for dragonflies) also differ among species and may lead to varying mortality rates during crossings (Shine et al. 2004; Andrews and Gibbons 2005; Bouchard et al. 2009; Soluk et al. 2011). These studies exemplify how important behaviour can be in determining mortality and other road impacts on wildlife, although much more research is needed involving a wider range of species and a focus on other road characteristics that may influence an animal’s behaviour.

This chapter investigates the road-crossing behaviour of red-necked wallabies (*Macropus rufogriseus banksianus*) and their behavioural responses to vehicles. Red-necked wallabies are one of two remaining macropod species in the study area, although swamp wallabies (*Wallabia bicolor*) were rarely directly observed crossing roads and never observed to remain in the road verge to forage. Due to this behaviour, it was not possible to observe swamp wallaby response to approaching vehicles, and the very few road crossing events observed were never during behavioural surveys, and thus were never recorded. Red-necked wallabies are an ideal study species in this context, as they regularly cross and forage beside certain roads. They are also relatively abundant in some sites, though are highly vulnerable to collisions with vehicles.
4.2. Methods

4.2.1. Behavioural data collection

The roadside-behaviour of red-necked wallabies was recorded at three road sites in south-east Brisbane and Redland cities, along which wallabies were reliably observed on a regular basis. Table 4.1 displays road and traffic attributes for the three road sites, Cherbon Street (27°32′59″S, 153°10′41″E) in Burbank, Sanctuary Drive (27°37′46″S, 153°14′45″E) in Mount Cotton and Heinemann Road (27°37′09″S, 153°15′28″E) in Mount Cotton (Figure 4.1). Surveyed sections of the three roads were a minimum of 1 km apart.

![Figure 4.1](image-url) The sections of Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton along which behavioural surveys were conducted in South East Queensland.
Each road was driven along slowly (40-60 km h\(^{-1}\)) between 15:00 and 19:00 hours while visually scanning for potential focal individuals. Potential focal individuals were wallabies which were within the road verge or close enough to the road to easily record (no more than 20 m from the road), were not obscured by other objects and were not moving further away from the road. Some wallabies were visible beyond the verge where vegetation was open or scattered adjacent to the road. When an appropriate focal animal(s) was seen, the car was slowly driven to the side of the road and used as a hide from which to record. The car was parked 30 – 100 m from the focal wallaby when initially stopped, however, on some occasions the wallaby moved closer to the car during the survey. Although it is possible that the presence of this car at the roadside may have altered the behaviour of the wallabies, this was the least disruptive option, as wallabies in this area would regularly see other vehicles parked along the roads. Wallaby behaviour was recorded using a Panasonic HDC-SD9 High Definition video camera until the wallaby either moved out of sight or moved too far from the road. If the wallaby failed to perform any of the desired behaviours within 10 to 15 minutes and did not move closer to the road, the recording was stopped and a new focal wallaby found. The behaviour of wallabies that were not focal animals, but were in the view of the camera was also recorded, including wallabies that suddenly appeared from outside the verge and crossed the road.
Table 4.1 Road and traffic attributes of the three roads used in behavioural surveys, Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland.

<table>
<thead>
<tr>
<th>Road attribute*</th>
<th>Cherbon</th>
<th>Sanctuary</th>
<th>Heinemann</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road width (m)</td>
<td>5.9</td>
<td>4.2</td>
<td>6.6</td>
</tr>
<tr>
<td>No. of lanes</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Traffic volume (24hr mean)</td>
<td>~200</td>
<td>773</td>
<td>1,358</td>
</tr>
<tr>
<td>Commercial vehicles (%)</td>
<td>~1.4</td>
<td>5</td>
<td>17.5</td>
</tr>
<tr>
<td>Speed limit (km/h)</td>
<td>50</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Fencing</td>
<td>Permeable fencing present along most sections, some small impermeable fenced and unfenced sections</td>
<td>No fencing, open front yards, a few with retaining walls</td>
<td>Permeable fencing present along most sections, some small impermeable fenced and unfenced sections</td>
</tr>
<tr>
<td>Land use</td>
<td>Rural with medium remnant woodland nearby</td>
<td>Residential with scattered remnant woodland</td>
<td>Rural with some small remnant woodland nearby</td>
</tr>
<tr>
<td>Wallaby road-kill rate (no./km/month)</td>
<td>0.085</td>
<td>0.180</td>
<td>0.883</td>
</tr>
</tbody>
</table>

*Traffic volume and percent commercial vehicles for Sanctuary Drive and Heinemann Road were obtained from Redland City Council. Traffic volume and percent commercial vehicles for Cherbon Street were collected manually over a period of three days (two week-days and one weekend-day), as this data was not available from other sources. Wallaby road-kill rates were calculated from surveys conducted for another section of this research project (see Chapter 2). Road width was measured at three sections of each road where behavioural surveys were often conducted and then averaged.

Observations were made between November 2010 and May 2012; a total of 182 video recordings of wallabies were used, providing a total of 31 hours, 38 minutes and 48 seconds of video.
Behavioural software was not used to score and/or analyse the video files as this would have been much more time consuming and produced much unwanted data, given the focus solely on road crossings and responses to vehicles. Desired variables were extracted from each video file manually. Playback speed of road crossings and responses to vehicles was viewed in VLC media player (VideoLAN 2012, versions 2.0.4 and 2.0.5 for Windows) and set to x1 or x0.5 to maximise accuracy. All other activities were viewed at x4 speed to maximise efficiency.

For road-crossing behaviours, the following variables were recorded from each road crossing in each video file: date, road, sex, maturity, locomotion method, change in locomotion, number of pauses in locomotion, total time to cross road, additional activities during crossing, vehicle approaches during crossing, activity before and after crossing, whether wallaby originated and remained in road verge before and after road crossing, and the main activity while in the road verge. Road verge was defined as the area beside the road from the edge of the bitumen to either a fence (if present), or a distinctive change in vegetation (e.g. from mown grass in the verge to shrubs and trees or landscaped garden outside the verge).

For response to vehicle behaviours, the following variables were recorded from each road crossing in each video file: date, road, sex, maturity, group size, vehicle size class (see Table 4.2), initial response behaviour, secondary response behaviour (when relevant), total response duration, activity before and after response, direction of flight (when relevant), flight to inside or outside verge (when relevant), and any unusual driver behaviour. Initial response behaviour was the first response (either alert or flee) of the wallaby to the vehicle. Secondary
response behaviour was recorded when the focal wallaby changed their behavioural response stance (changed from crouch alert to stand alert) or behaviour (alert to flee). Total response duration was the time from the start of the initial behavioural response (alert directed at vehicle or flee) until the conclusion of the either the initial or secondary (when present) response behaviour (other behaviour commenced, alert behaviour directed away from vehicle, or wallaby stopped fleeing). Activity before and after response are the activities immediately before and immediately after the response to vehicle behaviours. Flight to inside verge occurred when the wallaby only fled to a distance within the road verge, whereas, flight to outside verge occurred when the wallaby fled to a distance beyond the road verge. Only the response to the first vehicle was analysed for each individual during a recording to avoid pseudoreplication. Table 4.3 lists and describes the behaviours used in this chapter.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Size Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorbike</td>
<td>1</td>
</tr>
<tr>
<td>Small car (hatchback)</td>
<td>2</td>
</tr>
<tr>
<td>Medium car (sedan)</td>
<td>3</td>
</tr>
<tr>
<td>Small ute (2WD)</td>
<td>4</td>
</tr>
<tr>
<td>Van</td>
<td>5</td>
</tr>
<tr>
<td>Large ute / 4WD</td>
<td>6</td>
</tr>
<tr>
<td>Small truck</td>
<td>7</td>
</tr>
<tr>
<td>Large truck (freight size)</td>
<td>8</td>
</tr>
</tbody>
</table>
4.2.2. Data analyses

Due to low numbers of observations of subadults and juveniles, these categories were excluded from all analyses. Due to the difficulty of reliably determining the sex of wallabies at the roadside, some individuals were classified as ‘unknown sex’. This meant that for all statistical analyses involving significant sex comparisons, only those observations involving known male and female adults were included. Due to some stance and activity combinations (e.g. rear alert) being infrequently observed, stances were not analysed and activities alone were analysed (e.g. alert).

All statistical analyses were conducted using the statistical software R (The R Foundation for Statistical Computing 2011). Classification and regression trees are a type of predictive modelling that are displayed as binary splitting trees (De’ath and Fabricius 2000). Classification trees are used to predict outcomes for categorical dependent variables, whereas regression trees are used to predict outcomes for continuous numerical dependent variables. Classification and regression trees were produced using the RPART package in R and pruned where appropriate to avoid over-fitting the data and minimise the cross-validation error (Therneau and Atkinson 1997).
Table 4.3 Basic ethogram used to score wallaby road crossing and response to vehicle behaviours.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STANCES</td>
<td></td>
</tr>
<tr>
<td>Lay</td>
<td>Lays on side with hind legs stretched out</td>
</tr>
<tr>
<td>Sit</td>
<td>Sits with hind legs and tail held in front of body</td>
</tr>
<tr>
<td>Crouch</td>
<td>Crouches, usually pentapedal</td>
</tr>
<tr>
<td>Stand</td>
<td>Stands tripedally, not at full height</td>
</tr>
<tr>
<td>Rear</td>
<td>Stands tripedally, at full height</td>
</tr>
<tr>
<td>METHODS OF LOCOMOTION</td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>Pentapedal slow walk</td>
</tr>
<tr>
<td>Hop</td>
<td>Bipedal hopping at normal speed</td>
</tr>
<tr>
<td>Bound</td>
<td>Bipedal hopping at accelerated speed</td>
</tr>
<tr>
<td>Flee</td>
<td>Locomotion in response to a perceived threat, usually hopping or bounding</td>
</tr>
<tr>
<td></td>
<td>(used for scoring response to vehicle behaviours only)</td>
</tr>
<tr>
<td>MAINTENANCE ACTIVITIES</td>
<td></td>
</tr>
<tr>
<td>Forage</td>
<td>Biting and/or chewing (not while alert)</td>
</tr>
<tr>
<td>Drink</td>
<td>Drinks from water source</td>
</tr>
<tr>
<td>Groom</td>
<td>Grooms self</td>
</tr>
<tr>
<td>Rest</td>
<td>Lays down with head resting on ground</td>
</tr>
<tr>
<td>Feed young</td>
<td>Allows young to suckle</td>
</tr>
<tr>
<td>Suckle</td>
<td>Suckles from mother’s pouch</td>
</tr>
<tr>
<td>SOCIAL ACTIVITIES</td>
<td></td>
</tr>
<tr>
<td>Allogroom</td>
<td>Grooms other wallaby</td>
</tr>
<tr>
<td>Sniff wallaby</td>
<td>Sniffs other wallaby</td>
</tr>
<tr>
<td>Fight</td>
<td>Fights with other wallaby by hitting with forearms and/or kicking</td>
</tr>
<tr>
<td>Social</td>
<td>Performs other social activity</td>
</tr>
<tr>
<td>OTHER ACTIVITIES</td>
<td></td>
</tr>
<tr>
<td>Alert</td>
<td>Looks around at surroundings (may chew food simultaneously)</td>
</tr>
<tr>
<td>Sniff air</td>
<td>Sniffs the air</td>
</tr>
<tr>
<td>Sniff ground</td>
<td>Sniffs the ground</td>
</tr>
</tbody>
</table>

Classification trees were used to reveal the relative influence of factors in determining the categorical behaviour variables for both road crossing and response to vehicle observations. Regression trees were similarly used to reveal influential factors in determining time-to-cross and length of response to vehicles.
For the time-to-cross regression tree, only observations with no pauses were used in the analysis in order to remove the influence of the number of pauses. For all classification and regression trees, all potential influential factors were initially entered into the model using only male and female adult observations and the model was run. If sex was not an influential factor, it was removed from the model and the analysis was rerun on all adult observations.

In most cases, forage and alert were the only behaviours that were observed often enough to be analysed separately. Consequently, all remaining behaviours were pooled into a third behavioural category: ‘other’. In all cases when the category ‘other’ was used for as a dependent variable category, it was never predicted by the model, and so these observations were removed from the analyses.

A Chi-squared test was used to analyse the effect of road on the number of pauses during a crossing, with the number of pauses (0, 1, 2+) used as categories.

4.3. Results

4.3.1. Road-crossing behaviour

A total of 236 wallaby road-crossings were observed, with 192 observations being of adults; 123 adult observations were of sexed individuals. No collisions with vehicles were observed during behavioural surveys. Significant classification trees were not able to be constructed for verge presence and activity before crossing, locomotion mode and activity after crossing. Despite this, some differences were still apparent.
The ‘main’ behaviour of wallabies is the behaviour that wallabies displayed for the majority of the time for which they were recorded in the road verge. This analysis was conducted on 85 sexed adults that were present and visible within the verge. ‘Other’ activities (pooled) were too few to be predicted and so were removed from the analysis. Figure 4.2 shows the final classification tree for main verge activity. Sex was the most influential factor, with males predicted to spend the majority of their time alert and female behaviour being also dependant on the road and season. Females at Cherbon, and Heinemann and Sanctuary in autumn and winter were predicted to spend the majority of their time foraging. Alternatively, during spring and summer at Heinemann and Sanctuary females were predicted to be mainly alert in the road verges.

A classification tree was not able to be produced for wallaby verge presence prior to crossing the road, although large differences were apparent among the roads. Wallabies at Cherbon and Sanctuary were present in the verge 82% (n = 57) and 91% (n = 43) of the time before crossing the road, respectively. In contrast, only 58% (n = 92) of wallabies were present before crossing at Heinemann.

The activity immediately before crossing the road was also not differentiated enough to produce a classification tree, but differences were apparent between males and females. The majority of wallabies from both sexes were alert before crossing, however 16% (n = 70) of females foraged immediately before crossing, while males never foraged (n = 33). Six percent and 12% of females and males respectively performed ‘other’ activities before crossing, although the activities comprising ‘other’ activities are different between the sexes. ‘Other’ activities for females were groom, feed young, sniff air and sniff ground.
(1.4% each). Males, however, were found to sniff ground (6%), sniff air (3%) and sniff other wallaby (3%).

Figure 4.2 Classification tree for the main activity performed by wallabies in road verges along Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. Model misclassification rate = 28.2%

Figure 4.3 shows the final classification tree for pausing during a road crossing. For this analysis sex was not an influential factor, and so observations on all adult road crossings were used. Road was the most influential factor, with wallabies at Cherbon and Sanctuary predicted not to pause during a crossing. The
occurrence of pausing at Heinemann was, however, additionally dependant on season and whether a vehicle approached during the road crossing. Wallabies at Heinemann in spring and autumn were predicted to pause if a vehicle approached, and not to pause in the absence of an approaching vehicle. Alternatively, wallabies at Heinemann in summer and winter were predicted to pause during crossing.

Figure 4.3 Classification tree for pausing by wallabies during road crossings along Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. Model misclassification rate = 22.9%
At all three road sites the majority of wallabies did not pause during road crossings (Cherbon 90%, Sanctuary 84%, Heinemann 55%; Figure 4.4). The proportions of wallabies pausing zero, one and two or more times during a road crossing was significantly different at the three road sites ($\chi^2 = 31.6488$, df = 4, $p = 2.26 \times 10^{-6}$). The percentage of wallabies that paused one and two or more times was greater at Heinemann (24% and 21% respectively) than at Cherbon (7% and 3% respectively) and Sanctuary (8% for both; see Figure 4.4). During pauses in crossing, wallabies performed a range of activities. Fifty-eight percent of wallabies were only ever alert during pauses, with all wallabies being alert at some point during pauses. Twenty-eight percent of wallabies sniffed the ground and/or air and other activities were only performed by 11% of wallabies. Other activities were grooming, foraging and drinking. Foraging and drinking during a crossing occurred when the wallaby paused at the very edge of the bitumen (while still at risk of being hit) and foraged on grass at the immediate edge of the bitumen or drank from the gutter.
Figure 4.4 Observed (OBS) and expected (EXP) frequencies of wallabies pausing zero, one and two or more times during road crossings at Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Expected values were obtained from the Chi-squared test ($\chi^2 = 31.6488, df = 4, p = 2.26 \times 10^{-6}$). Road sites are ordered by ascending traffic volume (see Table 4.1 for details).

Pausing substantially lengthened the time that the wallaby remained on the road (see Table 4.4). Therefore, to reveal other underlying influences on time to cross, a regression tree was produced to predict the time it took wallabies to cross the road without pausing (Figure 4.5). Here, road and initial locomotion mode were the only significant explanatory variables used to create the regression tree. Wallabies at Sanctuary were predicted to cross the road in 1.41±0.10 seconds, whereas they took longer to cross at Heinemann and Cherbon. Wallabies bounded across the road in a mean of 1.46±0.11 seconds at Cherbon and Heinemann and in a mean of 2.43±0.09 seconds if they were walking or hopping.
After crossing the road wallabies would either remain in the road verge or continue until they had left the verge. The most influential factors in determining whether they stayed in the verge were whether the wallaby was present in the verge before crossing and whether a vehicle approached during the crossing (Figure 4.6). If the wallaby was absent from the verge before crossing, they were predicted to leave immediately after crossing. Alternatively, if they were present in the verge before crossing, verge presence after crossing was also dependant on whether a vehicle approached during the road crossing. In these instances, wallabies were predicted to leave the verge immediately when a vehicle approached the wallaby, although if no vehicles approached they were predicted to remain in the road verge.

Table 4.4 Mean time to cross the road when wallabies paused zero, one, two and three times at Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland.

<table>
<thead>
<tr>
<th>No. of pauses</th>
<th>Mean (±SE) time to cross (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.1±0.1</td>
</tr>
<tr>
<td>1</td>
<td>23.2±2.6</td>
</tr>
<tr>
<td>2</td>
<td>28.5±2.8</td>
</tr>
<tr>
<td>3</td>
<td>48.4±17.1</td>
</tr>
</tbody>
</table>
Figure 4.5 Regression tree for time to cross road when there are no pauses in locomotion at Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. RSS = 74.67

For those wallabies that were visible following the road crossings, the activity immediately after crossing the road was not differentiated enough to produce a classification tree, and there were no obvious differences among sexes, roads or seasons. The majority of wallabies were alert immediately after crossing the road (86%, n = 86), with only 7% foraging and 7% performing ‘other’ activities. ‘Other’ activities included sniff ground (3.5%), groom (2.3%) and sniff other wallaby (1.2%).
Figure 4.6 Classification tree for wallaby presence in road verges after road crossings along Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. Model misclassification rate = 30.7%

4.3.2. Response to vehicles

A total of 214 wallaby responses to vehicles were observed, with 166 observations being of adults; 99 adult observations were of sexed individuals. No collisions with vehicles were observed during behavioural surveys.

The activity that wallabies were performing before being disturbed by and responding to a vehicle depended on road, sex and group size (Figure 4.7). ‘Other’ activities (pooled) were too few to be predicted, and so were removed from the analysis. Wallabies at Cherbon and in groups of two or more (> 1.5) were predicted
to be disturbed from foraging before responding to a vehicle, whereas singletons at Cherbon were predicted to already be alert. Wallabies at Heinemann and female wallabies at Sanctuary were also predicted to be alert, however males at Sanctuary were predicted to be foraging before responding to a vehicle.

The first response to a vehicle was not differentiated enough to produce a classification tree, although differences were apparent among the roads. The majority of wallabies at all three roads immediately responded by being alert (Cherbon, 94%, n = 33; Sanctuary, 87%, n = 39; Heinemann, 97%, n = 94). Very small percentages of wallabies fled immediately at all three roads (Cherbon 3%; Sanctuary 3%; Heinemann 1%). Despite these similarities, 10% of the wallabies at Sanctuary did not respond at all, whereas at Cherbon and Heinemann this only occurred 3% and 2% of the time, respectively.
Figure 4.7 Classification tree for wallaby activity before responding to a vehicle along Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. Model misclassification rate = 25.3%
When responding to vehicles, 39% of wallabies fled, 57% were vigilant, and 4% did not respond (n = 166). Predicting the final response of a wallaby to a vehicle produced a large and complex classification tree that was influenced by the vehicle size class (see Table 4.2 for details), season, road and the activity they were performing before responding to the vehicle (Figure 4.8). ‘No response’ to vehicles was observed too seldom to be predicted and so was removed from the analysis. Wallabies that were approached by vehicles of size class seven or larger (> 6.5) were predicted to flee in response. However, predictions for wallabies that were approached by vehicle of size class six or smaller were much more complex. In these situations in spring or in any other season at Sanctuary, wallabies were predicted to respond with an alert posture. Alternately, in summer, autumn and winter at Cherbon, wallabies were predicted to respond by fleeing if they were previously foraging and respond alertly if they were either alert or performing an ‘other’ activity before the vehicle approached. At Heinemann, however, this situation was reversed and wallabies were predicted to respond alertly if they were previously foraging and respond by fleeing if they were either alert or performing an ‘other’ activity before the vehicle approached.

A regression tree was produced to predict wallaby response duration (Figure 4.9). Here, the final response of the wallaby was the only explanatory variable used to create the regression tree. The predicted mean response duration of 9.68±0.61 seconds resulted for wallabies that responded alertly, 6.61±0.45 seconds for wallabies that responded by fleeing and 0±0 seconds for wallabies that did not respond.
**Figure 4.8** Classification tree for the final response to an approaching vehicle at Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. Model misclassification rate = 30.8%
Figure 4.9 Regression tree for total duration of response to a vehicle at Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland.

Bold nodes are terminal nodes. RSS = 4133.67

For those adult wallabies that did flee in response to an approaching vehicle, flight direction was either away from the vehicle and road or across the path of the vehicle. The large majority of wallabies did flee away from the vehicle (91%), however six wallabies (9%) fled across the road. Of these six wallabies, four were females at Cherbon and one male and female each at Sanctuary. This tended to occur when habitat on the other side of the road may have been perceived as offering better protection and/or when an impermeable fence restricted the wallaby’s flight away from the road.

The activity that wallabies were performing after being disturbed by and responding to a vehicle depended on the final response to the vehicle and the activity being performed before the vehicle approached (Figure 4.10). 'Other'
activities (pooled) were too few to be predicted and so were removed from the analysis. Wallabies that fled in response to a vehicle were predicted to be alert after responding. Alternately, if the wallaby responded alertly or did not respond, and was previously alert or performing an ‘other’ activity, they returned to being alert. However, if the wallaby responded alertly or did not respond, and was previously foraging, they returned to foraging.

Figure 4.10 Classification tree for wallaby activity after responding to a vehicle at Cherbon Street at Burbank, Sanctuary Drive at Mount Cotton and Heinemann Road at Mount Cotton in South East Queensland. Bold nodes are terminal nodes. Misclassification rate = 32.7%
4.4. **Discussion**

4.4.1. *Road-crossing behaviour*

The activity that red-necked wallabies performed for the majority of time spent in the road verges is likely to be indicative of their priorities while at the roadside. Males were predicted to be alert for the majority of the time in the verge, whereas the ‘main’ behaviour of females depended on the road and season. Females at Cherbon, the least busy road, spent the majority of their time foraging, perhaps because of the low traffic volumes, and hence, low disturbance of foraging. Due to the relatively good conditions during the period of these surveys, many females had pouch-young or young-at-foot. This placed extra nutritional and energy demands on the females as they care for their young, and so foraging on good quality grass at the roadside may be prioritised (Lee 2006), particularly at roads with low disturbance. At the roads with higher traffic volumes, and thus, more frequent disturbances, females would mostly forage in autumn and winter and be alert in spring and summer. Along these more frequently disturbed roads, it is possible that females are more likely to be alert for the majority of the time during spring and summer, when they are slightly more likely to have emerging pouch-young and young-at-foot at keep watch over and protect in dangerous situations. Although red-necked wallabies are continuous breeders, the mainland sub-species, *M. r. banksianus*, in north-eastern New South Wales was shown to have partial seasonality, with more pouch-young emerging in spring than any other season (Higginbottom and Johnson 2000).

Wallaby verge presence and activity before crossing the road may be some indication of disturbance levels, but also of wallaby cautionary behaviour prior to
crossing the road. The majority of wallabies were present in the verge prior to crossing, although this proportion was much smaller at Heinemann. It is possible that this is due to the higher disturbance levels at Heinemann pushing more wallabies outside the immediate road verge, where the wallabies may feel safer. This, however, may also mean that wallabies are less aware of potential vehicle presence on the road before crossing, as they initiated locomotion to cross the road at a greater distance from the road. This potential for naivety in the current traffic condition may place them at greater risk of an encounter with a vehicle on the road with the greatest traffic volume.

For those wallabies that were present in the verge, awareness of traffic condition can also be drawn from their activity immediately before crossing. Here, most wallabies were alert immediately prior to crossing, and so are assumed to be aware of the current traffic condition, however many performed other activities before crossing. Higher proportions of males were alert, with few performing other activities, all of which involved sniffing. Fewer females were alert, with several foraging and performing other social and maintenance activities. It is possible that wallabies were able to assess the traffic condition and their surroundings while performing these other activities (Favreau et al. 2010); however it shows that their primary focus before crossing the road was not on the road itself. Tibetan antelope (*Pantholops hodgsoni*), Tibetan gazelle (*Procapra picticaudata*) and Kiang (*Equus kiang*) spend several minutes observing, approaching and being vigilant before crossing the road and always crossed in groups (Qiu and Feng 2004; Baofa et al. 2006). These ungulates were very cautious when crossing the Qinghai-Tibet Highway, however they may have become highly sensitised to traffic, as people
occasionally stop to whistle and watch them at the side of the road (Baofa et al. 2006).

During the actual road crossing, most wallabies did not pause, but were predicted to pause at least once in some circumstances at Heinemann, the road with the highest traffic levels and speeds. The seasonal differences apparent in the classification tree are illogical and may be a result of lower sample sizes in some seasons. Interestingly, however, wallabies were more likely to pause during autumn and spring when a vehicle approached them during the crossing. This suggests that the wallaby pauses to watch the vehicle approach instead of fleeing out of its path. This is also supported by the fact that higher proportions of wallabies paused once and two or more times at Heinemann, the busiest road, than they did at the other two roads and that all wallabies that paused were alert for at least part of the pausing time. Occasionally a wallaby would stand at the edge of the bitumen and start to graze or drink while still being in risk of being hit by oncoming traffic. This behaviour was unusual and has not been reported in any of the other mammal species for which road crossing behaviour has been recorded (Waring et al. 1991; Qiu and Feng 2004; Baofa et al. 2006). This behaviour makes wallabies especially susceptible to vehicle collisions; particularly when drivers are inattentive or indifferent, vehicles are travelling at high speeds, and/or the road is windy or undulating, where the view of the road ahead of the vehicle is reduced (Clevenger et al. 2003; Taylor and Goldingay 2004; Lee 2006).

The number of times a wallaby paused during crossing obviously greatly influenced the time that they spent crossing the road, and hence, increased the likelihood of encountering a vehicle. The time it took wallabies to cross the road
without pausing was shorter at Sanctuary, most likely because the road there was divided, and hence, the single-lane road width was shorter and quicker to cross than the other roads (see Table 4.1). This suggests that divided roads may be safer to cross, as the crossing time (if the wallaby crosses both divided road sections) is split into two shorter time periods of risk and allows the wallaby to focus on traffic coming from a single direction. This, however, would only apply when the median strip is vegetated (though not densely) and wide enough to allow wallabies to stop easily and comfortably without obstructing the road (> 7 m).

After crossing the road, wallabies tended to only stay in the verge if they were previously in the verge before crossing. This suggests that those wallabies present in the verges before and after crossing the road crossed simply to access a different patch on grass to graze, or in the case of males, perhaps to follow a female who has moved to graze on the other side of the road. Although this is not well supported by the fact that only 7% of wallabies started to forage immediately after crossing the road, many wallabies did proceed to forage in the verge. Most wallabies remained alert after crossing the road, perhaps to assess the area more closely before settling to forage or continuing to move elsewhere. If, however, a vehicle approached the wallaby during the crossing, the wallaby would leave the verge immediately, presumably to distance themselves from the threat of the vehicle and seek shelter.

4.4.2. Response to vehicles

Animal behavioural responses to vehicles can potentially have large impacts on their stress levels and disturbances in activity patterns, as well as determine the
likelihood of colliding with oncoming vehicles (Horejsi 1981; Mazerolle et al. 2005; Lee et al. 2010). Wallabies were more likely to be disturbed from foraging at Cherbon, the quietest road, when in a small group. This suggests that the wallabies were more relaxed and were more likely to be foraging when a vehicle approached along a low disturbance road and when other wallabies are also close by to assist in keeping vigilant (Coulson 1999). Several other mammal species also display such patterns of higher foraging proportions when in groups and in lower disturbance areas (Blumstein et al. 2003; Pays et al. 2009; Lian et al. 2011). This, however, is not direct evidence of group vigilance increasing individual foraging activity as time budgets would need to be analysed to examine these effects (Coulson 1999).

Responses to approaching vehicles were variable, but involved an alert response, fleeing (usually away from the vehicle), no response or an alert response followed by flight. Slight differences in the percentages of wallabies that did not respond to vehicles were evident when looking at the first response percentages of wallabies, as no response was never predicted in the final response classification tree, and so could not be included. Although the higher proportion of wallabies not responding at Sanctuary was only slight, it may be an indication of some habituation to passing vehicles occurring here, although a longer-term temporal study would need to be performed to confirm this (Bejder et al. 2009). These results contrast to what might be expected; Sanctuary had an intermediate level of traffic, yet some individuals displayed a higher tolerance level towards vehicles than individuals at both Cherbon and Heinemann, where there were much lower and much greater traffic volumes, respectively.
Higher tolerance levels along high traffic volume roads have been observed in another study, where red kangaroos (*Macropus rufus*), grey (eastern and western, *M. giganteus* and *M. fuliginosus*) kangaroos and euros (*M. robustus erubescens*) were less likely to take flight from a vehicle along a remote highway than along a less frequently used road (Lee et al. 2010). A study on guanacos (*Lama guanicoe*) has also produced similar results (Marino and Johnson 2012). One possible explanation for this inconsistent result is an interaction between traffic volume and traffic speed influencing wallaby tolerance to passing vehicles. At Heinemann, it is possible that the high traffic speeds reduce the ability for the wallabies to tolerate the traffic. Much more data that include long-term temporal comparisons would be needed to actually determine that there is in fact some level of habituation occurring at Sanctuary (Bejder et al. 2009), and more roads would need to be surveyed to determine if this interaction has occurred elsewhere. It is important to note here that none of the roads surveyed were recently constructed; their exact ages are unknown, however, all roads were at least 10 years old.

The proportion of red-necked wallabies that fled in response to vehicles was similar or slightly greater than that of red kangaroos, grey kangaroos and euros (Lee 2006; Lee et al. 2010). The wallabies’ final response to an approaching vehicle was influenced by many variables and produced complex results. Vehicle size class was the most influential variable, with wallabies predicted to flee from trucks (small and large). The tendency to flee (or mock charge) similarly greatly increased when Asian elephants encountered these vehicle sizes in southern India (Vidya and Thuppil 2010). This tendency for wallabies to flee from approaching trucks may be a key contributor to their susceptibility to road mortality (Lee et al. 2010).
2010), as the percent of commercial vehicle traffic was identified as a contributing factor to red-necked wallaby road-kill frequencies (see Chapter 2). For vehicles smaller than trucks, wallabies would respond alertly in spring and in all seasons at Sanctuary. Again this suggests that there may be some level of habituation occurring at Sanctuary, as wallabies were not predicted to flee in any circumstances from cars or motorbikes, thus showed a greater tolerance compared to the other two roads.

The seasonal effect at Cherbon and Heinemann was, however, contrary to that observed on red kangaroos, grey kangaroos and euros in north-west New South Wales (Lee et al. 2010). In this study, kangaroos were more likely to flee from an approaching vehicle in spring than any other season (Lee et al. 2010). The contrasting responses of wallabies at Cherbon and Heinemann in summer, autumn and winter may be influenced by the vastly different traffic conditions on these roads due to the combined differences in traffic volumes, proportions of commercial-sized vehicles and speeds. At Cherbon, if the wallaby was previously foraging, it may be taken by surprise at the sudden appearance of a vehicle along the usually quiet road, and so respond by fleeing. Alternatively, if the wallaby was previously already alert the vehicle may have been seen from a distance, and so the wallaby may not feel the need to flee from the slower-moving vehicles. At Heinemann these situations are reversed, as the activity of the wallabies increased from either foraging to alert or alert to flight in response to the high-speed vehicles.

Wallaby response duration was only influenced by the wallabies’ final response. Here it seems illogical for wallabies to respond for a longer period of
time when being alert than when fleeing, but fleeing wallabies did not often flee far. Additionally, wallabies sometimes fled into nearby bushland and so were assumed to have stopped fleeing once they were no longer visible from the road. These flight durations were, however, very short when compared to those of barren ground caribou (*Rangifer tarandus g ranti*) in Canada that fled from vehicles for a mean of 58±11 seconds (Horejsi 1981). The duration of alert responses were similar to that of Tibetan antelope being vigilant near the Qinghai-Tibet Highway in China (Lian *et al.* 2011).

When wallabies did flee in response to an approaching vehicle, they mostly fled away from the vehicle, with some wallabies fleeing across the path of the vehicle into habitat on the opposite side of the road. Flight across the path of the vehicle tended to occur when habitat on the other side of the road may have been perceived as offering better protection and/or when an impermeable fence restricted the wallaby's flight away from the road. These behavioural responses were also observed in kangaroos in north-west NSW (Lee 2006). Unlike Lee's (2006) study, wallabies were never recorded to flee directly towards the vehicle or parallel to the road. Anecdotally, wallabies have been observed fleeing parallel to the road, but these behaviours were never observed during surveys.

4.5. *Conclusion*

The behaviour wallabies displayed when crossing roads and responding to vehicles may be influential in determining the risk of collision with a vehicle. Unfortunately it is difficult to determine from the current study whether the flightiness of wallabies influenced their risk of mortality, as was shown in Lee *et al.*
(2010), because only one species was assessed at three very different roads. Despite this, from the road crossing observations, it can be seen that wallabies tended to display somewhat more risky behaviours when crossing Heinemann Road and this was likely to exacerbate the risk of road mortality at this already high-risk road (see Chapter 2 for road-kill data). The medium traffic levels and high speeds of this road, together with the more risky behaviour of the wallabies here, may have a synergistic effect on the frequency of wallaby road-kills along this road.

As most wallabies in the road verges foraged for some time while in the verge (and many for the majority of the time), it is recommended that the vegetation (particularly grasses) be minimised in the road verges. This will reduce the occurrence of wallabies within the verges, and so likely reduce the disturbance levels on the wallabies as they forage further from the road (Baofa et al. 2006; Li et al. 2009). This will also reduce the occasional behaviour of wallabies stopping on the edge of the bitumen to forage, while still being in the path of oncoming traffic. Although the grassy road verges were usually regularly mowed, they would sometimes be left unmown for substantial periods of time, allowing the grass to grow high and obscure drivers’ views of the road verge. By removing the grass altogether and replacing it with gravel, drivers would consistently have a clear view of the road verge and thus be able to respond more quickly to a wallaby approaching the road. An additional benefit is the reduced cost in constantly maintaining these verges.
Chapter 5

The impact of roads and traffic on the activity budgets of red-necked wallabies, *Macropus rufogriseus banksianus*
5. The impact of roads and traffic on the activity budgets of red-necked wallabies, *Macropus rufogriseus banksianus*

5.1. Introduction

In human-modified environments, disturbance from a variety of human activities is often frequent and sometimes intense. Wildlife species that persist in these environments have to learn to cope with these disturbances, both physiologically and behaviourally. It has been suggested that the behavioural responses of animals to human disturbances can be equivocated to that of increased predation risk (Frid and Dill 2002). This suggests that animal behavioural changes in highly human-disturbed areas should be similar to those in areas of high predation risk when compared to behaviour displayed in lower disturbance and lower predation risk areas.

Behavioural changes and shifts in activity patterns can occur if the disturbance is frequent and intense enough and coincides with peak activity periods. Shifts in animal activity budgets, particularly concerning vigilance and foraging time allocation and rates, have been demonstrated in both relatively high predation pressure environments and in human-disturbed environments (e.g. Blumstein and Daniel 2003; Dyck and Baydack 2004; Li *et al*. 2011), typically with vigilance increasing with predation risk or human disturbance. Such increases in vigilance must be balanced by a decrease in other behaviours, such as foraging, grooming, socialising and resting, and this may have negative fitness consequences.
if the extent of behavioural change is great or be such that the resource benefit is no longer worth the stress of foraging in the area (Frid and Dill 2002).

The impacts of tourism and recreational activities on wildlife behaviour have been relatively well studied due to concerns about the effects of such disturbances on wildlife populations in natural and protected areas (Galicia and Baldassarre 1997; Dyck and Baydack 2004; Naylor 2006; St-Louis et al. 2013). The impacts of other human disturbances in urban or peri-urban environments are less frequently studied, as conservation concerns of many of the species that persist in these areas are often minor (Li et al. 2011; Selman et al. 2013). An assumption could also be made that these species have adapted to and/or can cope with high levels of disturbance simply because they have persisted in disturbed areas (Sol et al. 2013). Yet, despite this, the associated behavioural changes may potentially result in increased energy expenditure, decreased time for foraging and self-maintenance activities (e.g. grooming), decreased time for social interactions (in species that socialise) and increased stress (Frid and Dill 2002; Ditchkoff et al. 2006; Banks et al. 2007). The extent of these alterations to normal behaviour may therefore be important in determining the long-term persistence of species in these areas (Frid and Dill 2002).

Disturbance from roads and traffic are one such human-induced disturbance that can alter wildlife behaviour. Investigations into roadside behaviour may reveal how animals perceive and react to roads and moving vehicles. Animals that regularly forage along roadsides may make a trade-off between coping with the road disturbance while foraging on higher quality roadside vegetation and foraging in lower quality sites further from the road.
(Grosman et al. 2009, 2011). In situations where roadside habitats provide especially valuable resources (such as high quality food, salt or easy access to road-killed animals), some animal populations or individuals may interact with the road environment on an almost daily basis, and incorporate movements to and through the road environment as part of their daily routine (e.g. Jaarsma et al. 2007; Klar et al. 2009).

Changes in activity budgets have been studied in free-ranging ungulates foraging close to roads, with changes varying in different species. Tibetan antelope (Pantholops hodgsonii) in China (Lian et al. 2011) and pronghorn (Antilocapra americana) in Canada (Gavin and Komers 2006), for example, increased their vigilance and foraged less when they were closer to roads. Some species, however, may alter their activity budgets in other ways; caribou (Rangifer tarandus granti) decreased time allocated to resting and spent more time standing and walking or running when around roads, yet did not change their foraging time allocation (Murphy and Curatolo 1987). The presence of roads and traffic can cause some species to even change the timing of their peak in activity to avoid the peak traffic times (Ditchkoff et al. 2006). For example, critically endangered Przewalski's gazelles (Procapra przewalskii) changed their activity patterns from a predominantly diurnal peak of activity before the Qinghai-Tibet Highway in China was built, to a crepuscular pattern after the highway was completed (Li et al. 2009). Unfortunately, studies relating changes in activity budgets to proximity to roads and/or traffic volume have been rare in other taxa (e.g. Li et al. 2011).

This chapter aimed to quantify changes to the activity budgets of semi-urban red-necked wallabies (Macropus rufogriseus banksianus) when in close
proximity to three roads with different traffic conditions. More specifically, changes in the time allocation to foraging, vigilance, locomotion, grooming and socialising were investigated to indicate potential changes in energy intake, energy expenditure and maintenance activities. Additionally, vigilance rates were investigated to assess whether changes in the rate of interruption of foraging and maintenance activities was associated with passing traffic.

Red-necked wallabies are known to sometimes form groups when foraging; these are typically small (typically 2-3 individuals), unstable groups that occur for short periods of time (Johnson 1989). Despite this, it is assumed that similar individual behavioural adjustments are made when they are part of a group, as can be seen in highly gregarious macropod species (e.g. eastern grey kangaroo, Macropus giganteus, Pays et al. 2007b). Because of this, group size was an important variable that may influence behaviour and an effort was made to include animals that were part of varying group sizes.

### 5.2. Methods

**5.2.1. Behavioural data collection**

The roadside-behaviour of red-necked wallabies was recorded at three road sites according to the methods in Chapter 4.

Wallaby behaviour was also recorded at two control sites in the Tingalpa Creek section of Brisbane Koala Bushlands at Burbank. This is in the same suburb as one of the road sites, Cherbon St, and consisted of similar habitat to that surrounding the road sites. All focal animals were a minimum of 250 m from roads, with the exception of one minor road (with an estimated traffic volume of <500
vehicles per day), which was a minimum of 100 m from all animals. Despite all roads being beyond the focal wallaby's sight (due to topography and vegetation), traffic noise could be heard; however, wallabies did not appear to respond to these noises. Both control sites consisted mostly of mown grass with scattered trees and nearby sections of Eucalypt woodland with a heath understorey. Wallabies were approached slowly, quietly and discreetly so as not to alert the wallaby to my presence. All observations were made between 15:30 and 18:00 hours. Wallaby behaviour was recorded using a JVC Everio High Definition video camera for 15 to 20 minutes or until the wallaby moved out of sight. If a wallaby became aware of my presence, it was not recorded, or if already recording, the recording was stopped.

A total of 111 video recordings of wallabies at the road sites were used, providing a total of 23 hours, 51 minutes and 24 seconds of video and 161 focal wallaby activity budgets. A total of 39 video recordings of wallabies at the control sites were used, providing a total of 6 hours, 56 minutes and 9 seconds of video and 54 focal wallaby activity budgets. Only data from adult wallabies were used in analyses as too few observations of juvenile and subadult wallabies were obtained. For a focal wallaby to be used in the dataset, they had to be in sight in the video for a minimum of three minutes.

The behavioural software package JWatcher (Blumstein et al. 2000-2012, version 1.0 for Windows) was used to score behaviours and produce summary statistics from the raw data of the scored data files (Blumstein and Daniel 2007). Playback of video files while scoring behaviour was in VLC media player (VideoLAN 2012, versions 2.0.4 and 2.0.5 for Windows). This playback was used
instead of JWatcher Video due to the inability to alter video start and stop times in JWatcher Video to when the focal wallaby entered and exited the video frame.

The following variables were recorded for each focal wallaby in each video file: date; time; site; sex; and group size. Wallabies were determined to be in a group if they were within 15 m of another wallaby; only adult wallabies were counted to determine group size (e.g. a female with a young at foot that is foraging with one other adult was classified as being in a group size of two). Group size was that which was applicable to the majority of the focal-observation period. Table 4.3 (in Chapter 4) lists and describes the behaviours used in this chapter, excluding the locomotion behaviour flee that was only used for response to vehicle behaviours.

5.2.2. Data analyses

All analyses compared variables among the control sites (pooled) and the three road sites separately, each representing different levels of traffic volume and speed. These will henceforth be referred to as the following treatments: control (away from roads); Cherbon (low traffic volume and speed road); Sanctuary (medium traffic volume and low speed road); and Heinemann (high traffic volume and speed road). See Chapter 4 for details of these roads.

Difficulties were sometimes experienced in determining the sex of wallabies; therefore some wallabies were classified as unknown sex. This meant that for all analyses involving significant sex comparisons, only observations involving known male and female adults were included.

As red-necked wallabies typically forage as singletons or in small groups, observations of three or more individuals were infrequent and not observed at all
sites. This meant that statistical analyses were conducted using only observations of individuals as singletons or pairs, allowing group size to be included as a potential influential factor. Even where group size was removed from the final model, observations of larger groups were not included, as there was a possibility that this could then change the influence of group size and potentially confound variables at larger group sizes.

Due to the short period of time over which data was collected from control sites, it was not possible to investigate potential influence of season on wallaby activity budgets. It was highly likely that this would have had little influence during the data collection period, as south-eastern Queensland typically experiences two main seasons: a wet hot summer and a dry mild winter. Despite this, the unusually high rainfall received in the study area during the period of data collection meant that the typical winter drying out of grass and vegetation did not occur, and pouch young and young-at-foot were observed throughout the year.

Initial statistical analyses were conducted in JWatcher (Blumstein et al. 2000-2012, version 1.0 for Windows). The following data were extracted from all focal wallaby data files for all behaviours: number of bouts; total duration; and proportion of time-in-sight.

Proportions of time spent foraging and vigilant were both normally distributed, while the proportion of time spent locomoting was transformed using logit \( (x + 0.001) \) (Warton and Hui 2010) to satisfy normality. One outlier was removed for both foraging and vigilance (no foraging occurred with an unusually high allocation to vigilance) and three outliers for locomotion (unusually high values). Separate ANOVAs were performed on the proportions of time spent
foraging, vigilant and locomoting using group, sex and treatment as independent variables. All ANOVA assumptions were met. Group and sex were removed when found to be insignificant. Tukey HSD post hoc tests were then performed to reveal where the significant effects occurred. A Pearson’s product-moment correlation was also conducted on the proportion of time spent foraging and the proportion of time spent vigilant by wallabies at all sites to examine whether there was a possible trade-off between these behaviours.

Proportion of time spent grooming was analysed differently due to grooming not occurring during all observations and, when grooming did occur, the variances appeared to be unequal across the four treatments. First, a Chi-squared test was conducted, comparing the frequencies of observations in each treatment where grooming occurred and did not occur. This investigated whether the decision to groom was distributed differently across the treatments. Further analyses were conducted only on observations where grooming occurred to compare the allocation of grooming across the treatments, after the decision to groom had been made. Second, a Levene test was performed to detect differences in the variance of the proportion of time spent grooming across the four treatments. Third, the variable was logit (x + 0.001) transformed to satisfy normality. Finally, multiple Welch two sample t-tests were performed between each pair of treatments, allowing for unequal variances across the samples (Ruxton 2006).

The variables bout duration for both foraging and vigilance were not normally distributed and no common transformation normalised the data. Both variables were, therefore, rank transformed and then analysed in the same way as
proportions of time spent foraging and vigilant. The data was treated in this way to enable post-hoc tests to be conducted.

The variable vigilance rate was calculated by dividing the number of alert bouts in an observation by the total time that the animal was in sight. Three outliers that were unusually high were removed. Vigilance rate was then analysed in the same way as proportions of time spent foraging and vigilant.

Bout durations were not included as covariates in the respective proportion of time analyses because this would have effectively controlled for the differences in bout duration across the treatments. Because proportions of time and bout durations are intrinsically related, any differences in bout duration would have overridden the differences in proportion of time among the treatments.

The statistical software package R (The R Foundation for Statistical Computing 2011) was used to conduct all statistical analyses.

5.3. Results

A total of 186 wallabies were observed as singletons or pairs and used in analyses: 41 at the control sites; 68 at Cherbon; 23 at Sanctuary; and 54 at Heinemann. For all analyses, differences in sex and group size were insignificant and were removed from the analyses, allowing observations of unsexed individuals to be included.

The proportion of time spent foraging by wallabies was significantly different among the treatments (df = 3, F = 6.739, p = 0.00025). The Tukey HSD test revealed that significant differences existed between the control (mean = 0.596±0.0450) and both Sanctuary (mean = 0.392±0.0460, adjusted p = 0.00496)
and Heinemann (mean = 0.432±0.0312, adjusted p = 0.00429; Figure 5.1) and Cherbon (mean = 0.555±0.0239) and both Sanctuary (adjusted p = 0.02139) and Heinemann (adjusted p = 0.02151; Figure 5.1). Differences between the control and Cherbon, and Sanctuary and Heinemann were insignificant.

The proportion of time spent vigilant by wallabies was similarly significantly different among the treatments (df = 3, F = 8.692, p = 2.03 x 10^{-5}). The Tukey HSD test revealed that significant differences lay between the control (mean = 0.308±0.0380) and both Sanctuary (mean = 0.511±0.0445, adjusted p = 0.00064) and Heinemann (mean = 0.482±0.0237, adjusted p = 0.00019; Figure 5.1) and Cherbon (mean = 0.377±0.0214) and both Sanctuary (adjusted p = 0.02805) and Heinemann (adjusted p = 0.02116; Figure 5.1). Differences between the control and Cherbon, and Sanctuary and Heinemann were insignificant. There was a significant negative correlation between the proportion of time spent foraging and the proportion of time spent vigilant by wallabies (Pearson correlation, r = -0.885, p = 2.2 x 10^{-16}; Figure 5.2). This shows that there is a clear trade-off between foraging and vigilance, such that with increasing vigilance, time allocated to foraging generally declines.
Figure 5.1 The mean proportion of time spent foraging and vigilant at all four treatments. Bars are standard errors. Road sites are ordered by ascending traffic volume (see Table 4.1 for details).

Figure 5.2 The trade-off between the proportion of time spent foraging and the proportion of time spent vigilant by wallabies at all sites (Pearson correlation, $r = -.885$, $p = 2.2 \times 10^{-16}$).

The proportion of time spent locomoting by wallabies was significantly different among the treatments ($df = 3, F = 9.578$, $p = 6.73 \times 10^{-6}$). The Tukey HSD
test revealed highly significant differences between the control (mean = 0.015±0.0032) and both Cherbon (mean = 0.032±0.0038, adjusted p = 1.41 x 10^{-5}) and Heinemann (mean = 0.041±0.0058, adjusted p = 3.87 x 10^{-5}; Figure 5.3). The difference between the control and Sanctuary (mean = 0.025±0.0052) was marginally insignificant (adjusted p = 0.07499; Figure 5.3). Differences among the three road treatments were all insignificant.

Figure 5.3 The mean proportion of time spent locomoting and grooming at all four treatments. Bars are standard errors. Road sites are ordered by ascending traffic volume (see Table 4.1 for details).

The frequency of grooming occurring in observations was significantly different across the treatments ($\chi^2 = 18.9534$, df = 3, p = 0.00028; Figure 5.4). The control had significantly more observations than expected where grooming occurred, whereas Heinemann had significantly more observations than expected where grooming did not occur. Furthermore, when grooming did occur, the Welch
t-tests revealed that there were significant differences in the proportion of time spent grooming between the control (mean = 0.047±0.0133) and both Cherbon (mean = 0.023±0.0055; t = -2.3807, df = 73.638, p = 0.01987) and Heinemann (mean = 0.024±0.0062; t = 2.0796, df = 65.464, p = 0.04148; Figure 5.3). Differences between the control and Sanctuary (mean = 0.030±0.0076) and among the three road treatments were all insignificant. The variances of proportion of time spent grooming appear to vary greatly across the treatments, with the control having a greater variance than the road treatments and ranged into much higher values, despite a relatively low median and mean (Figure 5.5). This difference in variance was, however, insignificant.

**Figure 5.4** Observed (OBS) and expected (EXP) frequencies of observations at all four treatments where grooming occurred and did not occur. Expected values were obtained from the Chi-squared test ($\chi^2 = 18.9534$, df = 3, p = 0.00028). Road sites are ordered by ascending traffic volume (see Table 4.1 for details).
Figure 5.5 Range of observations for proportion of time spent grooming at all four treatments. Whiskers are minimum and maximum values, boxes are first quartiles, medians and third quartiles, and points are means. Road sites are ordered by ascending traffic volume (see Table 4.1 for details).

Foraging bout durations were significantly different among the treatments (df = 3, F = 22.15, p = 2.9 x 10^{-12}). The Tukey HSD test revealed significant differences between the control (mean = 18.9±1.43 sec) and all three roads (Cherbon: mean = 12.1±0.65 sec, adjusted p = 0.00008; Sanctuary: mean = 12.1±1.04 sec, adjusted p = 0.00668; and Heinemann: mean = 8.2±0.59 sec, adjusted p < 1 x 10^{-7}; Figure 5.6). Heinemann was also significantly different to the
other two roads (Cherbon: adjusted p = 0.00013; and Sanctuary: adjusted p = 0.00575; Figure 5.6). Differences between Cherbon and Sanctuary were insignificant.

![Graph showing mean foraging and vigilant bout durations. Bars are standard errors. Road sites are ordered by ascending traffic volume (see Table 4.1 for details).](image)

**Figure 5.6** Mean foraging and vigilant bout durations. Bars are standard errors. Road sites are ordered by ascending traffic volume (see Table 4.1 for details).

Vigilant bout durations were significantly different among the treatments (df = 3, F = 6.413, p = 0.00038). The Tukey HSD test revealed significant differences between Sanctuary (mean = 11.2±0.86 sec) and the control (mean = 10.8±0.29 sec, adjusted p = 0.00026) and Sanctuary and the two other roads (Cherbon: mean = 7.9±0.70 sec, adjusted p = 0.00122; and Heinemann: mean = 7.8±0.49 sec, adjusted p = 0.01862; Figure 5.6). All differences among the control, Cherbon and Heinemann were insignificant.
Vigilance rates were significantly different among the treatments (df = 3, F = 35.87, p < 2 x 10^{-16}). The Tukey HSD test revealed significant differences between the control (mean = 2.0±0.14 bouts/min) and all three roads (Cherbon: mean = 2.9±0.10 bouts/min, adjusted p = 2 x 10^{-7}; Sanctuary: mean = 2.6±0.11 bouts/min, adjusted p = 0.02737; and Heinemann: mean = 3.8±0.13 bouts/min, adjusted p < 1 x 10^{-7}; Figure 5.7). Heinemann was also significantly different to the other two roads (Cherbon: adjusted p = 2.2 x 10^{-6}; and Sanctuary: adjusted p = 6 x 10^{-7}; Figure 5.7). Differences between Cherbon and Sanctuary were insignificant.

![Figure 5.7](image)

**Figure 5.7** Mean vigilance rates at all four treatments. Bars are standard errors. Road sites are ordered by ascending traffic volume (see Table 4.1 for details).

### 5.4. Discussion

The time allocation of foraging, vigilance, grooming and locomotion in red-necked wallabies at the control sites were similar to those observed in Bennett's
wallabies (*M. r. rufogriseus*, the Tasmanian subspecies) at Maria Island National Park (foraging: 59.6% cf. 70.9%, vigilance: 30.8% cf. 20.8%, grooming: 4.7% cf. 5.0%, and locomotion: 1.5% cf. 2.6% in this study and on Maria Is., respectively) (Blumstein and Daniel 2003). This confirms that the control sites were likely to be representative of wallabies in a more natural environment, with the approximately 10% difference in time allocation to both foraging and vigilance likely due to the peri-urban environment of the control sites, as well as other habitat and predation pressure differences.

The lack of significant differences in time allocation to foraging and vigilance between the control and Cherbon, suggests that a road with such a low traffic volume does not appear to impact greatly on overall foraging effort. There were, however, significant differences between the control and Cherbon when comparing foraging bout durations and vigilance rate. This reveals that even though the overall time allocation to foraging at Cherbon was similar to that at the control, foraging bouts were interrupted more frequently by vigilance.

The significant differences in time allocation to foraging and vigilance between the control and both Sanctuary and Heinemann suggest that the presence of higher traffic volumes at these roads reduced the potential for foraging to be the dominant behaviour. At both of these roads, wallabies allocated more time to vigilance than they did to foraging, and thus may need to spend longer periods of time in the open to gain the same potential to forage. The very slightly greater allocation to vigilance (and corresponding slightly lower foraging allocation) at Sanctuary may be due to its location in a more residential area where disturbance from other human activities is likely to also be influential on these variables. This
may also be the reason behind the pattern in vigilance bout durations and rate at Sanctuary. At Sanctuary, the similar vigilance rate (and foraging bout duration) to Cherbon suggests that the wallabies here do not react to every passing vehicle (also see Chapter 4), but when they do look up, they may also be assessing human activity around them, and thus are vigilant for longer bouts. This evidence of a higher tolerance to passing traffic at Sanctuary than might be expected was also seen in Chapter 4, and may suggest that some habituation to traffic has occurred along this road, yet further research over long time frames would be needed to confirm this (Bejder et al. 2009).

The proportion of time spent locomoting at each treatment could be used as a rough indicator of energy expenditure. Wallabies allocated significantly less time to moving around at the control than at both Cherbon and Heinemann, and almost significantly less than at Sanctuary. This means that near roads, wallabies tended to move around more than when they were far from roads. This is most likely partially due to some wallabies fleeing in response to passing vehicles (see Chapter 4), but may also be due to other factors. Wallabies typically moved around in short bouts (<1 – 2 sec) while foraging, assumingly to access other patches of forage (personal observation). It is possible that preferred foraging resources are more patchily distributed (at a site-level scale) close to roads, and so wallabies may need to move very small distances more frequently while foraging in order to access other patches of preferred forage (Lee 2006). For this to be confirmed, however, the distribution of preferred forage would have needed to be measured at each treatment. It is also possible that social interactions may alter when close to roads (Banks et al. 2007), such that subordinate animals are usurped more often, and
therefore generally move more. Unfortunately, social interactions between wallabies occurred too infrequently to be analysed during this study, although it was noted that fighting between males was only observed at the roadside treatments (A. Blacker, unpublished data).

The proportion of wallabies that groomed during an observation was significantly different from what would be expected at the control and Heinemann. At the control, wallabies were more likely to groom during an observation than expected, whereas, at Heinemann, wallabies were less likely to groom during an observation. Additionally, when wallabies did groom, they allocated significantly more time to grooming at the control than at both Cherbon and Heinemann. This may be explained by wallabies perhaps being more relaxed at the control than at Cherbon and Heinemann due to the lack of vehicles, and therefore affording more time to self-maintenance. Although the difference in variances was insignificant, it is clear that wallabies sometimes groomed for much longer at the control than near the roads (Figure 5.5). It is possible that some wallabies were able to afford this larger proportion of time to grooming because of the lack of potentially threatening circumstances (Blumstein et al. 1999). Time allocation to grooming would also intrinsically be related to the parasite load of the wallabies at each treatment. This might explain the lack of a difference in time allocation to grooming between the control and Sanctuary. It is possible that the wallabies at Sanctuary may have higher parasite loads than wallabies at the other treatments due to their location in a residential area. For example, it is possible that transfer of parasites between wallabies and pets maintains overall higher levels of parasites,
thus leading wallabies to allocate more time to self-maintenance (Adams 2003; Wells et al. 2012).

Although this is the first study to have specifically investigated the changes in behaviour of a macropod species when near roads, several similar studies have been conducted on other species (e.g. Gavin and Komers 2006; Naylor 2006; Lian et al. 2011). Additionally, a study has been conducted on three wallaby species (swamp wallabies, *Wallabia bicolor*, bridled nailtail wallabies, *Onychogalea faenata*, and red-necked wallabies) in a tourist wildlife sanctuary section of the Western Plain Zoo in Dubbo, New South Wales (King et al. 2005). When a vehicle approached the wallabies, their allocations of time to ‘maintenance activities’ (feeding, resting, grooming and socialising pooled) of all three wallaby species were reduced to less than half of that allocated when there was no approach from either vehicles or people on foot (King et al. 2005). Unfortunately, there was no separation of the ‘maintenance activities’ in the study, nor were actual time allocations clearly stated for direct comparison.

Tibetan antelopes similarly reduced foraging time allocation and bout duration and increased vigilance time allocation and frequency when they were close to the Qinghai-Tibet Highway in China (Lian et al. 2011). Lian and colleagues (2011) also showed that Tibetan antelopes tended to reduce foraging (both time allocation and bout duration) and increase vigilance (both time allocation and rate) during periods of high traffic volume. Additionally, pronghorn in Canada were found to be significantly more vigilant near roads with high traffic volumes, when compared at roads with medium traffic volumes (Gavin and Komers 2006). This generally aligns with findings from the present study, where foraging time
allocation and bout duration was lower at high traffic volume roads, and vigilance
time allocation and rate were higher.

In studying the behavioural impacts of human disturbances on yellow-
bellied marmots (Marmota flaviventris), high levels of vehicular and bicycle traffic
(measured and analysed separately) corresponded with an increase in time
allocated to vigilance and a decrease in time allocated to foraging (Li et al. 2011).
Rocky Mountain elk (Cervus elaphus, now C. canadensis) also reduced time
allocated to foraging when all-terrain vehicles were present, compared to when elk
were undisturbed (Naylor 2006); alternately, time allocated to foraging remained
unchanged for caribou in Alaska when they were close to a road and elevated
pipeline where human disturbance was high (Murphy and Curatolo 1987). For the
caribou, however, instead of making a trade-off between foraging in quality areas
and vigilance due to disturbance, the animals seemed to be making a trade-off
between the disturbance caused by the pipeline and road and the benefit of
reduced insect harassment close to these structures (Murphy and Curatolo 1987).
Pronghorn also tended to increase their time allocation to foraging and decrease
that to vigilance when they were greater distances from roads (Gavin and Komers
2006).

Additionally, caribou (Murphy and Curatolo 1987) and Rocky Mountain elk
(Naylor 2006) time allocation to locomotion generally increased when close to the
road and pipeline or vehicles were present, respectively, similar to the that of
wallabies grazing near roads in the current study. In both the caribou and Rocky
Mountain elk studies, time allocated to resting was also investigated, although the
results were mixed, and in the present study resting was observed very rarely at
all treatments. Time allocated to grooming was not reported in any of these studies.

Greater time allocation to vigilance may correlate with stress indicators, such as cortisol concentration, and therefore may suggest relative stress levels of animals in disturbed environments. Vigilance time allocation and cortisol concentration levels have been simultaneously measured in sheep of varying group sizes (Michelena et al. 2012), with both variables decreasing with increasing group size. Despite this, however, vigilance time allocation and cortisol concentration levels were marginally insignificantly correlated with each other (Michelena et al. 2012). Further research into the relationship between vigilance and stress hormones in animals would be informative in drawing more solid conclusions about the impact of disturbance on stress levels without the need for invasive procedures.

Some studies investigating foraging and vigilant behaviours of macropods have revealed an influence of group size on time allocation to foraging and vigilance and/or vigilance rate (e.g. Coulson 1999; Pays et al. 2007b). This general effect of group size seems to occur more consistently in highly social and gregarious species e.g. eastern grey kangaroo (Blumstein and Daniel 2003; Pays et al. 2007b), Tasmanian pademelon, *Thylogale billardierii* (Blumstein and Daniel 2003) and tammar wallaby, *Macropus eugenii* (Blumstein et al. 1999). Conversely, such a relationship appears to be less consistent for species that form less stable groups, such as the red-necked wallaby (Johnson 1989).

Significant group size effects on the behaviour of red-necked wallabies were not found in the current study. This is consistent with the findings of Johnson...
(1989), where no relationship was found between group size and foraging time allocation (1 = 76.7%, 2 = 78.6%, 3+ = 72.6%) nor vigilance time allocation in red-necked wallabies at Wallaby Creek, NSW. In this study, group sizes of one, two and three or more were used as larger groups were rarely observed. Bennett’s wallabies in Maria Island National Park and Mt. William National Park in Tasmania also showed no relationship between vigilance time allocation and group size (Blumstein and Daniel 2003). Although the present study found no significant influence of group size on any of the dependant variables investigated, this was most likely due to the use of observations from only singletons and pairs of wallabies. When examining data across all group sizes, a trend of decreasing vigilance with increasing group size was apparent, but could not be separated from the effect of treatment due to the unequal distribution of group sizes across the treatments. Beauchamp (2013) argues that the general negative relationship between vigilance levels and group size may be underestimated when there are other unmeasured variables that may interact with groups size (e.g. predation risk, conspecific competition, sex). This may create heteroscedasticity, which (if the interaction is negative) lowers the apparent magnitude between vigilance and group size when considering simple linear regression models (Beauchamp 2013).

The negative correlation between proportion of time spent foraging and vigilant suggests a trade-off between the two behaviours. This trade-off is similar to that shown for Tibetan antelope along the Qinghai-Tibet Highway (Lian et al. 2011) and for pronghorn in Alberta, Canada (Gavin and Komers 2006). When interpreted for the situation in the current study, it is likely that when wallabies graze near roads, there is a trade-off between higher disturbance (‘predation risk’).
at the roadside and higher quality and/or abundance of forage (Frid and Dill 2002).

5.5. Conclusion

Red-necked wallabies significantly altered their activity budgets when near roads, compared to when they were away from roads. Differences in their activity budgets were also apparent among the three different roads, which was likely to be greatly influenced by the traffic levels at each of the roads. It is also likely, however, that interactions among traffic volume, traffic speed and other human disturbances are influencing wallaby activity budgets, yet limitations in the number and location of appropriate roads restricted detailed investigation into this area.

It is possible that increased vigilance time allocation and/or frequency near roads may be an indicator of increased stress levels, however more research needs to be conducted into the nature of this relationship (Michelen et al. 2012). Finally, the trade-off between high levels of disturbance and higher quality and/or abundance of forage at roadsides suggests that, if the quality and/or abundance of fresh grass are reduced at roadsides, wallabies may be less willing to risk foraging in these areas. Consequently, both stress from being in a risky environment and road mortality of red-necked wallabies might be reduced (also see Chapters 2 and 4). This has implications for the management of roadside verges in areas where macropods and other grazing animals, such as some ungulates, may be attracted to grass that grows in road verges. In these areas, it is recommended that vegetation growth in the road verges be discouraged and grassy verges be replaced by gravel.
While this will not prevent grazing animals from crossing roads directly, it avoids attracting them to spend additional time in close proximity to the road environment, and thus reducing the potential for disturbance-induced stress and wildlife-vehicle collisions.
Chapter 6

Macropods, roads and peri-urban landscapes:
a synthesis and future research priorities
6. Macropods, roads and peri-urban landscapes: a synthesis and future research priorities

This thesis has contributed to the understanding of the interactions between macropods and road environments in several ways. To my knowledge, this is the first study to reveal a link between commercial vehicles and macropod (or other wildlife) road mortality. This link was not only found when examining the spatial patterns of wallaby road-kill, but also when studying the responses of wallabies to approaching vehicles. Wallaby response to vehicles primarily depended on vehicle size, with commercial-sized vehicles predicted to cause a flight response. A causative relationship between flightiness and susceptibility to road mortality was found by Lee (2006; Lee et al. 2010) and my results loosely support this concept. By studying the behaviour of wallabies near roads, some understanding of the way they perceive vehicles can be revealed. Wallabies apparently perceive passing vehicles as a form of predation risk (by increasing vigilance), yet do not always recognise this threat to be high when crossing roads. Finally, first steps in assessing and optimising the design of wildlife warning signs were taken, although much broader thought and research needs to be invested in such widespread mitigation measures.

This research also has potential applications for research in road ecology internationally. Due to the similar ecological niches filled by macropods and ungulates, some of the findings regarding road-kill patterns and roadside behaviour may also relate to some large grazing ungulate species. It is possible that
spatial associations of road-kill may be similar for some species of ungulates (e.g. proximity to water, Ng et al. 2008). Although the proportion of commercial vehicle traffic has not been widely used in road-kill spatial modelling, this may be an important variable for predicting road-kill patterns of large animals due to the large vehicle size and the protection this gives the driver, who thus is less likely to avoid the animal. Similarities with ungulates in their roadside behaviour are also evident, with regard to their response to vehicles (Lian et al. 2011; Marino and Johnson 2012) and alterations in activity budgets close to roads (Gavin and Komers 2006; Lian et al. 2011). These similarities may, therefore, extend to the management implications and recommendations to mitigate the impacts of road mortality and behavioural disturbance.

6.1. Current understanding of interactions between macropods and roads

The research conducted on the interactions between macropods and roads encompasses studies on road mortality, behaviour around roads, population modelling, and the effectiveness of road mitigation measures. Patterns of road mortality have been attributed to local and landscape features, seasonality, and weather conditions in a range of environments and for several species. Macropod road-kills have been associated with traffic volumes (both spatially and temporally) (Osawa 1989; Burgin and Brainwood 2008), proportion of commercial traffic (Chapter 2), verge width (Chambers et al. 2010) and vegetation (Lee 2006), water sources (Chapter 2 and Ramp et al. 2005), habitat (Buchanan 2005; Ramp et al. 2005), moon phase (Coulson 1982; Lintermans and Cunningham 1997), rainfall (Chapter 2 and Ramp et al. 2005), drought (Coulson 1989; Lee et al. 2004), and
other weather related variables (Chapter 2 and Lee 2006). Despite the findings of these studies, it is likely that patterns of road-kill differ with species and location, and thus remain integral for planning future local road mitigation strategies and avoiding building new roads through habitats where high rates of wildlife-vehicle collisions would be likely.

The behaviour of macropods around roads and in response to vehicles can be varied and often differs among species (Lee 2006) and with different road attributes (traffic volume and speed) (Chapters 4 and 5 and Lee 2006). The response of an animal to an approaching vehicle can greatly influence the outcome of an encounter, even to the extent of increasing the susceptibility of flighty species to road mortality (Lee 2006). Although very little has been investigated in relation to roadside behaviour, it is likely that complex interactions exist among traffic volume, speed and other disturbances in determining macropod responses to vehicles and the disturbance caused by the road (Chapters 4 and 5).

Roads have the potential to significantly contribute to the decline of macropod populations, through substantial mortality rates and alteration of metapopulation dynamics by restricting movement between populations (Ramp and Ben-Ami 2006). This pressure can be exasperated in macropod populations that have already declined, as the number of road-killed individuals can represent a large proportion of the remaining population (e.g. Hazlitt et al. 2006). These impacts will be more obvious in regularly-monitored populations of species of conservation concern, but there is also the potential for roads to contribute to declines in larger populations of more common species (e.g. Ramp and Ben-Ami 2006), with losses continuing unnoticed. It is for this reason that it is crucial to
firstly consider avoiding the placement of roads through areas where such wildlife population declines may occur due to these impacts. It is only where such areas cannot be avoided, that minimisation of impacts and mitigation measures should be considered, or, as a last resort, compensation through offsets.

The effectiveness and use of a variety of road mitigation measures for wildlife have been studied to varying degrees. Road crossing structures in combination with fauna-exclusion fencing appear to be the most effective form of mitigation, yet most studies to date have typically presented evidence of use by certain species and/or reduced road mortality, and have rarely demonstrated effective restoration of population dynamics (see Taylor and Goldingay 2010). Road-crossing structures are also only suitable in certain locations. Other, less expensive mitigation measures, that aim solely to reduce road mortality, are yet to be shown to do so substantially (Glista et al. 2009; Huijser et al. 2009). This is with exception for fauna-exclusion fencing alone, which, without the road crossing structures, exasperates the barrier effect of roads. The effect of current wildlife warning signs on road-kill rates, for example, appears to be minimal (e.g. Coulson 1982), yet very few studies have definitively assessed the effectiveness of these signs. Drawing from research conducted overseas, wildlife warning signs may be effective in some situations (Sullivan et al. 2004a), but this likely depends on sign design and driver perception of risk (Chapter 3). Management or minimisation of vegetation in road verges has the potential to limit the encouragement of wildlife remaining in the immediate transport corridor to forage. This mitigation measure may reduce the potential for wildlife-vehicle collisions and disturbance-induced stress in wildlife by minimising the interaction time between vehicles and wildlife.
and ensuring that verges provide a clear view for drivers to see wildlife near the road as well as wildlife to see approaching vehicles.

Importantly, these mitigation measures are not limited in their applicability to many taxa and locations. It has clearly been demonstrated that road-crossing structures, wildlife-exclusion fencing and wildlife warning signs can be applied to multiple and varied taxa, and have been used around the world (Clevenger et al. 2001a; Olsson et al. 2008; Glista et al. 2009; Taylor and Goldingay 2010; Found and Boyce 2011b). The minimisation of vegetation in road verges also has implications for a variety of wildlife in many habitats. Grazing and browsing animals will no longer be attracted to forage in road verges (Ramp et al. 2006a), small animals that may use this vegetation as habitat will be removed from the immediate vicinity of the road and danger of collisions with vehicles (Clevenger et al. 2003), and both animals and drivers will have unobstructed views of the road and verge, enabling greater time for avoiding wildlife-vehicle collisions.

6.2. Future research directions

Despite research to date covering a range of interactions between macropods and roads, there remain some important areas where further research is needed. To my knowledge, no studies have investigated the movement of macropods around and through road networks. Such research would identify spatial and temporal patterns of usage of the road environment, successful road-crossing locations, avoidance of or attraction to the road environment, and the impact on daily movements and home ranges (Lewis et al. 2011; Jones et al. 2012;
Additionally, if large numbers of animals are able to be tracked, road permeability and landscape connectivity could also be assessed.

Population viability analyses or other population models need to be applied to assess the impact of roads on macropods in a wider range of environments. These tools can be particularly useful for comparing different management strategies and identifying key processes in landscapes where populations may be influenced by several pressures (Ramp and Ben-Ami 2006; Chambers and Bencini 2010). Not only is it important to conduct population modelling on species that are of conservation concern, but it is also vital to monitor populations of currently abundant species that live in increasingly stressful environments (Roger 2009). By monitoring such populations, signs of decline may be noticed early and further decline or local extirpation may be able to be avoided if managed effectively and efficiently. Larger regional-scale occupancies can also be predicted under potential future development levels and associated loss of habitat, fragmentation and change in land use (Bettigole et al. 2014). Additionally population modelling could be used to assess the effectiveness of road crossing structures at restoring connectivity between wildlife populations separated by the road (Taylor 2010; Taylor and Goldingay 2012).

Assessments of the effectiveness of mitigation measures in relation to their intended ecological function are much needed. Most studies to date have reported species use of various road crossing structures, yet have not taken the next step to assess effectiveness at population or metapopulation levels (Taylor and Goldingay 2010). Assessments are needed on whether such structures can restore population dynamics such as migration, gene flow and ultimately increase long-term
population viability. Furthermore, studies of wildlife use of road crossing structures are important for improving our understanding of the conditions under which certain species do and do not use these structures, the frequency of use and possible reasons for crossing roads.

Although road crossing structures are very important road mitigation measures, future research must also include assessment of other approaches that are able to be implemented in a wider range of conditions. Wildlife warning signs are a simple mitigation measure that has been widely implemented, yet are severely under-researched. Further research needs to be conducted into optimising sign design for maximum driver awareness and response. This is particularly important for reducing wildlife-vehicle collisions in areas where other mitigation measures are impractical or inappropriate. Optimising such cheaper and easily implemented mitigation measures may be important in reducing the impacts of roads on wildlife across the vast landscapes present in Australia.

Finally, one potential simple management strategy for reducing macropod road-kills is to control vegetation growing in the road verges. This is exemplified by a reduction of Proserpine rock-wallaby (*Petrogale persephone*) road-kills following the removal of guinea grass (*Panicum maximum*) from road verges (Department of Environment and Resource Management 2010). Verge vegetation management or removal may reduce the attraction of grazing macropods to the roadside and reduce time spent in close proximity to the road, thus possibly reducing susceptibility to road mortality and behavioural disturbance. Further exploration of this as a potential macropod road management strategy is needed through experimental manipulation of road verge vegetation.
6.3. Peri-urban research priorities

Peri-urban and urbanising landscapes are likely to have higher rates of local extinction as many species are unable to cope with the increasing levels of habitat loss, fragmentation and anthropogenic disturbance. Research on macropod populations in peri-urban and urbanising landscapes has been very limited. To draw comparisons with the koala, an iconic species that was thought to be common in the same region only a little over a decade ago, our knowledge of macropod ecology in peri-urban landscapes needs to expand in order to detect potential population declines and/or shifts early.

Since regular koala population monitoring commenced in South East Queensland (Dique et al. 2004; Department of Environment and Resource Management 2009, 2012), regional declines were detected and prompted further intensive research. A series of studies investigated the influence of habitat and land use configuration on the distribution and occurrence koalas in human-modified landscapes (McAlpine et al. 2006a; McAlpine et al. 2006b; Rhodes et al. 2006; Januchowski et al. 2008). These studies used a combination of natural and anthropogenic variables at site, patch and landscape scales to predict the presence of koalas in the region. From this, areas of critical importance to the persistence of the koala populations were able to be identified and inform land managers as to the potential impact of conservation strategies and further development (McAlpine et al. 2006b; Rhodes et al. 2006; Januchowski et al. 2008). Similar studies on the macropod species that persist in peri-urban landscapes – often in the same areas as those supporting koalas – would be useful to assess the potential risk of
population declines under increasing pressure from anthropogenic land use changes and activity.

Identification of key threats in urban and peri-urban landscapes is crucial, particularly where these differ greatly from those that may be present in other, more natural landscapes. Such a study has been conducted for koalas in a similar area to that of the current study (Preece 2007). A spatial analysis of the occurrence of these threats revealed high priority areas for mitigation of the three main threats to koalas and where mitigation efforts should be focussed (Preece 2007). Additionally, detailed records are kept of all reported koala mortalities and hospitalised injuries in the DEHP koala hospital database (Department of Environment and Heritage Protection 2013), including location and cause of injuries or death (Dique et al. 2003; Preece 2007; Department of Environment and Resource Management 2009, 2012). Although all mortalities and injuries are unlikely to be detected, this provides a large and comprehensive dataset that can be used to focus conservation and threat mitigation strategies (Dique et al. 2003; Jones et al. 2012; Jones et al. 2013b; Sullivan et al. 2013).

Recently, research on koala movements and home ranges have also been used to identify crucial areas for koala movement, dispersal and habitat use in peri-urban landscapes (Jones et al. 2012; Jones et al. 2013b). This research was also important in confirming the use of retro-fitted underpasses by koalas to cross roads where fauna-exclusion fencing has been installed to reduce wildlife-vehicle collisions (Jones et al. 2012).

The research briefly outlined above has provided crucial information to managing and conserving koala populations in urban and peri-urban landscapes,
particularly along the ‘Koala Coast’, part of which was the study area for the current study. Unfortunately, however, this research was conducted out of a desperate need for a better understanding of their needs and threats as these populations continued to decline. Such research may have been more valuable if it were conducted prior to the dramatic decline of koalas in the region, thus allowing for earlier detection of the decline and allowing more time to implement strategic management and conservation efforts to prevent further severe decline. A similar situation can also be seen with the plight of another iconic common species, the common wombat, *Vombatus ursinus* (Roger 2009). Prevention of such declines may have been possible with the dedication of research resources into monitoring urban and peri-urban wildlife populations. For some macropod species, however, the prevention of similar declines may be possible if further research and monitoring is conducted in these highly dynamic landscapes.
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Appendices

Appendix A – Wildlife warning sign design survey

Wildlife Warning Sign Design Survey Information Sheet

This survey is part of a PhD research project.

This research project aims to provide potentially more effective wildlife warning sign designs by assessing the potential relative driver response to various signage designs through a public opinion survey.

Wildlife warning signs are commonly implemented mitigation measures to reduce wildlife-vehicle collisions in areas of high occurrence. Despite being the most commonly implemented road mitigation measure, evidence of their effectiveness in producing desired driver responses and reducing road-kill incidence is inconsistent and they are generally thought to not have an impact. Regardless of this, wildlife warning signs will continue to be implemented due to their inexpensive cost compared to other mitigation measures.

This research is part of a PhD research project and will contribute to a PhD thesis and scientific journal articles. This research is being conducted by PhD candidate Amy Bond (A.Bond@griffith.edu.au) under the supervision of the chief investigator Associate Professor Darryl Jones (D.Jones@griffith.edu.au). Please contact either researcher if you have any questions or concerns about this research. Participation in this survey is voluntary and you are able to exit the survey without submission at any point during the survey.

This survey is anonymous and your privacy is protected. At no point will your personal identity be asked or recorded.

Griffith University conducts research in accordance with the National Statement on Ethical Conduct in Human Research (2007). If you have any concerns or complaints about the ethical conduct of the research you should contact the Manager, Research Ethics on (07) 3735 4375 or research-ethics@griffith.edu.au.

Thank you for your interest and participation.
Consent to Participate in the Wildlife Warning Sign Design Survey

I confirm that I have read and understood the information provided and in particular I note that:

- my involvement in this research will be through a survey;
- I consent to the use of direct quotes;
- personal data will not be collected in any form;
- I have had all questions answered to my satisfaction;
- I understand the risks involved;
- there will be no direct benefit to me from my participation in this research;
- I will not be paid for my participation;
- my participation in this research is voluntary;
- I am free to withdraw from the survey at any time without comment or penalty;
- I can contact the student researcher, Amy Bond at A.Bond@griffith.edu.au, or the chief investigator, Associate Professor Darryl Jones at D.Jones@griffith.edu.au, if I have any questions or concerns about this research or to obtain a summary of the results of the research;
- I can contact the Manager, Research Ethics on (07) 3735 4375 or at research-ethics@griffith.edu.au if I have any concerns about the ethical conduct of the project;
- I agree to participate in the project; and
- I am 18 years or older.

Completion and submission of this survey will be deemed to be consent to your participation in this research. Click next if you consent to participate in this survey.
Wildlife warning sign design survey

PART A

1. Do you regularly drive in areas that display wildlife warning signs?
   a. Yes
   b. No
   c. Unsure

2. Have you ever hit a wild animal while driving? Please note that in this context a wild animal would be any animal that is not a domestic or stock animal and include both native and non-native species.
   a. Yes...please go to Q3
   b. No...please go to Q4

3. If you answered yes to Q2, how many wild animals do you estimate you have hit while driving?
   a. 1-5
   b. 5-10
   c. 10-30
   d. >30

4. Have you ever hit a domestic or stock animal while driving?
   a. Yes
   b. No
5. Do you usually notice wildlife warning signs?
   a. Yes
   b. No
   c. Sometimes (please explain)

_________________________________________________________________________________
_________________________________________________________________________________

6. When you see a wildlife warning road sign, what do you think is the desired driver response?
   a. Reduce driving speed
   b. Increase alertness
   c. Reduce driving speed and increase alertness
   d. Continue driving as before the sign
   e. Increase driving speed
   f. Other (please explain)

_________________________________________________________________________________
_________________________________________________________________________________

7. When you see a wildlife warning road sign, what is your usual response?
   a. Reduce driving speed
   b. Increase alertness
   c. Reduce driving speed and increase alertness
   d. Continue driving as before the sign
   e. Increase driving speed
   f. Other (please explain)

_________________________________________________________________________________
8. On wildlife warning signs, does the type of animal displayed make you more aware of that animal near the road? Please circle the most correct answer for you.
   a. Yes, I specifically look for the animal displayed
   b. Yes, I look for the animal displayed as well as other animals
   c. No, I look for any animals near the road
   d. No, I don’t actively look for animals near the road

9. Would you respond differently to different types of animals being displayed on wildlife warning signs? For example, would your response to a kangaroo warning sign be different to that of a koala, quoll, deer or wild boar?
   a. Yes
   b. No
   Please explain:________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

10. On some roads, lesser-known animals (e.g. quolls or bandicoots) are the most likely animal to be involved in a collision with a vehicle. Does displaying an image of these animals on a sign (instead of the kangaroo) help your awareness of the animal of greatest concern?
   a. Yes
   b. No
   Please explain why or why not:________________________________________
   ________________________________________________________________
Some wildlife warning signs display specified time periods (e.g., 6pm – 6am, Aug – Dec). Are you more or less likely to respond to a sign with time periods with increased alertness and reduced driving speed if:

11. you are driving during this period (6pm – 6am, Aug – Dec)? e.g. 8pm in November
   a. More likely
   b. Less likely
   c. I am equally likely to respond to signs in this way, whether or not time specifications are displayed

12. you are driving outside this period (6pm – 6am, Aug – Dec)? e.g. 10am in April
   a. More likely
   b. Less likely
   c. I am equally likely to respond to signs in this way, whether or not time specifications are displayed
13. Are you more or less likely to respond to a sign that displays the number of road-killed animals that have occurred on that road over the previous year with increased alertness and reduced driving speed?
   a. More likely
   b. Less likely
   c. I am equally likely to respond to signs in this way, whether or not road-kill numbers are displayed

14. Are you more likely to respond with increased alertness and reduced driving speed to a permanent, periodic or temporary wildlife warning sign?
   a. Permanent
   b. Periodic (sign is present for a two-week period every three months)
   c. Temporary (sign is displayed for a one month period every year)
   d. I am equally likely to respond to a sign whether it is permanent, periodic or temporary

15. Are you more likely to notice a wildlife warning sign if it is positioned on the roadside or in the median strip (where available)?
   a. Roadside
   b. Median strip
   c. I am equally likely to notice both
PART B
For the next set of questions, you will be shown several different wildlife warning signs and asked a set of questions about each sign. Please answer each question with regard to the sign displayed on that page only.

Sign #1

(Image source: Department of Transport and Main Roads)

16. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

210
17. Please explain the message that is conveyed to you by this sign.
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

18. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

19. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

20. What part or aspect of this sign stands out the most to you?
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
21. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________

_____________________________________________________________________________________________

_____________________________________________________________________________________________

22. Please explain the message that is conveyed to you by this sign.

_____________________________________________________________________________________________

_____________________________________________________________________________________________

_____________________________________________________________________________________________
23. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

24. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

25. What part or aspect of this sign stands out the most to you?

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
26. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

(Image source: Department of Transport and Main Roads)
27. Please explain the message that is conveyed to you by this sign.

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

28. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

29. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

30. What part or aspect of this sign stands out the most to you?

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________
Sign #4

**PLEASE NOTE:** A single sign is displayed; the electronic message that is displayed above the sign is variable. The first message is activated when a speeding vehicle is detected and the second message is activated if the speeding vehicle slows down.

![Sign Image]

(Image source: Department of Transport and Main Roads)

31. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

32. Please explain the message that is conveyed to you by this sign.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

216
33. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

34. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

35. What part or aspect of this sign stands out the most to you?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
36. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

37. Please explain the message that is conveyed to you by this sign.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
38. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
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<tr>
<td>60</td>
<td>1</td>
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<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

39. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
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<td>3</td>
<td>4</td>
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<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

40. What part or aspect of this sign stands out the most to you?

______________________________________________________________________________________________
______________________________________________________________________________________________
______________________________________________________________________________________________
______________________________________________________________________________________________
41. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

42. Please explain the message that is conveyed to you by this sign.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
43. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

44. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
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<td>3</td>
<td>4</td>
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</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

45. What part or aspect of this sign stands out the most to you?

_____________________________________________________________________________________________
_____________________________________________________________________________________________
____________________________________________________
_____________________________________________________________________________________________
46. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

47. Please explain the message that is conveyed to you by this sign.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

(Photo source: Amy Bond)
48. Please indicate the likelihood that you would **notice this sign** when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

49. Please indicate the likelihood that you would **respond to this sign** by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
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</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

50. What part or aspect of this sign stands out the most to you?

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
51. Please explain how you are likely to respond to this sign if you saw it while driving.

_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

(Photo source: Western Australia Police)
52. Please explain the message that is conveyed to you by this sign.

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

53. Please indicate the likelihood that you would notice this sign when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
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<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

54. Please indicate the likelihood that you would respond to this sign by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
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</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

55. What part or aspect of this sign stands out the most to you?

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
56. Of all of the signs displayed above, which one are you most likely to respond to by increasing alertness and reducing driving speed?
   a. Sign #1
   b. Sign #2
   c. Sign #3
   d. Sign #4
   e. Sign #5
   f. Sign #6
   g. Sign #7
   h. Sign #8

Please explain why: __________________________________________
__________________________________________________________________________
__________________________________________________________________________
57. Of all of the signs displayed above, which one do you think drivers in general are most likely to respond to by increasing alertness and reducing driving speed?
   a. Sign #1
   b. Sign #2
   c. Sign #3
   d. Sign #4
   e. Sign #5
   f. Sign #6
   g. Sign #7
   h. Sign #8
   Please explain why:________________________________________________________________________
________________________________________________________________________________________

58. Please indicate the likelihood that you would respond to any sign that included flashing lights or an electronically displayed message that was activated by the presence of an animal at the roadside by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

59. Please indicate the likelihood that you would respond to any sign that included flashing lights or an electronically displayed message that was activated by a speeding vehicle by increasing alertness and reducing driving speed when driving at the following speeds.

<table>
<thead>
<tr>
<th>Speed (km/hr)</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Unsure</th>
<th>Likely</th>
<th>Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
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<td>3</td>
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<td>5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
60. Do you have any additional comments about designing more effective wildlife warning signs?
PART D

61. Please indicate your age group.
   a. 18-25
   b. 25-40
   c. 40-60
   d. > 60

62. Please indicate your gender.
   a. Male
   b. Female

63. Where do you live?
   a. QLD
   b. NSW
   c. VIC
   d. TAS
   e. SA
   f. WA
   g. NT
   h. ACT
   i. Outside Australia (please specify) ____________________________

64. Do you currently have a driving licence?
   a. Yes, I have an Australian licence
   b. Yes, I have an international licence or a licence from another country that allows me to drive in Australia
   c. No

65. How long have you had a driving licence?
   a. < 1 year
   b. 1-5 years
   c. 5-10 years
   d. 10-20 years
   e. 20-40 years
   f. > 40 years

66. How frequently do you drive?
   a. Daily
   b. One to a few times per week
   c. One to a few times per month
   d. Less than once a month
Thank you for taking the time to participate in this survey. Your answers are highly valuable and will hopefully contribute to designing more effective wildlife warning signs.

If you have any questions regarding this research, please contact Amy Bond by email at A.Bond@griffith.edu.au
Appendix B – Demographics and driving experience of survey participants

Appendix Table 1. Survey participant state of residence.

<table>
<thead>
<tr>
<th>State of residence</th>
<th>Response percent</th>
<th>Response count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queensland</td>
<td>70.1%</td>
<td>94</td>
</tr>
<tr>
<td>New South Wales</td>
<td>10.4%</td>
<td>14</td>
</tr>
<tr>
<td>Victoria</td>
<td>3.0%</td>
<td>4</td>
</tr>
<tr>
<td>Tasmania</td>
<td>0.7%</td>
<td>1</td>
</tr>
<tr>
<td>South Australia</td>
<td>3.7%</td>
<td>5</td>
</tr>
<tr>
<td>Western Australia</td>
<td>9.0%</td>
<td>12</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>0.7%</td>
<td>1</td>
</tr>
<tr>
<td>Australian Capital Territory</td>
<td>2.2%</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>134</td>
</tr>
</tbody>
</table>

Appendix Table 2. Survey participant age.

<table>
<thead>
<tr>
<th>Age</th>
<th>Response percent</th>
<th>Response count</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-25</td>
<td>9.7%</td>
<td>13</td>
</tr>
<tr>
<td>25-40</td>
<td>38.1%</td>
<td>51</td>
</tr>
<tr>
<td>40-60</td>
<td>26.1%</td>
<td>35</td>
</tr>
<tr>
<td>&gt; 60</td>
<td>26.1%</td>
<td>35</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>134</td>
</tr>
</tbody>
</table>
### Appendix Table 3. Survey participant length of driving experience.

<table>
<thead>
<tr>
<th>Years retained a drivers’ licence</th>
<th>Response percent</th>
<th>Response count</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 year</td>
<td>2.2%</td>
<td>3</td>
</tr>
<tr>
<td>1-5 years</td>
<td>10.4%</td>
<td>14</td>
</tr>
<tr>
<td>5-10 years</td>
<td>14.2%</td>
<td>19</td>
</tr>
<tr>
<td>10-20 years</td>
<td>20.1%</td>
<td>27</td>
</tr>
<tr>
<td>20-40 years</td>
<td>24.6%</td>
<td>33</td>
</tr>
<tr>
<td>&gt; 40 years</td>
<td>28.4%</td>
<td>38</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>134</td>
</tr>
</tbody>
</table>

### Appendix Table 4. Survey participant driving frequency.

<table>
<thead>
<tr>
<th>Driving frequency</th>
<th>Response percent</th>
<th>Response count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily</td>
<td>76.1%</td>
<td>102</td>
</tr>
<tr>
<td>One to a few times per week</td>
<td>17.2%</td>
<td>23</td>
</tr>
<tr>
<td>One to a few times per month</td>
<td>3.7%</td>
<td>5</td>
</tr>
<tr>
<td>Less than once a month</td>
<td>3.0%</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>134</td>
</tr>
</tbody>
</table>

### Appendix Table 5. Survey participant exposure to wildlife warning signs.

<table>
<thead>
<tr>
<th>Do you regularly drive in areas that display wildlife warning signs?</th>
<th>Response percent</th>
<th>Response count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>69.4%</td>
<td>93</td>
</tr>
<tr>
<td>No</td>
<td>27.6%</td>
<td>37</td>
</tr>
<tr>
<td>Unsure</td>
<td>3.0%</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>134</td>
</tr>
</tbody>
</table>