Modelling koala road-kill blackspots

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Abstract

Loss and fragmentation of habitat are considered the biggest threats to the long term survival of the koala. However, several other threats are also known to exert additional stress. Many of these are the consequence of loss of habitat which causes koalas to move long distances on the ground. Fragmentation also causes koalas to cross roads more often, which in turn can lead to collisions with vehicles (Caneris & Jones, 2004; Dique et al., 2003; Lunney et al., 2007); by forcing koalas to spent more time on the ground, they may also increase the risk of being attacked by dogs (Caneris & Jones, 2004; Lunney et al., 2007). These risks increase with the decrease in habitat availability (Cork, Clark, & Mazur, 2000). Even though mortality caused by dogs and road accidents are localised events, (Martin & Handasyde, 1999) they are of significant concern because they are contributing factors to population declines (Lunney et al., 2014; Santika, McAlpine, Lunney, Wilson, & Rhodes, 2014).

In Ballarat, both cars and dogs have been assumed to be the most important threats to koalas (Prevett, 1996). This PhD focused on one case—cars via the influence of a highway intersecting with koala habitat within a developed rural landscape. The project investigated:

1) the relative significance of koala animal-vehicle collisions (AVCs) by analysing Victorian wildlife carer data. It was found that AVCs were the most significant cause of koalas entering a wildlife shelter (over dogs attacks), and also the greatest contributor to the cause of death of all koalas in care. The high rates of admissions into care, and of death, especially for male koalas, may impact on the viability of local koala populations.
2) whether koala AVCs occurred uniformly along the highway, or whether there was an uneven distribution of AVCs, and if so whether these road stretches with an apparently higher frequency of kills formed definable zones termed Koala Road-kill Blackspots

(KRBs). If the blackspots did exist, the question was what factors, if any, influenced such occurrences.

Several KRBs were confirmed. Principal Component Analysis (PCA) of the mapped habitat on either side (5 km) of the 50 km long study site [using radii of various sizes (at 50 m chainage points along the road)], revealed that the amount of Secondary A (*areas of forest or woodland where primary koala food tree species < 50% ≥30% of the over-storey trees; or primary koala food tree species < 30%, but together with secondary food tree species ≥ 50% of the over-storey trees; or secondary food tree species alone ≥ 50% with primary koala food tree species absent)* and primary (*areas of forest or woodland where primary koala food tree species ≥ 50% of the over-storey trees*) habitats and the degree of their fragmentation had the greatest influence on the likelihood of KRBs occurring. For example, PC1 accounted for 32.4% of the variation; this included Secondary A habitat variables such as landscape proportion (proportion *of the* landscape *occupied by habitat type*) (0.265) and Number of patches (*equals the number of patches for each habitat type*) (0.275) as well as visibility by drivers (-0.264). PC2 explained 26.2% of variation and included primary habitat variables such as landscape proportion (0.337) and Patch density (*equals the number of patches in the landscape, divided by total landscape area*) (0.32). The amount of the lower quality habitats, Secondary C (*areas of forest or woodland where koala habitat is comprised of secondary and supplementary food tree species with primary koala food tree species absent except for possible scattered individual trees, where secondary food tree species comprise < 30% of the over-storey trees*) (e.g. Landscape proportion 0.256 in PC3 with 16.4% of variation as well as -0.280 in PC2 and Patch density 0.264 in PC3 as well as -0.274 in PC2) and Secondary habitat B (*areas of forest or woodland where primary koala food tree species < 30% of the over-storey trees; or primary koala food tree* *species together with secondary food tree species ≥ 30% (but < 50%); or secondary food tree species alone ≥ 30% but < 50% with primary koala food tree species absent*) (e.g. Landscape proportion PC2 0.293 and Number of patches 0.28 in PC4 with 7.9% of variation) showed a lower level of significance.

3) what aspects of the koala's habitat usage were likely to be responsible for the increased likelihood of an AVC at a black spot. Radio tracking and diet studies using scat analysis, revealed that koalas occupying better quality habitat, preferentially browsed trees of the species *Eucalyptus viminalis*, had the smallest home ranges, used fewer trees and changed trees less often. They also used and consumed fewer non-preferred fodder and non-eucalypt species, and had fewer road crossings.
4) the use of a conceptual model to describe how the interactions of various factors may contribute to determine a KRB. The main factors included were quality of habitat and degree of its fragmentation, and the average size of home ranges for koalas occupying the poorer habitats. This model was then applied, conceptually, to a new study site in Queensland with the aim of executing the field investigation in the near future.

At this Ballarat study site, koalas occur at greater densities in good quality habitat such as (Primary and Secondary A) and as a guide, KRBs are likely to be found along the road where nearby habitats of these types show the greatest fragmentation. The findings from this research show that koalas exclusively using trees in primary koala habitat, and where fragmentation is limited, do not move as much and as frequently as those koalas that use trees in fragmented habitat of all classes or across combinations of habitat classes. The movement of these animals in search for suitable trees, causes them to move trees more frequently and cross roads more often, increasing the likely occurrence of AVCs. Given these findings, it is expected, that by exclusively using vegetation maps or koala habitat atlases, it would be difficult to determine movements of koalas and therefore exact KRBs; radio tracking needs to be an additional tool to ascertain their movements in order to develop appropriate management plans and refine areas for the introduction of mitigation measures. There is a need to prevent and reverse fragmentation of this habitat and of remnant stands of preferred food tree species, especially those of *E. viminalis* which was preferentially used and browsed in this study. It is recommended that new roads should be constructed away from good quality koala habitat, and existing roads should be retrofitted with proven mitigation devices near KRBs areas such as koala exclusion fencing and under-paths.

Declaration

I, Rolf Schlagloth, declare that this thesis comprises only my original work, except where due acknowledgement has been made in the text to all other materials used. This work has neither been presented nor is currently being presented for any other degree.

Signature Redacted

Rockhampton, 18 April 2017

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Figure D 1 Koala ♀, part of this study. Initial capture.

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and keep us together; to my children Ludovica, Alessia, Riccardo and Anneliese who all have been part of this journey and have patiently waited for me to achieve all this—thank you and good luck with your own academic endeavours. Ti amo molto.

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Copyright Statement

Rockhampton, 18 April 2017

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Table of Acronyms and Initialisms

AVC	Animal-Vehicle Collision
APA	Australian Postgraduate Award
ARRB	Australian Road Research Board
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DbH	Diameter at Breast Height
DIF	Direct Immunofluorescence
DSE	Department of Sustainability and Environment
ELISA	Enzyme-Linked Immunosorbent Assay
EPBC	Environment Protection and Biodiversity Conservation
EVC	Ecological Vegetation Class
FPC	Formulated Phloroglucinol Compounds
GPS	Global Positioning System
HR	Home Range
KH	Koala Habitat
KHA	Koala Habitat Atlas
KRB	Koala Road-kill Blackspots
LecoS	Landscape Ecology Statistics
NSW	New South Wales
PCA	Principal Component Analysis
PCR	Polymerase Chain Reaction
PRIMER	Plymouth Routines in Multivariate Ecological Research
QGIS	Quantum Geographic Information System
RACV	Royal Automobile Club of Victoria
RE	Regional Ecosystems
SEQ	South East Queensland
SPIRT	Strategic Partnerships with Industry—Research and Training Scheme
UTM	Universal Transverse Mercator
WHO	World Health Organisation

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Chapter 1. Introduction to the koala and overview of thesis

This Chapter features an introduction to the biology of the koala and an outline of the topics dealt within the remaining four chapters of this thesis.

- Chapter 2: Carer’s data on injured and dead koalas
- Chapter 3 Road-kill blackspots
- Chapter 4: In-depth investigation of a black spot
- Chapter 5: Conceptual model and management issues

1.1 Koala Characteristics and Distribution

The koala (*Phascolarctos cinereus*), the only living representative of the family *Phascolarctidae* (Strahan, 1983), is a unique Australian marsupial and a popular and iconic animal. Koalas are sexually dimorphic with vocalisation and scent marking important in maintaining social structure (Gordon, McGreevy, & Lawrie, 1990; Melzer, Ellis, & Bercovitch, 2010). The life span of wild koalas has been estimated at a maximum of 15 years (Martin & Handasyde, 1991). Female koalas are sexually mature at around two years of age and in populations free of disease will usually give birth to a single young each year (Martin & Handasyde, 1991).

The species was once widely distributed throughout the forests and woodlands of eastern Australia (Martin & Handasyde, 1999) (Figure 1.1).

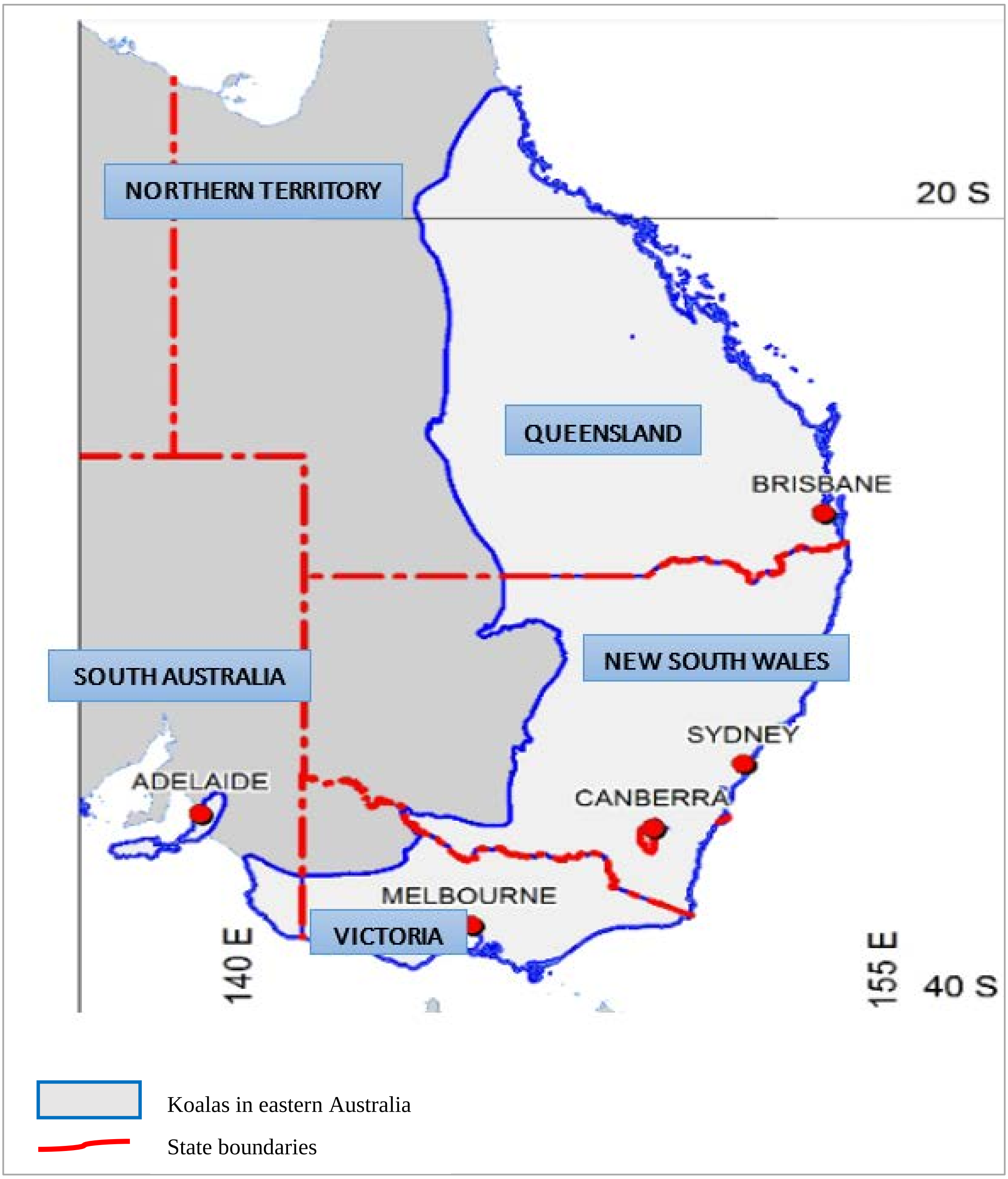

Figure 1-1 Geographic range of koalas in eastern Australia.

The koala's range spans along the east coast of Australia; they are found in Queensland, New South Wales, the Australian Capital Territory, Victoria, and the South-East corner of South Australia (Phillips, 1990a). There are no wild koalas in Western Australia, Tasmania, or the Northern Territory. Since European settlement numbers throughout the species' range have decreased by more than 50% (Melzer, Carrick, Menkhorst, Lunney, & St. John, 2000).

In fact, many populations in Queensland (Rhodes et al., 2011) and Australian Capital Territory and New South Wales are decreasing in number (ANZECC, 1998; Penn et al., 2000; Seabrook et al., 2011; Sullivan, Baxter, Lisle, Pahl, & Norris, 2004) and some are extinct (Rhodes, Beyer, Preece, & McAlpine, 2015). Some areas of Victoria and South Australia, due to translocation programs, have high population densities (Stratford, Mazur, Lunney, & Bennett, 2000), however, other populations are decreasing in number due to habitat fragmentation and other threats (Department of the Environment, 2009); such locations include Phillip Island (Veitch et al., 1997), Macedon Ranges (Phillips, 2000) and the Grampians (Martin & Handasyde, 1999; Menkhorst, 2008). Therefore, koalas are listed as vulnerable in Queensland, New South Wales and the Australian Capital Territory (Department of the Environment, 2009, 2013).

Koalas display morphological variations along their range: those in the southern part of the range are larger, with thicker, darker fur and shorter limbs than those in the northern range (Martin & Lee, 1984).

These were described by various authors and summarised by: Troughton (1947, p. 133)

Strangely enough, although it was to be expected that a mammal of such sedentary habits should develop racial characteristics owing to variation of climate and food trees over the extensive eastern range, it was not until 1923 that Oldfield Thomas, of the British Museum described a northern race (*Phascolarctos cinereus adustus*) from specimen collected in the Eidsvold district of south-eastern Queensland. The race was stated to be smaller, with the skull shorter in both sexes, and the fur generally shorter, while the back was described as more strongly suffused with reddish or tawny compared with the greyish or grey-brown of the typical race of New South Wales. As it had become evident from Australian Museum specimen that the southern Victorian animal was even more definitely distinguishable by its robust build and sparser rather shaggy coat of a more uniform brown above, a southern race (*Ph. cinereus victor*) was described by the author in 1935.

However, mitochondrial DNA analysis, based on evolutionarily significant units, which are used to determine the divergence among groups of populations, has revealed insufficient support for the three distinct subspecies (Houlden et al., 1999). Although, high differentiation has been found among populations (i.e. populations of Queensland, New South Wales and Victoria) based on nucleotide divergence (Houlden et al., 1999). These differentiations appear to be based on morphological adaptation to habitat and environmental conditions along a latitudinal north-south (Carrick, 2013; Melzer, 1995; Melzer et al., 2000; Sherwin, Timms, Wilcken, & Houlden, 2000) with populations at the two extremes of the north-south cline showing stronger genetic differences (Sherwin et al., 2000).

The koala faces many threats to its survival (Department of the Environment, 2009), in particular habitat loss and fragmentation (Department of the Environment, 2013; Rhodes et al., 2015; Smith & Smith, 1990), increased number and intensity of wildfires (Lunney, Gresser, O'neill, Matthews, & Rhodes, 2007) and climate change (Clifton, Ellis, Melzer, & Tucker, 2007; Seabrook et al., 2011). Moreover, populations which become isolated due to loss of habitat are threatened by the risk of loss of genetic diversity due to the potential of genetic bottlenecks (Sherwin et al., 2000) and diseases (Department of the Environment, 2009; McKenzie, 1981; Tarlinton, Meers, Hanger, & Young, 2005), increased predation by dogs and collisions with vehicles (Rhodes et al., 2015).

Severe drought and bushfires have also been suggested as causes of large numbers of koala deaths in certain populations in Queensland e.g. Noosa (McAlpine, Bowen, et al., 2006), New South Wales e.g. Port Stephens (Gordon et al., 1990; Lunney, O'Neill, Matthews, & Sherwin, 2002; Matthews, Lunney, Gresser, & Maitz, 2007, 2016) and South Australia e.g. Mount.

Lofty Ranges (Melzer et al., 2000). This issue is expected to become of greater concern with the expected changes in climatic conditions as a result of climate change (Adams-Hosking, Grantham, Rhodes, McAlpine, & Moss, 2011; Lunney, Stalenberg, Santika, & Rhodes, 2014).

The next section is an overview of Chapter 2 where the impact of some of these threats, especially the significance of attacks by dogs and collisions with cars, on local koala populations is explored.

1.2 Chapter 2: Carer's Data on Injured and Dead Koalas

Even as early as 1858, in his journal, Henry David Thoreau wrote in his journal "We have an account in the newspapers of every cow and calf that is run over, but not of the various wild creatures … It may be many generations before the partridges learn to give the [railway] cars a sufficiently wide berth" (Thoreau, 1858).

1.2.1 Threats to koala's survival. As previously mentioned, the loss and fragmentation of habitat are considered the biggest threats to the long term survival of the koala. However, several other threats are also known to exert additional stress on koalas. Many of these threats are the consequence of loss of habitat (Dique et al., 2003) which necessitates koalas move from tree to tree by walking on the ground for longer distances rather than climbing across branches, and crossing roads to access suitable habitat, leads to collisions with vehicles (Caneris & Jones, 2004; Dique et al., 2003; Lunney et al., 2007; Obendorf, 1983) and dog attacks (Caneris & Jones, 2004; Lunney et al., 2007); and the risk of exposure increases with the decrease in habitat availability (Cork, Clark, & Mazur, 2000).

Even though mortality caused by dogs and road accidents are localised events, (Martin & Handasyde, 1999) they are of significant concern because they are contributing factors to population decline (Lunney et al., 2014; Santika, McAlpine, Lunney, Wilson, & Rhodes, 2014). In Ballarat both cars and dogs were considered to be most important threats to koalas (Prevett, 1996).

Furthermore, diseases also have taken a heavy toll on many koala populations in the past (Gordon & McGreevy, 1978a). Koala retrovirus for example, has been found to cause immune depression and the onset of neoplastic diseases (Hanger, Bromham, McKee, O'Brien, & Robinson, 2000; Tarlinton et al., 2005; Tarlinton, Meers, & Young, 2006). *Chlamydia,* was reported in early studies (Pratt, 1937; Troughton, 1947), and is currently believed to be one of the major limiting factors, together with habitat loss, to the abundance and distribution of populations (Melzer et al., 2000), as well as impacting on overall mortality (Rhodes et al., 2015; Rhodes et al., 2011). Increased occurrences of chlamydial overt signs of infection, such as conjunctivitis or urogenital tract infections, have been attributed to environmental stress (Canfield, Love, Mearns, & Farram, 1991; Hume, 1990; Lunney et al., 2012) such as urban and agricultural development (Brown, Carrick, Gordon, & Reynolds, 1984; Ellis, Girjes, Carrick, & Melzer, 1993).

1.2.2 Care for injured koalas. Care for injured koalas is undertaken by a wide variety of groups with wildlife carers being the primary group, together with selected veterinarians, the Australian Government, state and territory governments, local governments, local conservation groups, the rural community and researchers by coordinating koala conservation actions and some of these running wildlife hospitals (Department of the Environment, 2009).

Details of wildlife rescue, rehabilitation and release are often recorded in large databases and such information has enormous research potential, however, such databases have been little used, few studies have assessed reasons for admissions or investigated success of rehabilitation (Pyke & Szabo, 2017).

In Queensland and New South Wales, data on koala mortality, for sick and injured koalas admitted at every hospital and carers' facilities are recorded on information systems and used by the designated department to produce maps and reports which guide koala management decisions (Department of Environment and Heritage Protection, 2016; Office of Environment and Heritage, 2015). However, recording of data in Victoria has been less organised, formalised and rigorous (Blanshard, 1994; Booth & Curtis, 2014; Tribe & Brown, 2000). Data on injuries and mortality, nevertheless, are collated by individual Victorian wildlife carer, and have been used in this research to determine the most frequent causes of admission and the likely impact on local populations.

The next section is an overview of Chapter 3 which deals with koala road kills, their geographical distribution and the contributing factors.

1.3 Chapter 3: Road-kill Blackspots

When the common riddle, that starts with the question: "Why did the chicken cross the road?" was first published in 1847 (Clark, 1847), not many people would have anticipated that the issue of roads impacting on structure and processes of ecosystems, would become such a significant worldwide issue as to attract a new branch of science named 'road ecology' (Forman, 1998).

The answer to the question is: "To get to the other side". The statement of fact highlights that animals, including wildlife, in most cases, lived in an area long before a road was built, and usually have limited ability to sense the oncoming danger and avoid injury or death.

Maybe it was this view that Albert Einstein wanted to relay with his answer to the riddle: "The chicken did not cross the road. The road passed beneath the chicken". While we have progressed in finding explanations to why some species, in some areas, cross roads

(Andrews, Gibbons, & Reeder, 2005; Grosman, Jaeger, Biron, Dussault, & Ouellet, 2011) and other species avoid it (Jaeger et al., 2005), it is a fact that millions of animals are injured and killed by vehicles every year (Litvaitis & Tash, 2008; Taylor & Goldingay, 2004).

In Australia, it is well established and documented that one of the main threatening processes to the survival of koala populations is vehicular collisions (Department of the Environment, 2009).

Koalas suffer from high mortality rates associated with anthropogenic landscape change which contribute to vehicle collisions with koalas (Dique et al., 2003; Rhodes et al., 2006). Therefore, there is a need to develop modelling approaches that can improve the ability to make informed decisions for koala conservation.

Only a few Australian studies have focused specifically on models of fauna fatalities on roads (Ramp, Caldwell, Edwards, Warton, & Croft, 2005; Roger & Ramp, 2009) and very few so far exclusively on koalas, even though some studies have explored factors leading to koalas mortality on roads (Dique et al., 2003; Lassau et al., 2008). The use of predictive models have been shown to improve both wildlife survival and road safety (Malo, Suárez, & Diez, 2004). Many species-specific habitat and landscape variables such as fodder, vegetation along the road-side, circadian rhythm, road size and traffic volume have been shown to play important roles in the distribution of collisions that result in deaths and injuries and incorporated into models (Jaeger et al., 2005; Ramp, Wilson, & Croft, 2006; Rhodes, Lunney, Callaghan, & McAlpine, 2014).

Several types of models have been used to investigate causes for wildlife road-kill. The source-sink model (Pulliam, 1988) has been used for the identification of road-kill locations of opossums (Kanda, Fuller, & Sievert, 2006) and turtles (Aresco, 2005). In the case of the koala this could be the removal of habitat or the construction of a road (Polak, Rhodes, Jones,

& Possingham, 2014). Models have also been applied at different scales (Johnson & Omland, 2004): micro-habitat, larger habitat patches (Walker, Novaro, & Branch, 2003) and landscape (McAlpine & Eyre, 2002). A multiscale model which considered 12 parameters on koala occurrence in Ballarat found it was essential to protect remaining core areas of high quality habitat and scattered habitat patches. These provided connectivity and enhanced opportunities for safe koala movement between habitat patches intersected by main roads (Januchowski et al., 2008). Only few of the previously mentioned studies have used koala habitat quality as parameters in their models and none have applied them to determine the relationships that may exist between them and areas along roads with concentrations of koala roadkill in an Victorian population.

One main aspect of this current research was to establish the impact of koala-vehicles collisions on the koala populations in regional Victoria, (Australia) with particular focus on those living in road-side habitat. Data and various analyses were used to determine the location of koala roadkill in relation to local roads and the surrounding koala habitat, and to identify parameters that may contribute to the occurrence of blackspots, that is, areas where they are more likely to be killed or injured by collisions with vehicles (Ramp et al., 2005).

Given that it is not possible to reverse more than 200 years of habitat clearing; the identification of factors that cause koalas to be killed on certain sections of roads (Koala Road-kill Blackspot) seems to be a more achievable task with a realistic hope of attaining some reduction in the threats to the long term survival of the koala.

1.4 Chapter 4: In-depth Investigation of a Black Spot

In Chapter 4, a detailed investigation of the population ecology and dynamics of a specific koala population along a highway was undertaken. Habitat use by individual koalas, tree choice and home ranges were also explored.

Koalas, living in an area of a suspected black spot along a section of the Ballarat-Geelong (Victoria) Highway, were the subject of this study.

1.4.1 Study area. Ballarat is Victoria's third largest city, with its population predicted to grow from 96,000 in 2010 to 127,000 by 2030 (Macroplan Australia, 2010).

The city has a rich history in goldmining and is a popular tourist destination (Sunter, 2001). As a consequence of the expansion of gold mining and pastoral activities in the 1850s, today 70-90% of the Ballarat subregion ecosystem is at risk with many vegetation types (Ecological Vegetation Classes—EVCs (Department of Environment, 2016b)) and several wildlife species at risk of extinction (Schembri, 2004). Four woodland EVCs are categorised as vulnerable and three are endangered, two grassland types (Carland & Kennedy, 2010) and Swampy Riparian Woodland (Milne, D'Ombrain, & Leversha, 2005). The wildlife species include the Striped Legless Lizard (*Delma impar*) and the Golden Sun Moth (*Synemon Plana*) (AECOM Australia, 2012). Past urban expansions were primarily directed to the east of the city where the majority of the remaining koala habitat is found (Schlagloth, Callaghan, & Thomson, 2006). The introduction in 2009 of the Koala Plan of Management (Schlagloth, Thomson, & Mitchell, 2006), together with other planning directions, assisted with the refocussing of future development plans to the west of the city. However, one of the main highways, linking Ballarat with Geelong runs through parts of the most important koala habitat in Ballarat and neighbouring municipalities.

This research was conducted along a 50km section of the Midland Highway (from Ballarat towards Geelong) traversing parts of the local government areas of the City of Ballarat, Golden Plains and Moorabool Shires in Western Victoria (Figures 1.2 a and b).

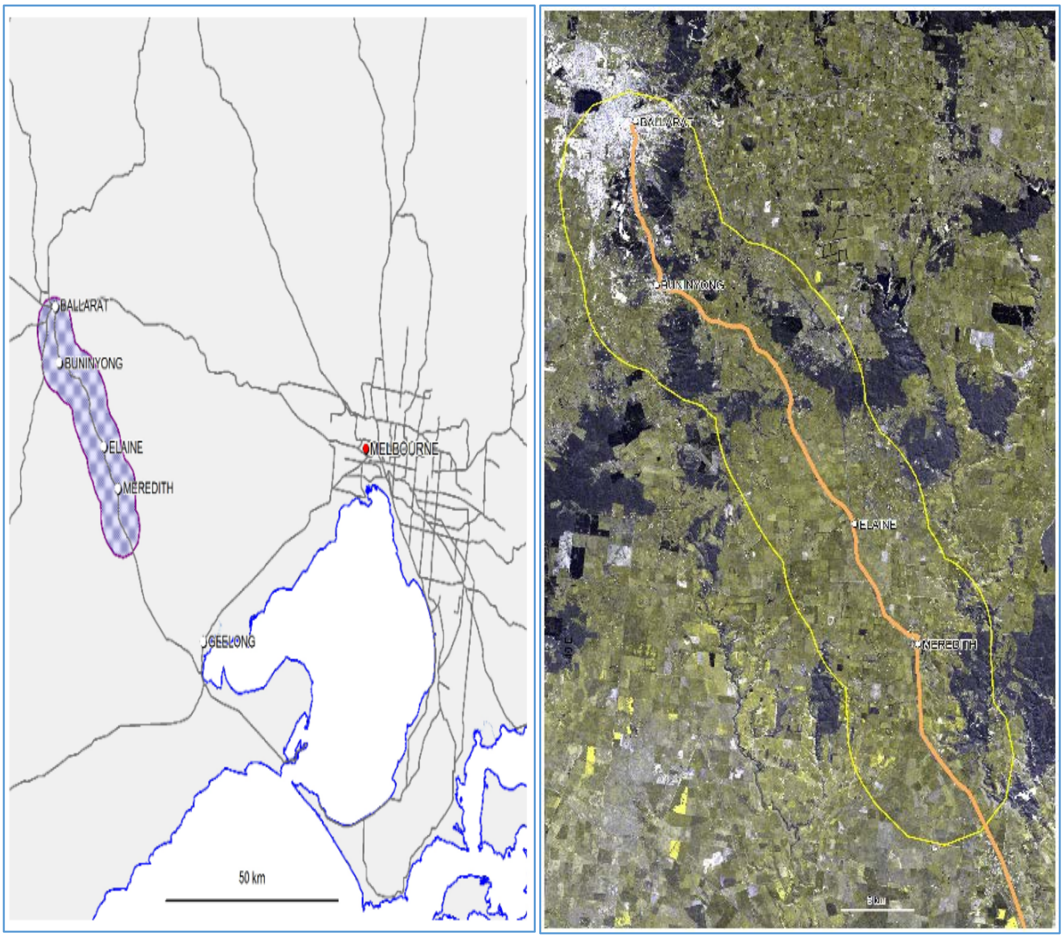

Figure 1-2 a): Location of study area (blue hatching) in western Victoria and b): Study area (detail—yellow outline) overlayed on Landsat image in regional context. Midland Highway is in orange.

1.4.2 Home range.

Home range is, as it was originally defined (Burt, 1943), an area traversed by an individual animal while gathering food, mating and caring for progeny and in particular related to each species' specific living requirements (Stickel, 1954). Home range is characterised typically with descriptors of its size, shape and structure (Kenward, 2000); it is used to determine animal movement (Crook, 2004; Tufto, Andersen, & Linnell, 1996); it is also relative to the size and sex of the animal (Anderson et al., 2005; Jetz, Carbone, Fulford,

& Brown, 2004; Lassau et al., 2008); and over a given time interval (Burt, 1943; White & Garrott, 1990).

Koalas are essentially solitary animals living within, often overlapping, home ranges of varying sizes depending on the quality of habitat and population densities (Melzer, 1995; Mitchell, 1990a, 1990b) and social standing (Lee, Martin, & Handasyde, 1990). As a general rule male koalas occupy larger home ranges than females (Mitchell, 1990a).

Different analytical techniques have been used to define the concept of home range for koalas. Eberhard (1972) determined that the number of trees used by a single koala is sufficient to determine the size of a home range, however, it is important to be able to quantify and define the spatial localisation of a home range (Hindell, 1984; Mitchell, 1990a). The harmonic mean measure of animal activity, originally developed by Dixon and Chapman (1980) to determine the centres and areas of animal activity for brush rabbits (*Sylvilagus bachmani*), has also been applied to determine koalas' home ranges (Ellis, Melzer, Carrick, & Hasegawa, 2002; Goldingay & Dobner, 2014). As the name suggests, the method establishes the harmonic mean centre of activity of individual animals, their home range configuration and size by calculating isopleths of various proportions. The 95% isopleth (the region which accounts for 95% of an animal's utilisation of its habitat) (Cresswell & Harris, 1988), is the one most widely used in general (Goldingay & Dobner, 2014), and it was also used for this PhD research. However, this method has also been criticised because it could overestimate home ranges when used in areas of low koala densities for example Brigalow (Davies et al., 2013) and Mulgalands, Queensland (Melzer & Lamb, 1994; Sullivan et al., 2004).Therefore it sometimes difficult to compare harmonic mean ratios between studies at different locations (McAlpine et al., 2008); nevertheless, the method is widely used for determining home ranges for koalas within same study sites.

Moreover, due to competition for dominance, home ranges of male koalas are more fluid than those of most females, as they frequently disperse from their natal area, between weaning and three years of age (Dique et al., 2003; Gordon et al., 1990). Mitchell (1990a) proposed that young males stay in sub-optimal habitat until older koalas die or until they are large enough to compete with other males. The timing of dispersal, especially for males, mostly corresponds with the breeding season (White, 1994) and was found to be between 4-7 years of age at some sites (Gordon, 1991). Other studies have also found that young females dispersed (Dique et al., 2003; Mitchell, 1990a), and the same was observed for older females between four and seven years of age (Gordon, 1991).

1.4.3 Diet. Koalas are the largest, arboreal, folivorous marsupial in the southern hemisphere (Strahan & Martin, 1982). Their high fibre diet consists mainly, but not exclusively, of *Eucalyptus* leaves and individual animals showing differences in their selection (Ellis et al., 2002; Hindell & Lee, 1990; Melzer, Baudry, Kadiri, & Ellis, 2011; Melzer, Cristescu, Ellis, FitzGibbon, & Manno, 2014; Moore & Foley, 2000; Ough, Handasyde, Martin, & Lee, 1988). Koalas not only exhibit seasonal species preferences in some locations, but show preferences for individual trees within a species and individual preferences for specific foliage within a tree (Phillips, Callaghan, & Thompson, 2000). This preference is likely to be influenced by their social organisation, the structure of the trees, the chemistry and water content of the leaves, which vary between seasons (Hindell & Lee, 1990; Wu, McAlpine, & Seabrook, 2012). Climateic changes have also been suggested as influencing tree preference (Clifton et al., 2007; Ellis, Melzer, Clifton, & Carrick, 2010). Also, koalas’ preference for particular habitat types change with climate (Melzer, 1995). In southern Australia the preferred species are *E. viminalis* (Hindell, Handasyde, & Lee, 1985) and *E. ovata* (Santamaria, Keatley, & Schlagloth, 2005). The sighting of koalas in trees has been equated to tree usage for shelter and fodder (Hindell et al., 1985). This was subsequently turned into an index of feeding preference (Eberhard, McNamara, Pearse, & Southwell, 1975). Koalas' folivorous diet contributes to their difficulty in meeting energy requirements from poor-quality leaf diets low nutrient content (Cork & Foley, 1991; Mitchell, 1990a; Moore & Foley, 2000) Therefore, koala's ecology and physiology reflect the need to conserve energy (Hindell & Lee, 1990; Krockenberger & Hume, 2007). However, others (Ellis et al., 2002; Melzer et al., 2011; Pfeiffer, Melzer, Tucker, Clifton, & Ellis, 2005) suggested that trees provide additional, important resources, such as resting sites, protection from predators, and shelter from adverse environmental conditions. This thesis will make clear distinction between 'tree use', as established by radio tracking, and 'tree preference' as a fodder species, as determined by scat analysis which is discussed below, however, data will be compared for individual animals and to other koala populations. Both terms will be combined to establish "habitat preference" by koalas.

1.4.4 Scat analysis. One objective of this research was to determine the food preference of koalas in the study area and link it to the distribution of preferred koala habitat. Due to the presence of koalas in the road-side vegetation it is important to establish if and how local food tree preferences impacts on the movements and use of habitat of this species.

Faecal analysis provides a reliable indication of botanical composition of the diet of any herbivore (Krockenberger & Hume, 2007; Leslie, Bowyer, & Jenks, 2008; Norbury, 1988; Pahl & Hume, 1991). Microscopic techniques to identify plant fragments for determining the food eaten by herbivores were established as a valid and valuable non-invasive technique in the 1960s (Storr, 1961) and as a consequence have been used with rare or endangered animals (Dawson & Ellis, 1979; Norbury, 1988). A similar approach was used in this research to determine the tree species of the foliage consumed by koalas.

The use of faecal analysis, however, requires an understanding of the nature of plant cuticles. The plant cuticle is a continuous layer on the outer surface of the shoot or leaf which is formed by the polymerisation of unsaturated fatty substances. It is impermeable to water and resistant to some enzymes and the action of microbial organisms (Dawson & Ellis, 1979) and therefore not affected by these during the digestive process. The cuticle is detached from the underlying leaf tissue by the breakdown of structural cellulose during the digestion process. Even though digestibly varies between plant species and individual animals, the cuticle survives (Barker, 1986).

Analysis of koalas' faecal pellets is, therefore, likely to provide a qualitative and quantitative description of its fodder. A key to identify the cuticle of different species was developed for this study in collaboration with Dr Chris Allen, from Sydney University. Around 85% of the cuticles found in the faecal pellets were identified to species level; some fragments were undistinguishable to this level and were excluded from the analysis.

This dietary information, coupled with a general knowledge and understanding of koala ecology and behaviour, was utilised in the development of mitigation measures. The evidence can now be applied in other areas in the assessment of koalas' susceptibility to similar situations.

The next section is an overview of Chapter 5 which deals with the management of koala populations and the conceptual application of the road-kill model.

1.5 Chapter 5: Conclusion, Discussion and Recommendations

This Chapter also covers the management issues and conceptual models.

1.5.1 Management. The Federal Government under the Environment Protection and Biodiversity Conservation Act (EPBC Act, 1999) is tasked with the protection of threatened species (Martin & Handasyde, 1999), but the management of those species chiefly lies with state governments. In 2012, the Federal Government listed the koala as a vulnerable species in New South Wales, Australian Capital Territory and Queensland (Department of Environment and Energy, 2016), Previously, in 2004 the Queensland government had listed the koala population in the South-East Queensland bioregion as vulnerable (Environmental Protection Agency, 2006) and in 2015 the koala was listed as vulnerable across the whole of the state (Department of Environment and Heritage Protection, 2015).

Legislative listing of the species has not been the only management action. Some of the practical management actions are discussed in section1.5.2 (Historical Management), most management measures have been so far post-construction of roads and reactive. Some examples are the erecting of fencing along roads to prevent koalas from crossing (Clevenger, Chruszcz, & Gunson, 2001; Jones & Veage, 2007; Polak et al., 2014), speed restrictions and warning signs (Dique et al., 2003) or installing koala under/over-passes (Australian Museum Business Services, 1997; Jones, Bakker, Bichet, Coutts, & Wearing, 2011). However, with the advent of 'Road Ecology', over the past decade, more measures, which are aimed at preventing or minimising anthropological threats to local koala populations, have been taken into account during the design phase of new roads, as for example the construction of over/under road wildlife passages, in conjunction with fencing structures along the road to discourage animals from crossing (Polak et al., 2014).

Managers and policy makers require timely and detailed information on koala population demographics, dynamics and the extent and condition of the habitat in order to ensure the long term survival of koala populations. Some of this information is available from previous research and past management actions.

1.5.2 Historical overview of the management of koalas and their habitat.

Anthropogenic activities had and still have significantly negative effect on the distribution and abundance of koalas (Gordon, Hrdina, & Patterson, 2006). Recent estimates (McAlpine et al., 2012) for the Victorian koala population were between 75,000–325,000 with a likely mean of 185,000, whereas the Australian Koala Foundation (2013) has suggested between 43,000 and 85,000 for the entire koala population in Australia (Australian Koala Foundation, 2010). Due to the cryptic nature of the species, it has often been difficult to detect individual animals over, sometimes, large areas, and the issue has generally been extremely politically sensitive (Praded, 1999). There are few estimates of regional, state, and national koala populations and they are inconsistent (Melzer et al., 2000).

Martin and Handasyde (1999) describe in detail the rise and fall of koala populations over time since European settlement. They list several factors including clearing, hunting, disease and wildfires as contributing factors to koala population declines. Nevertheless, it is difficult to determine the relationships between these factors and to qualify and quantify the impact they have on koalas as they often vary across different areas (Martin & Handasyde, 1999). Ultimately, it is difficult to forecast any drastic changes in local or regional koala populations. However, more recently, habitat destruction has been confirmed as the major threat to the long term survival of koalas (Department of Environment and Energy, 2016; Department of the Environment, 2009). It is estimated that two-thirds of koala habitat has been cleared or severely altered since European settlement of Australia (Barson, Bordas, & Randall, 2000; Wells, 1984), and that in Queensland alone between 1997–1999, an average of 425 000 hectares were lost (Lindenmayer & Burgman, 2005), between 1999–2000 an average of 758 000 ha, between 2002-2003 an average 554 000 ha and between 2003–2004 an average of 482 000 ha (Department of Natural Resources and Mines, 2004). With such large areas being cleared every year it is estimated that 19 000 koalas were killed annually in Queensland between 1997–2000 (Cogger, Ford, Johnson, Holman, & Butler, 2003).

Some researchers suggest that koala numbers were kept in balance before European settlement by a combination of hunting by Aboriginal people and predation by dingos (Martin, 1983; Parris, 1948). An increase in the Victorian koala population occurred when Victoria experienced a large influx of people during the gold rush (1851–1860), which resulted in a change in Aboriginal hunting patterns and the decline of the dingo Menkhorst (2008). However, Hrdina and Gordon (2004) believe that the impact of Aboriginal hunting of koalas has been exaggerated greatly and they maintain that such beliefs show a lack of understanding of animal population processes. In fact, already in 1978, Gordon and McGreevy (1978b) suggested that periodic koala declines may be a natural and important aspect of the population ecology of the species. However, others (Howlett, 1979; Phillips, 1990b; Pratt, 1937) believe that the expansion of the koala fur industry (Figure 1.3), which developed around 1870, was the main reason for the decline in koala numbers as across its range millions of skins were sold and exported. For example, during an open season in Queensland in 1927, koala harvests resulted in more than one million animals being killed (Fowler, 1993).

Figure 1-3 Truck load of koala skins in the Clermont area, ca. 1927.

Creator: G. Pullar. John Oxley Library, State Library of Queensland.

In Victoria, the koala was protected through legislation in 1898 by proclaiming it a Native Game species under the *Game Act 1890*) and closing the hunting seasons permanently (Seebeck, 1988). Nevertheless, the damage had already been done due to the combination of habitat destruction, hunting, wildfire and possibly disease contributing to a rapid decline in koala abundance (Hrdina & Gordon, 2004; Menkhorst, 2008). Koalas were extinct in South Australia by the end of World War 1 (Dickens, 1975) and almost extinct in Victoria and New South Wales (NSW) by the time koala hunting ceased (Phillips, 1990b).

Koala management in Australia is both active and custodial (Caughley & Sinclair, 1994). Management in south-eastern Queensland and north-New South Wales has been largely protective aiming at reducing external influences on koala populations and their habitat (Dique et al., 2003; Thompson, 2001). In Victoria, in contrast, a few individual koalas were introduced to French and Phillip Islands in the late 1800s (Martin & Handasyde, 1999). The French Island population rapidly increased and, in the early 1920s, koalas started to over-populate and over-browse their food trees (Cristescu et al., 2009). Koalas were then translocated to more islands including Kangaroo Island in South Australia (Menkhorst, 2008). Subsequently, manipulative management occurred in Victoria and South Australia where overabundance in both island and isolated mainland populations were managed through translocation and sterilisation programs (Masters, Duka, Berris, & Moss, 2004; Menkhorst, 2008). As a consequence koalas in Victoria, with the exception of South Gippsland (Lee, 2013) have been found to exhibit little genetic diversity (Emmins, 1996; Lee, Zenger, Close, & Phalen, 2012). Extreme cases of genetic isolation and bottlenecks have been shown to occur in southern island populations (Cristescu et al., 2009).The extensive relocation program of more than 24 000 animals from islands, lasted eight decades, finished in 2007 and saw the repopulation of most mainland areas (Menkhorst, 2008), including forests around Ballarat (Santamaria, 2002; Santamaria & Schlagloth, 2016). Translocations resumed on a smaller scale in 2015 with 37 animals at Great Otway National Park (Department of Environment, 2015), another small-scale translocation program in 2016 on private properties near Cape Otway (Department of Environment, 2016a) and the same year, 30 koalas from French Island (Department of Environment, 2016c). In total 236 koalas over these two years were translocated.

1.5.3 Koala habitat management in Ballarat. Victoria has a thriving koala population which is widespread in lowland and foothill eucalypt forests and woodlands (Menkhorst, 2004). However, it is highly probable that the situation is not as healthy as it may be inferred by this statement; the continuing incremental loss of mature trees through land development, declining health of remnant trees in rural landscapes and changes in land-use are significant threats (Menkhorst, 2008). Government have focused mostly on habitat protection of large reserves such as national parks rather than private properties and roadsides, where preferred koala habitat often exists (Lunney, Matthews, Moon, & Ferrier, 2000). In Victoria, more than 50% of the original native vegetation, which includes more than 80% of native vegetation on private land, has been cleared since European settlement (Victorian Environmental Assessment Council, 2011), with a large percentage of this now not being under control of relevant government authorities (Barson et al., 2000). This is especially relevant in Ballarat where the majority of koala habitat remains on private property and along roadsides (Schlagloth, Thomson, et al., 2006). In addition, the habitat is highly fragmented with road-side vegetation often forming the only corridors linking those fragments (Januchowski et al., 2008).

A survey of Ballarat residents (Schlagloth, Callaghan, & Santamaria, 2004) on the distribution of koalas and historical sightings, as well as attitudes towards conservation needs and initiatives, provided valuable information on the 2003 status of the species within the city. The results of this survey provided the Ballarat City Council with the opportunity to introduce environmental management initiatives to protect koala habitat, such as biodiversity education, vegetation protection measures through the Ballarat Planning Scheme and revegetation projects (Schlagloth et al., 2004). With the adoption of the Ballarat Koala Plan of Management by the Ballarat Council in September 2006 (Schlagloth, Thomson, et al., 2006), the protection and management of native vegetation became a critical environmental issue, particularly where conservation of that vegetation may conflict with proposals for development. The Canadian Valley and Buninyong are popular residential areas and have significant road infrastructure where koala roadkill were reported (Schlagloth et al., 2004). In the Ballarat region, the only study showing size of koala home ranges was that of Hindell and Lee (1988), which found that in good quality habitat, koalas had an average home range of one koala/ha. However, urbanisation is causing an increase in home range size due to the decrease of food tree species that koalas can use (McAlpine, Rhodes, et al., 2006; Melzer & Houston, 2001).

A primary outcome will be that the findings from this thesis are relayed to the decision makers with the ability to implement them. For example, in Ballarat, with a Koala Plan of

Management already implemented in the Planning Scheme (Schlagloth, Thomson, et al., 2006), there is an opportunity to improve the information already available. This should then guide the management and development of urban, semi-urban and rural areas and include the planning of roads that connect these areas, for koalas and wildlife in general.

1.5.4 Conceptual model. Additionally structured decision-making is becoming more common. Conceptual models play a role in this processes. Given the complexity of biological, social and economic factors, it is more economic to apply conceptual models to facilitate planning (Sanderson, Redford, Vedder, Coppolillo, & Ward, 2002). One such model incorporates population dynamics, landscape ecology, human dimensions, and political and economic variables to manage beavers (Deblinger, Field, Finn, & Loomis, 2004). Another, draws upon many different biotic and abiotic parameters, including details on individuals, populations, communities, and systems to make conclusions about restoration success of a river (Trexler, 1995).

1.6 Hypotheses

This thesis focuses on one of the key threatening processes acting on koalas—collisions with vehicles; and explores this issue using a major road corridor near Ballarat, Victoria.

It is hypothesised that:

a) collisions between vehicles and koalas pose no risk to the longevity of koala populations in the Ballarat region;
b) most of these collisions do not occur in so called ‘blackspots’ along roads, but could occur anywhere; and that in relation to perceived blackspots; and
c) koala visibility and availability of koala habitat are not important variables which could determine the likely occurrence of ‘blackspots’.

1.7 Problem Statement

Koalas are under threat from increasing urbanisation which also includes development of road infrastructure and associated traffic volume (Department of the Environment, 2009); yet, the processes enabling koalas to persist in such habitat areas are not well understood and receive different priority in different states. Consequently, road planning and management decisions are often ineffective (Department of the Environment, 2009), rarely consider the needs of the koala or are even incompatible with the long term conservation of the species (Polak et al., 2014).

1.8 Aims and Objectives

This research aims at analysing roads with high numbers of koala roadkill, and at establishing patterns that might lead to define blackspots. The parameters used to define these blackspots are also used to design a model that can be implemented to predict blackspots in other areas in other states such as Queensland and New South Wales where koalas face similar threats. It is hoped that the model will also be useful for other species but is beyond the scope of this research.

In particular, the project addresses the questions:

1) Are there sections on roads where koala roadkill are more frequent?
2) If so, what are the physical and biological characteristics of these sections?
3) What parameters are needed to define a koala road-kill black spot?
4) How do koalas use habitat near a black spot?

The main objectives of this study were identified to effectively address these questions:

- Exploration of local wildlife carer data files and analysis of the proportion of deaths and injuries attributable to vehicle collisions;

- Assessment of whether koala road-kill blackspots exist by analysis of detailed information on koala roadkill data;
- Development of a model based on multiple influences on koala road-kill occurrences;
- Detailed investigation of koalas living near a black spot to illuminate local koala ecology and inform management;
- Development of management recommendations including the application of a conceptual model.

1.9 Limitations

1.9.1 Limitations. The following section describes the primary potential limitations of this study and further details the solutions derived to offset such problems, should they occur.

1) **Theoretical Boundaries—**Humans impart theoretical or virtual boundaries onto the landscape, such as Local Government Authority (LGA) and private property boundaries. Such boundaries rarely affect the natural dispersal of wildlife species. Theoretical boundaries are also an inherent component of scientific studies, allowing research to be concentrated in areas of interest. Influenced only by the research topic and practicalities, scientific survey boundaries are often '… laid down by the scientist more or less arbitrarily …' (Rebele, 1994). To prevent problems arising from such boundaries, all scientific research must acknowledge the potential influence of external processes and dynamics on those features of interest with the 'scientific' bounds.

This study was conducted within parts of the political boundaries of the City of Ballarat, Moorabool Shire Council and the Golden Plains Shire local government areas. Potential effects of differences in vegetation and road management by the different LGAs were not considered and no distinction was made between areas of different management nor were

differences in vegetation management by individual property owners considered. Chapter 3 on the koala road-kill analysis utilised aerial photography of tree assemblies to determine *Eucalyptus* communities rather than identification of individual trees; any significant changes in tree cover would have been detected during ground-truthing and general fieldwork. Chapter 4 involved the recording and marking of some 10 000 individual trees in a sub-section of the study site; any removal of trees would have been noticed during fieldwork.
It was envisaged that any potential changes would have been small over the time period of this study and that habitat quality was assessed accurately during the various habitat mapping exercises.

2) **Accuracy of data—**Whenever there are data collected by more than one person and without the use of a common proforma, there is the potential for results to be affected by 'human error' (differences in individual recording ability). The data collection component of this study used records of a small set of volunteers and professionals. The data required were a sub-set only of a large volume of some 7100 reports and were filtered and cross-checked as much as possible to avoid any duplications and inaccurate sightings. Only accurate data were used in this study.
3) **False-negatives—**'… absence of evidence is not evidence of absence …' (Crawley, 2002). False-negative errors are an integral component of presence/absence field surveys where detectability of an organism is questionable. A false-negative error occurs when a '… species may be present at a sampling unit yet fail[s] to be detected…' (Stauffer, Ralph, & Miller, 2002), which in turn could have an '… impact on statistical models …' (Tyre et al., 2003). There are two main error components; real errors and apparent errors. Real errors occur due to species-specific behaviours such as seasonal population variations, cryptic natures and human-avoidance, whereas apparent errors result from high detection uncertainty as a result of limited or inappropriate

sampling (Stauffer et al., 2002). The data on road-kill koalas to be utilised in this study span years (1989–2005) and surveyed the same stretch of highway all year round for the entire period. Data were obtained from a variety of sources: some gathered opportunistically, others collected from regular driven transects. Details on each approach used can be found in the method section of each Chapter.

4) **Integration and implementation—**an anticipated outcome of this project is for the scientific recommendations (relating to koala habitat management and road design/planning issues) to be put into practice by vegetation managers, politicians and planners. However, there is the potential that these principles and decision guidelines will not be integrated and utilised by various parties. In an attempt to minimise this possibility, aspects of this project have been discussed with various managers (e.g. VicRoads) and discussions are ongoing in regards to the identification of which parts are practical and easy to implement and those that are more challenging and need further investigation. Offers will be made to present findings to the various stakeholders (e.g. councils) and received feedback. The results are converted into the applicable format - presenting concise, clear and practical recommendations that may be immediately integrated into planning policies and schemes at the regional and local level. This project has the potential to achieve this outcome because there is a Koala Plan of Management for the LGA of the City of Ballarat.

"We do not inherit the earth from our parents; we borrow it from our children."

Native American Saying

(Berry, 1971)

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Chapter 2. Exploration of local wildlife carer data files and analysis of the number of koalas injured and killed by cars to ascertain local significance of the issue

2.1 Introduction

The threats to the long term survival of the wild koala population are widely acknowledged as being loss and fragmentation of habitat, disease, AVC and dog attack (Department of the Environment, 2009; Menkhorst, 2004). Ballarat is no exception (Schlagloth, Callaghan, & Santamaria, 2004); I have, for several decades, worked closely with a number of wildlife carers in the Greater Ballarat area, and gathered qualitative insights about the management of injured koalas. I have also obtained quantitative data on koalas admitted into care. There is limited published information on the outcome of rehabilitated wildlife in general, and of koalas in particular, in Victoria. Differences among care facilities in both the type and quality of data collected affect the statistical value of the information (Trocini, 2008). There are, however, reports available on the outcome of rehabilitation of animals from Queensland and New South Wales' carers and hospitals ((Tribe & Brown, 2000); (Lunney, O'Neill, Matthews, & Sherwin, 2002); (Griffith & Higgins, 2012)).

2.1.1 Issues associated with roads and wildlife. The effect of the impact of roads on wildlife has been quantified in a number of studies in Europe, North America, and Australia but, lacking stratification and replication, it is difficult to readily relate their findings to different road types or animal species. According to Longcore and Rich (2001) the significant increase in mortality rates in some species is a direct result of collisions with traffic, with the percentage of individuals killed, increasing relatively with road width and number of vehicles. Koenig, Shine, and Shea (2002) consider AVCs as the major cause of wildlife mortality. Between 720 000 and 1.5 million deer and moose are victims of AVCs on United States' roads with nearly 90% of these resulting in death (Forman, 2003). Forman also mentions many other species such as salamanders, turtles, and amphibians follow this trend. Aside from animal welfare, Ramp, Caldwell, Edwards, Warton, and Croft (2005) stress that fatalities may have a significant impact on the population dynamics of species living adjacent to roads and this can adversely affect the viability of local populations. Koenig et al. (2002) have cited AVC as a primary agent of human induced mortality of blue tongue lizards. Beebee (2013) pointed out that the negative impact of roads on population decline of amphibians, with an average of 57% deaths associated with AVCs (data obtained from European, South and North American, Asian and Australasian publications). Hels and Buchwald (2001) also report roads as being the direct cause of high rates of mortality and population decline for many amphibian species. Barthelmess and Brooks (2010) determined road-kill rates for mammal species and compared road-kill rates between mammals of different sizes and diet between seasons. They found that the highest rate of roadkill was represented by omnivores and herbivores of a medium size and that there was a seasonal difference in the number of roadkill. Also, Cook and Blumstein (2013) found that solitary mammals are more likely to be killed during an AVC than social species. Roger, Bino, and Ramp (2012) established that deaths caused by AVC on roads in prime habitat and in protected areas had a significant impact on the decline of wombat populations in New South Wales.

Coulson (1997), found that among most species of macropods (*Macropus* sp., *Wallabia* sp, *Thylogale* sp.) there is a strong bias in sex related roadkill with males exceeding the number of females. This could be due to males' larger home range and more frequent movement. A study by Klöcker, Croft, and Ramp (2006) has found no such bias among macropod (*Macropus* sp.) roadkill. However, a bias towards female roadkill was found by Romin and Bissonette (1996) in mule deer (*Odocoileus hemionus*) in the United States. The bias was attributed to the greater energy demand for lactating females hence their preference for higher quality road-side vegetation. Also, Steen et al. (2006) found a bias towards female turtle roadkill due to these travelling across roads between wetlands to find available nesting sites.

There are other types of impact of roads on wildlife that need consideration. The removal of vegetation to construct the road infrastructure constitutes the initial impact on wildlife habitat (Clevenger & Wierzchowski, 2006). The 'edge effect', which, in the case of a dual carriageway, can extend up to 200 m from the road, can be the cause of pollution from vehicle exhausts, chemical spills and the diversion of water and nutrients (Trombulak & Frissell, 2000).

Moreover, Goosem (2002) investigated the role of roads on the movement pattern of three species of native rats in tropical Queensland and found that roads, rather than level of traffic, inhibited the movement of these species. Ramp, Wilson, and Croft (2006), also concluded that roads in peri-urban reserves have the potential to alter the movement of animals and thus have an impact on their populations through loss of life. Roads were found to cause habitat fragmentation and a decrease in wildlife genetic flow (Andrews, 1990; Levy, 2005) and this is also the case for beetle populations (Keller & Largiader, 2003) as well as amphibians (Beebee, 2013). Also, Berthinussen and Altringham (2012) showed that light, noise, and pollution in proximity of roads have a major negative impact on bat foraging activity and species diversity. Roads have the potential to become 'habitat sinks' (Forman & Alexander, 1998) because fatalities on roads continuously reduce the number of individuals occupying surrounding road-side habitat. Roads are therefore serious contributors to the increase of mortality rates and changes in population dynamics for many species.

2.1.2 Issues associated with roads and koalas. The National Koala Conservation Management Strategy (Department of the Environment, 2009) acknowledged that AVCs are a major factor for koala admissions into care and also one of the main causes of mortality.

As a result of a study into the types and severity of fractures koalas sustain, Henning, Hannon, McKinnon, Larkin, and Allavena (2015) found that from a total of 2031 wild koalas submitted to wildlife hospitals in South-East Queensland, over a period of 13 years, approximately 84.1% of fractures were caused by vehicle collisions, 9.1% by dog attacks, 3.3% by falls from trees, 1.3% by train collisions, 0.2% by livestock trampling and 1.8% were due to unknown causes. This clearly underlines the serious impact that vehicles and dogs have on koalas especially when considering that the findings of the same authors show that the prognosis for koalas with fractures was poor; 63.8% of koalas were admitted dead on arrival, 34.2% had to be euthanised, and only 2.0% of koalas were able to be released.

The Queensland Government recognised (Queensland Government, 2006) that koala mortality caused by AVCs has the most significant impact on this species' population dynamics after habitat clearing and fragmentation. In fact, road mortality was the leading contributor in the dramatic decline in koala numbers within the Koala Coast region of South-East Queensland (Preece, 2007). Indeed, this and other studies by (Dique et al., 2003; Gonzalez-Astudillo, Allavena, McKinnon, Larkin, & Henning, 2017) indicate that this species is especially susceptible to AVCs. Already, in 1995, the Queensland Parks and Wildlife Service, the Queensland Department of Main Roads and Redland Shire Council initiated the Koala Speed Zone Trial in the Koala Coast region which is in South-East Queensland (Dique et al., 2003). This trial found that 1407 koalas were hit by vehicles in the Koala Coast during the five-year study and that approximately 83% did not survive. The Port Stephens Comprehensive Koala Plan of Management Steering Committee (2010) reported that during a four year study, out of 500 reported cases of injured koalas, nearly 38% were hit by motor vehicles. According to the Department of Environment and Heritage Protection (2012), mortality is more than 85% and many more cases were not reported. The Hunter Koala Preservation Society (Hunter Koala Preservation Society, 2012) reported that in 2010 out of 15 incidences of koalas hit by cars near Tomaree and Tilligerry, 60% died. Lunney et al. (2002) in their study of a koala population in New South Wales concluded that koala deaths resulting from disease and AVCs were the two most significant contributors to the increased mortality rates and to the related demise of the population as evidenced by radio tracking and modelling extinction using the demographic computer program VORTEX.

Koalas, living in urbanised areas, cross roads and highways to get to pockets of fragmented, remnant habitat. Koala populations are directly affected by AVCs, but also indirectly through habitat fragmentation which increases exposure to dogs and cars (Lassau et al., 2008). McAlpine et al. (2006), also raised the issue that habitat fragmentation forces koalas to travel more frequently to sustain themselves; therefore increasing the risks of AVCs or dog attacks while moving from tree to tree.

Canfield (1991), in a case study on a population of the central northern coast of New South Wales, suggests that healthy young to middle-age males are particularly prone to AVCs during the mating period. Young males (Dique et al., 2003; Sullivan, Appleby, Dexter, & Jones, 2013) and in general, breeding-age animals (Taylor & Goldingay, 2004), are more likely to be involved in and killed by AVCs during the breeding season (Sullivan et al., 2013). This was also established by Prevett, Hives, and Cerini (1992) who found that in summer more male koalas were killed by vehicles as they dispersed or defended their home range. Other researchers, like theDepartment of Environment and Heritage Protection (2012) and Dique et al. (2003), support this by stating that “Male animals are most commonly killed by motor vehicles due to their need to disperse and find other populations”. Male koalas were also found to be more vulnerable to collisions with cars due to their larger home range (in Queensland and New South Wales) and therefore cover more distance than females (Rhodes, Lunney, Callaghan, & McAlpine, 2014).

Moreover, road infrastructure interferes with the dispersal and subsequently may disrupt gene flow (Department of the Environment, 2009; Dudaniec et al., 2013; Lee et al., 2010). Phillips (2000) suggests that a decrease in the number of koalas of less than 2–3% should not cause the extinction of a population. A link has been made between the abundance of roads and the density of koalas (McAlpine et al., 2006; Rhodes et al., 2014). Also, the geographical location of resources can be cause for negative impact on koalas if roads are crossing their habitat where food trees are found; AVCs can be avoided if roads do not cross koala habitat (Department of Environment and Heritage Protection, 2012).

2.1.3 Carers' data. The gathering of useful statistics has not yet been rolled out throughout Australia; most data available on koalas in care are from Queensland and New South Wales. A study carried out in South-East Queensland (Dique et al., 2003) found that approximately 83% of rescued koalas from AVCs did not survive. Data lodged with the Department of Environment and Heritage Protection for the Pine Rivers District of the Moreton Bay Regional Council area (Pine Rivers Koala Care Association, 2013) showed that for the financial year 2011/12, 126 koalas were reported to have been hit by cars and 38 attacked by dogs. Australia Zoo (2013) is Australia's largest wildlife hospital and holds on average around 80 injured koalas of which 26% are hit by cars and 10% attacked by dogs. Moreover, data obtained from the Department of Environment and Heritage Protection (Department of Environment and Heritage Protection, 2012) show that in the 14 years between 1997 and 2011, 10 972 koalas were admitted to the three main hospitals in Queensland. Of these, 4714 (43%) were AVCs of which 3849 (81.7%) were dead on arrival or had to be euthanised. Data from carers and agencies in Victoria is at times patchy due to inconsistencies in the collection of records. Wildlife Victoria and the Australian Wildlife Health Centre's (Healsville Sanctuary) (accessed 18 May 2014) websites have very limited information on statistics of rescued wildlife. Data from shelters should be filed by the

Department of Sustainability and Environment (DSE); however, it does not release any regular or comprehensive statistics on the activities of shelters. Data from carers prior to 2001 are non-existent as compliance was poor. Submitters to the Senate's Environment and Communications References Committee (Commonwealth of Australia, 2011) highlighted that a significant number of dog attacks on koalas may go unreported as many dog attacks occur at night and in bushland largely unfrequented by people. It was suggested that that perhaps only one in every two dog attacks is reported.

Indeed, most records were hand-written and rarely analysed in any great detail (K. Greengrass, personal communication, January 2013). In Ballarat, aside from brief reports on koala road-kill incidences which are gathered and mapped for the publication of the Koala Plan of Management for Ballarat (Schlagloth, Thomson, & Mitchell, 2006), data from wildlife carers were never collated and analysed in any great detail.

The above information shows that there are two main causes of koala injuries, AVCs and dog attacks, and that these, together with the reduction in habitat, are cause for concern for the long term survival of the species in the wild. Given the information available from other states along the east coast of Australia, it is important to investigate and analyse the information available from carers in Victoria. This will enable us to understand if there is a trend in the data obtained from all carers, and it will be possible to compare the new information to that available from other states. This Chapter reports and analyses the data on koalas obtained from the (a) Ballarat Residents Koala Survey, (b) a wildlife carer in Ballarat, (c) a carer on the Mornington Peninsula and (d) the Department of Environment & Primary Industry's wildlife carers' annual returns in Victoria. The aim is to establish the local significance of the issue, especially for koalas in Ballarat.

2.2 Methods

Information about admissions of koalas to shelters was sourced from two wildlife carers (one in Ballarat and one in Mornington) and from DSE returns.

The following databases were assessed and the treatment of the koalas is described below. Some of the data were cleaned (inconsistent entries and unknown incidents ignored).

Table 2-1 Databases used for Chapter 2: analysis, source, date range, treatment and number of records. (Cleaned: inconsistent entries and unknown incidents ignored)

Database	Source	Date Range	Treatment	Records analysed
1. Ballarat Residents Koala Survey	City of Ballarat; Australian Koala Foundation (AKF); (Schlagloth et al., 2004)	1996–2001	Cleaned	270
2. Ballarat wildlife Carer	Unnamed wildlife carer Ballarat, Victoria	1995–2006	Cleaned	212
3. Mornington wildlife carer	Unnamed wildlife carer Mornington Peninsula, Victoria	1987–2006	Cleaned	495
4. DSE wildlife carer returns	Department of Environment & Primary Industry, Victoria	2000–2011	Cleaned	2248

2.2.1 Ballarat residents koala survey.

Data were obtained from a mail survey of 10 000 Ballarat residents as part of the preparation for a Koala Plan of Management for the municipality. The Rates Department computer randomly selected 10 000 ratepayers in 54 localities within the boundaries of the City of Ballarat equally distributed between the nine wards of the city. The duplication of property owners (i.e. multiple landholders) was eliminated. Of the 10 000 surveys mailed, 52 were returned unopened where the recipient was no longer at that address. These returned letters were forwarded to the Rates Department for updating of their database. Properties owned by state or federal departments or their agencies were excluded. Questionnaires were mailed out ‘reply paid’ over a period of one week at the end of August 2001 and returns were accepted until 21 September 2002. In addition to this a specific questionnaire on proposed koala conservation measures was sent out (Schlagloth et al., 2004) and were returned by 11% of residents. Koala sightings were solicited for any dead, injured or healthy animals. Reports were checked for accuracy and duplications were eliminated by cross-checking dates and locations. These were then categorised into incidents with koalas injured or killed by cars or dogs and sightings of healthy koalas in trees or on the ground. Animal sightings lacking these details were excluded from the analysis. All data were entered into Microsoft Excel.

2.2.2 Ballarat and Mornington wildlife carer data. Several books with hand-written records of all wildlife activities were inspected. Of these only incidents relating to koalas were used. These were checked for accuracy, and duplications were eliminated by comparing dates and locations. Of all the records, only 444 for Ballarat and 818 for Mornington were transcribed into a Microsoft Excel spreadsheet. However, because much of these data were not specific about the reasons for admission of these animals, only 212 for Ballarat and 495 for Mornington were considered for analysis. Where the information for specific analysis was not relevant, the number of records was reduced. This is expressed as ‘unknowns excluded’ in the results section. The outcomes that were analysed were AVCs, dog attack and ‘other’. The ‘other’ category included all cases that were not specified by the carer and could not be directly attributed to either AVCs or dog attack.

2.2.3 DSE wildlife carer returns. The DSE carer returns database used for this study, only comprised data for koalas’ admitted into care for shelters across Victoria (excluding those from Ballarat and Mornington). Compared to the previous records (Mornington &

Ballarat), a much greater range of admission types to shelters, were recorded (e.g. trapped in building, stuck in fence) depending on the local issues faced by koalas and the accuracy of record keeping and reporting. Two sets of Microsoft Excel spreadsheets with 3914 entries from 2000–2009 and 2010–2011 were analysed. Data were cleaned (inconsistent entries and unknown incidents ignored). The remaining 2248 valid entries were sorted into incident types ('car', 'attacked by dog', and 'other') and outcomes recorded ('dead', including euthanised, 'released' and 'unknown').

The following outcomes were grouped into 'other' for ease of analysis due to the low numbers for each type.

Table 2-2 Outcomes combined into the 'other' category.

Outcome type	Outcome explanation
Animal attack	By any kind other than dog or cat
Abandoned	Young animal separated from mother
Away from habitat	Far away from suitable habitat, maybe dispersal
Entanglement	Coat in some rope or line
Attacked by cat	
Fire/Lightning	Bushfire or lightning strike
Compromised health	Sick/exhausted/starving
Loss of habitat	found after logging
Natural	Falling out of tree; abandoned by mother
Other	Non-categorised
Old age	
Sighting	Ballarat Resident survey only
Trapped accidentally	Chimney or building
Unnecessary rescue	Human error, overzealous
Weapon	Shooting of any kind/cruelty
Wire/Fence	Caught in fence or wire

2.2.4 Analysis of all databases

Records were analysed and results displayed using Microsoft Excel. Contingency tables were analysed by applying a *Pearson Chi-square* test, a *Fisher Exact Test* using SPSS (IBM SPSS Statistics, Version 22).

2.2.5 Consideration of data relating to fire.

Admissions of koalas related to fire were only present in very few DSE records due to the localised and temporary nature of the incident. Because these data were only found in one set of data, they were not comparable to the other sets of data; therefore, DSE carer returns were analysed with and without details about koalas injured in fires.

2.3 Results

2.3.1 Ballarat residents koala survey.

As part of the Ballarat Resident Survey a total of 270 koala sightings were reported for a period from 1990 to 2005 (Schlagloth et al., 2004). Of these, 146 were reported alive (54%). Figure 2.1 shows that 46% (124) of all sightings of koalas were either hit by cars or attacked by dogs.

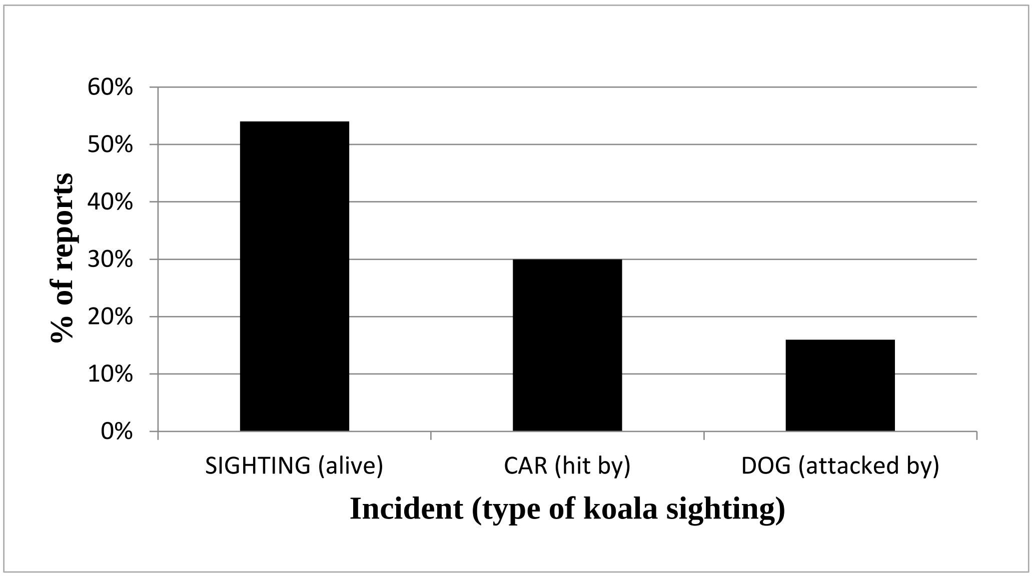

Figure 2-1 Koala sightings from survey of Ballarat Residents Koala Survey in 2002; n = 270

Table 2.3 shows the outcomes of incidents caused by AVCs ('car') and attacks by dogs ('dog'). Of the 44 koalas attacked by dogs 55% died; of the 80 koalas that were hit by cars, 90% died.

Table 2-3 Ballarat Residents Survey 2002—Sightings of koalas colliding with cars/being attacked by dogs and the percentages attributed to the various outcomes; n = 124; actual numbers in parenthesis.

Incident type	Dead	Injured	Not-injured	Unknown/other
Car (80)	90% (72)	7.5% (6)	2.5% (2)	0
Dog (44)	55% (24)	11% (5)	16% (7)	18% (8)

A *Pearson Chi-square* showed a significant difference (x^2 = 23.015; p = 0.001, df = 3, n = 124) in the proportions of the four outcomes for the two incident types. The mortality rate for koalas hit by cars was significantly greater than for those attacked by dogs.

2.3.2 Ballarat and Mornington wildlife carers' data. There were 212 injured koalas recorded by a Ballarat wildlife carer. The two main causes of the injuries were due to AVCs and dog attack.

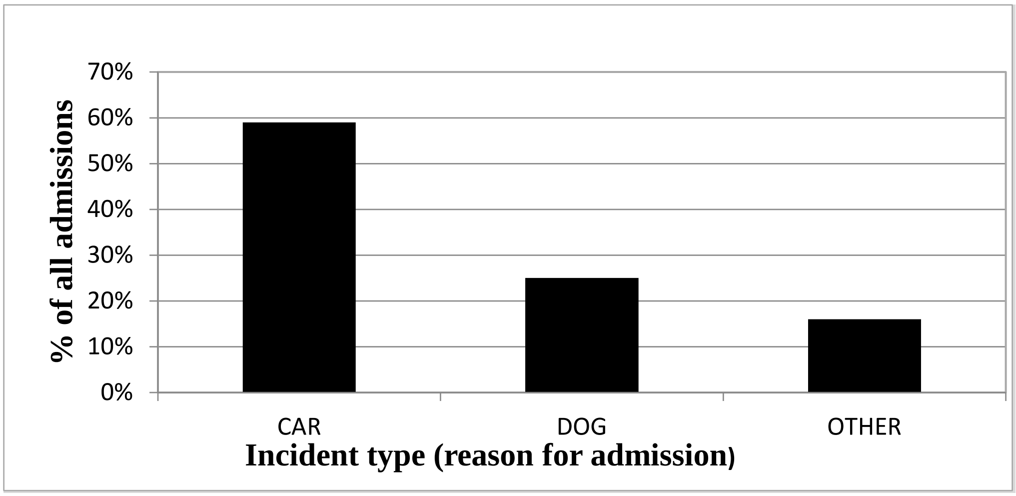

Figure 2-2 Admissions of koalas to a Ballarat wildlife carer by incident (Feb 1995–June 2006); *n* = 212 (unknown incident types were excluded from analysis).

All admissions (Figure 2.2) 84% (178) can be attributed to the two types of incidents, ‘car’ (59%) and ‘dog’ (25%). Table 2.4 shows that AVCs (‘car’) caused the highest mortality out of all incidences. The unknown category was excluded from analysis. Therefore, the number of koalas analysed was 111 of which 63 animals died due to AVCs (‘car’).

Table 2-4 Ballarat wildlife carer—Number of koalas that died by incident as a percentage of all admissions (unknowns excluded) n = 187. Actual numbers in parentheses.

Incident type	Deaths of all admissions
Car	33.7% (63)
Dog	15% (28)
Others	10.7% (20)

Table 2-5 Ballarat wildlife carer—Percentage of all koala deaths (unknowns excluded) by type of incident. Actual numbers in parentheses.

Incident type	Percentage of all deaths
Car	57% (63)
Dog	25% (28)
Others	18% (20)
Total	100% (111)

Of all koalas that died in care at the Ballarat wildlife shelter (Table 2.5), those that were admitted because of AVCs contributed to the majority of deaths (57%). Car related deaths were higher than 'dog' and 'others' combined. A *Chi-square* test showed a significant difference between the three incident types compared to the null hypothesis of equal numbers for each (x^2 = 13.076; p = 0.0014; df = 2; n = 111).

Table 2-6 Ballarat wildlife carer—Percentage of koalas that died or were released within each admission type; n = 187 (unknowns excluded). Actual numbers in parentheses.

Incident type	Died	Released
Car	56% (63)	44% (50)
Dog	67% (28)	33% (14)
Others	62.5% (20)	37.5% (12)
Total	59.4% (111)	40.6% (76)

Although a *Chi-square* test (x^2=1.670, p= 0.4339; df=2, n=187) on the data presented in Table 2.6 found no difference in the proportions of the two outcomes between the three types of incidents of 'car', 'dog' and 'other', there was a greater percentage of koalas that died compared to those that were released. However, the data also show that a smaller percentage (56%) of those hit by cars died compared to those of 'dog' (67%) and 'others' (62.5%).

Figure 2.3 illustrates that most (69%) of all koalas coming into the care of the Mornington Wildlife Shelter were due to AVCs and 29% because of dog attacks; this means a combined 98% of all admissions in Mornington can be attributed to the two admission types.

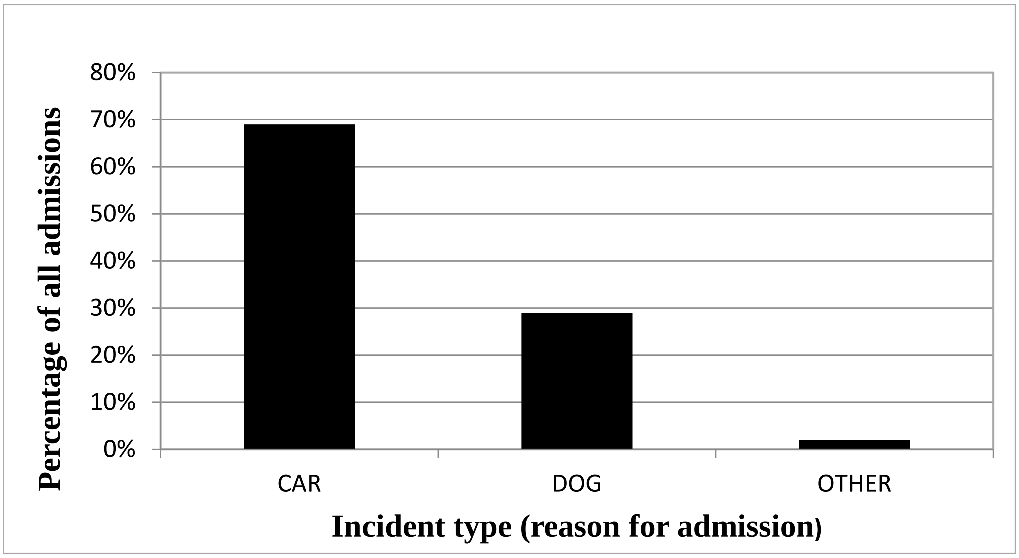

Figure 2-3 Admissions of koalas to a Mornington wildlife carer by incident (March 1987--June 2006); n = 495 (unknown incident types were excluded from analysis).

Table 2.7 shows that AVCs ('car') caused the highest mortality out of all incidences.

Table 2-7 Mornington wildlife carer—Number of koalas that died by incident as a percentage of all admissions (unknowns excluded) n = 444. Actual numbers in parentheses.

Incident type	Deaths of all admissions
Car	42.8% (190)
Dog	17.8% (79)
	0.9% (4)

As displayed in Table 2.8, of all koalas that died in care at the Mornington wildlife shelter, those that were admitted because of AVCs contributed to the majority of deaths (70%). Car related deaths were higher than double those of 'dog' and 'others' combined.

Table 2-8 Mornington wildlife carer—Percentage of all koala deaths (unknowns excluded) by type of incident. Actual numbers in brackets.

Incident type	Percentage of all deaths
Car	70% (190)
Dog	29% (79)
Others	1% (4)
Total	100% (273)

A *Chi-square* test showed a significant difference between the proportion of admissions in the three incident types compared to the null hypothesis of equal numbers for each category (x^2=115.4; p <.0001; df = 2; n = 273).

A *Chi-square* test (x^2 = 727; p = 0.695; df = 2; n = 444) carried out on the data shown in Table 2.9 has found no difference in the proportions of the two outcomes between the three type of incidents of ‘car’, ‘dog’ and ‘other’. However, overall, there was a greater percentage of koalas that died (57.5%) than those that were released (42.5%), with ‘car’ showing the highest percentage of dead animals.

Table 2-9 Mornington Wildlife carer—Percentage of koalas that died or were released according to their type of admission; n = 444, (unknowns excluded). Actual numbers in brackets.

Incident type	Died	Released
Car	62.5% (190)	37.5% (114)
Dog	60% (79)	40% (53)
Others	50% (4)	50% (4)
Total	57.5% (273)	42.5% (171)

2.3.3 DSE wildlife carer returns. The main causes of admission found in the data provided by DSE were related to AVCs and ‘other’ incidents.

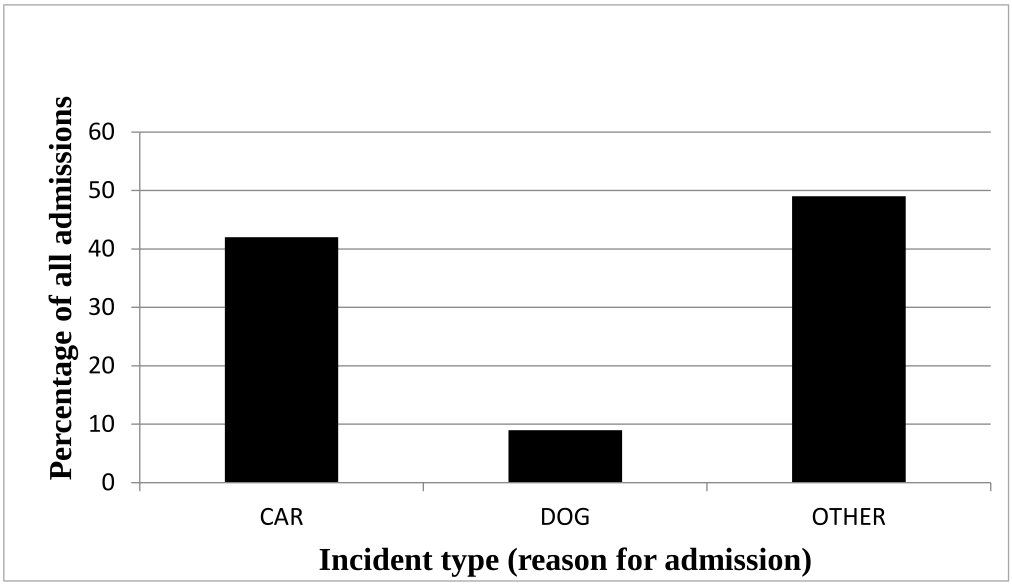

Figure 2-4 Admissions of koalas to wildlife carers in Victoria by incident as per returns to DSE by incident (Jan 2000—March 2011); n = 2248 (unknown incident types were excluded from analysis).

The ‘other’ incident type displayed in Figure 2.4, comprised 49% of all admissions to wildlife carers in Victoria. This group includes 15 causes (see methods section for a complete list) as well as ‘fires’ which represented 371 admissions or (16.5%) of all admissions. The graph also shows that 42% of cases were due to AVCs and 9% were dog attacks. Therefore, the incident type ‘car’ is the single category with the highest percentage of cases.

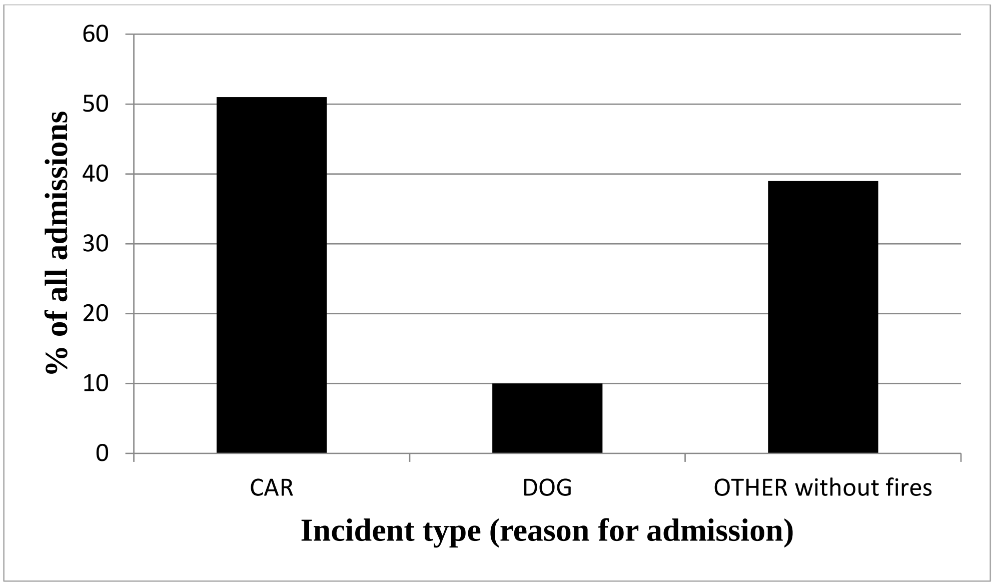

Figure 2-5 Admissions of koalas to wildlife carers in Victoria by incident as per returns to DSE by incident (Jan 2000—March 2011); n = 1877 (unknown incident types were excluded from analysis as were all entries relating to koalas coming into care from bush fires).

Subsequently, with admissions due to fire removed (Figure 2.5), the graph shows that, of the two main causes of admission, ‘car’ was the largest (51%) incidence, while ‘dog’ and ‘other’ were 10% and 39% respectively. Table 2.10 shows that AVCs (‘car’) caused the highest mortality of all admissions.

Table 2-10 DSE wildlife carer Returns—Number of koalas that died by incident as a percentage of all admissions (unknowns excluded) n = 1877 (excluding fire). Actual numbers in parentheses.

Incident type	Deaths of all admissions
Car	28.2% (530)
Dog	5.6% (105)
Other (excl. fire)	22.6% (424)

The incident type ‘car’ is the largest single cause of admission and deaths, especially when ‘fires’ is removed from analysis (Table 2.11).

Table 2-11 DSE wildlife carer Returns—Percentage of all koala deaths (unknowns excluded) by type of incident. Unknowns excluded from analysis.

Incident type	Percentage of all deaths	Percentage of all deaths (excl. Fire)
Car	44% (530)	50% (530)
Dog	9% (105)	10% (105)
Other	47% (569)	40% (424)
Total	100% (1204)	100% (1059)

A *Chi-square* test of these data shows a significant difference between the three incident types compared to the null hypothesis of equal numbers for each category ($x^2 = 176.256$; $p <.0001$; df = 2; n = 1059). In fact, it can be seen that AVCs related deaths account for 50% of all cases, including the large 'other' category.

Table 2-12 DSE wildlife carer Returns—Percentage of koalas that died or were released according to their type of admission; n = 1877 (excluding fire). Actual numbers in brackets.

Incident type	Died	Released
Car	56% (530)	44% (419)
Dog	52% (105)	48% (98)
Other (excl. fire)	59% (424)	41% (301)

A *Chi-square* test ($x^2 = 3.201$; $p = 0.202$; df = 2, n = 1877) shows no difference between the proportions in the two outcomes between the three type of incidents of 'car', 'dog' and 'other'. The data also show that a higher percentage of animals died than were released within each category. The number of deaths in all cases was more than 52%.

2.3.4 Combined Carers: Focus on influence of car, sex and seasons.

Table 2-13 Percentage Died vs. Released for incident type AVC only for the three wildlife carer databases and averages. Actual numbers in parenthesis.

Incident type Car	Died	Released
Ballarat	56% (63)	44% (50)
Mornington	62.5% (190)	37.5% (114)
DSE	56% (530)	44% (419)
Average	58	42

Across the three databases (Table 2.13), the majority of koalas that were admitted because of AVCs died. On average the ratio of Died/Released was nearly 1.4:1.

Table 2-14 Wildlife carers' data—Percentage of male/female koalas admitted, Unknowns excluded; percentage of males/females that either died, were released or their outcome was unknown. Actual numbers are shown in parenthesis.

Database	Male			Female			Total number of koalas	
	Dead	Released	Unknown	Dead	Released	Unknown	Male	Female
Ballarat	67% (158)	25% (59)	8% (20)	49% (97)	41% (80)	10% (20)	55% (237)	45% (197)
Mornington	60% (274)	35% (157)	5% (21)	66% (220)	26% (88)	8% (26)	58% (453)	42% (334)
DSE	48% (943)	38% (733)	14% (268)	44% (805)	44% (796)	12% (268)	52% (1944)	48% (1826)
Total	**59% (1375)**	**41% (949)**	**309%**	**54% (1122)**	**46% (964)**	**314**	**52.8% (2634)**	**47.2% (2357)**

Table 2.14 shows that the number of males admitted into care was 52.8%. When the data were analysed using a *Chi-square* test there was a significant difference between the proportions of male and female koalas admitted into care across all three sources of data combined ($x^2 = 7.692$; $p = 0.006$; df = 1; n = 4991). Moreover, the table shows that 59% of males and 54% of females died; *Chi-square* shows there was a significant difference between the number of dead and released animals for both sexes (males $x^2 = 26.026$; $p < 0.001$; df = 2;

n = 2324 and females $x^2 = 46.554$; $p < 0.001$; df = 2; n = 2086). When the number of dead females and males were combined, 55% of all deaths were males; a *Chi-square* test shows significant difference between the number of dead males and females when these are compared to the null hypothesis of equal numbers for each ($x^2 = 12.848$; $p = 0.0003$; df = 1; n = 2497).(‘Unknown’ outcome was removed from analysis).

Table 2-15 Wildlife carers’ data—Percentage of koalas admitted for each month and proportion of male/female for each month. Unknown sex excluded. Actual numbers are shown in parentheses.

Month	Ballarat			Mornington			DSE		
	Both sexes	**Male**	**Female**	**Both sexes**	**Male**	**Female**	**Both sexes**	**Male**	**Female**
January	10.9% (47)	55.3% (26)	44.7% (21)	13% (81)	66.7% (54)	33.3% (27)	14.8% (549)	51.4% (282)	48.6% (267)
February	9.5% (41)	39% (16)	61% (25)	7.4% (46)	58.7% (27)	41.3% (19)	15.9% (592)	49% (290)	51% (302)
March	9.5% (41)	58.5% (24)	41.5% (17)	8.7% (54)	51.9% (28)	48.1% (26)	7.7% (288)	50.3% (145)	49.7% (143)
April	6.7% (29)	51.7% (15)	48.3% (14)	5.8% (36)	61.1% (22)	38.9% (14)	6% (224)	52.2% (117)	47.8% (107)
May	10.7% (46)	47.8% (22)	52.2% (24)	7.1% (44)	52.3% (23)	47.7% (21)	5.2% (193)	54.4% (105)	45.6% (88)
June	8.8% (38)	60.5% (23)	39.5% (15)	6.9% (43)	39.5% (17)	60.5% (26)	4.4% (163)	47.9% (78)	52.1% (85)
July	6.3% (27)	44.4% (12)	55.6% (15)	6.1% (38)	52.6% (20)	47.4% (18)	4.3% (159)	50.3% (80)	49.7% (79)
August	6.9% (30)	60% (18)	40% (12)	6.6% (41)	48.8% (20)	51.2% (21)	5.5% (203)	54.7% (111)	45.3% (92)
Septembe r	6.7% (29)	48.3% (14)	51.7% (15)	6.3% (39)	64.1% (25)	35.9% (14)	4.9% (182)	48.4% (88)	51.6% (94)
October	6.3% (27)	51.9% (14)	48.1% (13)	11.3% (70)	52.9% (37)	47.1% (33)	9.2% (342)	53.5% (183)	46.5% (159)
Novembe r	8% (35)	71.4% (25)	28.6% (10)	10.5% (65)	67.7% (44)	32.3% (21)	11.3% (419)	54.4% (228)	45.6% (191)
December	9.7% (42)	64.3% (27)	25.7% (15)	10.3% (64)	64% (41)	36% (23)	10.9% (405)	51. % 6(209)	48.4% (196)
Total	**100% (432)**	**54.6% (236)**	**45.4% (196)**	**100% (621)**	**57.7% (358)**	**42.3% (263)**	**100% (3719)**	**51.5% (1916)**	**48.5% (1803)**
Average	**8.3% (36)**			**8.4% (52)**			**8.3% (310)**		

The information on Table 2.15 was analysed to establish if there were differences in the ratio of admissions of male and female koalas across the 12 months of the year. In the *Chi-square* test conducted for each set of carer data (Table 2.15), Ballarat (x^2 = 13.699; p = 0.250, df = 11, n = 432), Mornington (x^2 = 15.252; p = 0.077, df = 11, n = 621) and DSE (x^2 = 6.835; p = 0.812, df = 11, n = 3719) shows no significant difference in the sex ratio of admissions during these months.

Table 2-16 Wildlife carers' data—Percentage of male/female koalas admitted during the breeding and non-breeding seasons. Unknown sex excluded. Actual numbers are shown in brackets.

Season	Ballarat		Mornington		DSE		Combined databases		
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Both sexes**
Breeding	55.9% (132)	51.5% (101)	64.5% (231)	56.7% (149)	69.8% (1337)	69.8 % (1258)	67.7% (1700)	67.8% (1588)	67.8% (3288)
Non-breeding	44.1% (104)	48.5% (95)	35.5% (127)	43.3% (114)	30.2% (579)	30.2% (545)	32.3% (810)	32.2% (754)	32.2% (1564)
Total	**236**	**196**	**358**	**263**	**1916**	**1803**	**2510**	**2342**	**4852**

To examine if a difference between the proportions of males and females taken into care existed between breeding (October–March) and non-breeding (April–September) seasons, data in Table 2.16 were analysed for each site using a 2 X 2 contingency table and a *Chi-square* test showed that there were no significant differences at all three sites (p > 0.05) that is, Ballarat (x^2 = 0.835; p = 0.36; df = 1; n = 432), Mornington (x^2 = 3.96; p = 0.0552; df = 1; n = 621) and DSE (x^2 = 0; p = 2.08; df = 1; n = 3719). No statistical difference was also found by combining the data.

However, a significant difference was found when data from the combined sexes were analysed. A *Chi-square* test showed a highly significant difference (x^2 = 316.27; p < 0.0001; df = 1; n = 4852) between the proportion of animals admitted during the breeding and non-breeding seasons. The number of admissions (for male and female koalas combined) increased by around 110% during the breeding season.

2.4 Discussion

2.4.1 Ballarat residents koala survey. Almost half (46%) of all reports from this survey showed that injuries were caused by AVCs or by dog attacks. The high death rates for both types of incidents (car 90% and dog 55%) confirmed the perception of the surveyed residents (Schlagloth et al., 2004) through their comments in which many stated that dog attacks and the impact of vehicles and the construction of road were strong contributors to the decline of koalas in the area. The community based survey had the potential for bias, as people might be more likely to remember koalas in ‘unfortunate’ circumstances than sightings of them alive in a tree. However, there is also a strong possibility that number of dog attacks and AVCs may be higher, as some of these incidents are unreported or underrepresented (Rowden, Steinhardt, & Sheehan, 2008; Seiler & Helldin, 2006). For example, the Commonwealth of Australia Senate report (Commonwealth of Australia, 2011) states that dog attacks often occur at night and in areas largely unfrequented by people.

2.4.2 Ballarat, Mornington and DSE wildlife carer databases. Comparison between information from various wildlife carers is at times challenging due to the different methods in which this was categorised and recorded. The characteristics of the area where carers were located (number and types of roads, traffic volume, distribution of koala habitat, urban, semi-urban and rural area), and their special skills (preference to care for certain species or types of injuries; training and experience) as well as their network of helpers (speed of rescuing, access to specialised veterinarians, level of reports by public and accuracy of recording of admissions and their outcomes (Griffith, Dhand, Krockenberger, & Higgins, 2013) are variables that will influence rescue as well as data collection (Trocini, 2008).

Ballarat, Mornington and DSE wildlife carer data have shown that the majority of koalas were admitted due to AVCs (59%, 69% and 51% respectively). The second most important cause for admission was due to dog attacks (25%, 29% and 10% respectively). Australia Zoo data (Australia Zoo, 2013) show that approximately 70% of koalas being treated as a result of car accidents or domestic pet attacks. Port Stephens Comprehensive Koala Plan of Management Steering Committee (2010) reports that 37.8% of all koala admissions were due to AVCs. This figure is low compared to the three databases combined in this study.

Results from Ballarat, Mornington and DSE shelter data also revealed that, out of all admissions, a greater percentage of animals that were in care because of AVCs died (33.7%, 42.8% and 28.2% respectively) compared with incidents related to dog attacks (15%, 17.8% and 5.6% respectively). The impact of car incidents on death is even greater if the percentage is calculated on the overall deaths only (57%, 70% and 50% respectively). Dique et al. (2003), found that approximately 83% of koalas taken into care did not survive. This pattern was also reported by a recent study carried out by the Hunter Koala Preservation Society, (Hunter Koala Preservation Society, 2012), where 60% of koalas hit by cars in areas of New South Wales were fatal. In Queensland it was found that nearly 75% of koalas involved in AVCs did not survive (Commonwealth of Australia, 2011). A more recent report for South-East Queensland Department of Environment (Department of Environment, 2013), highlighted an outcome of 86% deaths for incidences related to AVCs. The reduced chances for a koala to survive an AVC are highlighted by the results from the combined databases where only 42% of animals admitted in shelters were released; this approximates to a ratio of 3:2 (died/released). Death of animals resulting from collision with cars has been reported for many species throughout the world (Barthelmess & Brooks, 2010; Beebee, 2013; Cook & Blumstein, 2013; Coulson, 1997; Forman, 2003; Hels & Buchwald, 2001; Klöcker et al., 2006; Koenig et al., 2002; Longcore & Rich, 2001; Ramp et al., 2005; Roger et al., 2012) with a 90% death rate seen as a consequence in the case of large ungulates and higher for reptiles and amphibians. Moreover, the increase in human population and the consequent expansion of urban environment and road networks are causing an increase in AVCs worldwide (Koenig et al., 2002; Longcore & Rich, 2001). A report by Biodiversity Assessment and Management (2009) states that solutions need to be found to decrease the number of koala deaths from collisions with vehicles and attacks by dogs.

Studies on various faunal species have found that roadkill can reduce fauna population densities (Dique et al., 2003) and that such mortalities have the potential to cause local extinction (Jones, 2000). Lunney et al. (2002), have highlighted that koala deaths resulting from AVCs had been significant contributors to the demise of a population of koalas.

The fate of koalas taken into care is well monitored; however, the fate of released animals and those that are not taken into care is mostly unknown. Only three studies are known to have monitored the fate of koalas released from care (Ellis, White, Kunst, & Carrick, 1990; Jones, 2008; Tribe, Hanger, Nottidge, & Kawakami, 2005). Ellis et al. (2005) in their study with a sample of four koalas released after care, provide a small spectacle on the outcome of such releases. In the case of this study only one male settled successfully. However, this study did not offer a valid statistical sample size to determine a trend in the outcome of releases from care.

2.4.3 Combined data of outcomes vs sex. Coulson (1997), found that among most species of macropods (Macropus sp., Wallabia sp, Thylogale sp.) there was a strong bias in sex related roadkill with males exceeding the number of females. Such trends also exist for other species. The results from this research confirm such findings as they show that more males (52.8%) than female koalas are admitted into care. Similar results on male bias for trauma caused admissions for koalas were found by (Griffith et al., 2013). It is also apparent that more of both sexes die in care than are released; with the male death rate being slightly higher at 59.2% than the rate for females is 53.8%. McLean (2006) found no bias on sex when examining koala skulls from road-kill animals and those who died of natural causes across Victoria. The results of the present study mirror the finding of Dique et al. (2003) who report a 61% male bias for koala road kills for a population in South-East Queensland where the established male/female ratio within the population was 41%/59%. A study by Lunney et al. (2002) at Iluka in NSW, found a similar sex ratio. It is difficult to ascertain the impact of the outcome on local koala populations related to this study, because the proportions of male and female in these areas are unknown. However, assuming a similar sex ratio in most koala populations is due to their polygamous nature (Mitchell, 1990), the results shown in this study underline the threat to the viability of a population. Population modelling and genetic analysis by Thompson (2006) demonstrated that different populations rely on the immigration of koalas from other areas in Australia to maintain their viability (Queensland Government, 2009). Males are also important in maintaining genetic diversity due to their 'transient' nature reproducing with females who are not part of their 'resident' group (Ellis, Melzer, Carrick, & Hasegawa, 2002). Also, young male koalas disperse at around two years of age to other populations (Mitchell & Martin, 1990). This movement is possibly the cause for a larger number of males being injured and therefore admitted into care. Griffith et al. (2013) have suggested that aspects of the behaviours of male koalas can be an important risk factor for this group. Successful dispersal of males is essential for many mammal species to prevent inbreeding or kin competition (Lawson Handley & Perrin, 2007) and to allow colonisation of new territory or to escape crowding (Perrin & Goudet, 2001). However, it needs to be considered that the loss of females from a population through anthropogenic causes has, as a likely consequence, caused the overall reduction in number of individuals in that population over future generations when that loss, together with other causes of death, exceeds the birth rate. As female koalas can reproduce with any male koala, the loss of any female koala has to be considered to be more significant than the loss of males.**Effect of seasonality on koala admissions.** The results have highlighted that almost twice as many individuals were admitted during the breeding season compared to the non-breeding season but the sex ratio was similar between seasons and during individual months. By contrast, Griffith et al. (2013) report an increase in male koala admissions related to seasons. It is well known and widely reported that koala activity and movement increases during the breeding period, (Dique et al., 2003; Queensland Department of Main Roads, 2009; Taylor & Goldingay, 2004) and therefore, it is expected to observe an increase of animals being injured or killed by AVCs and dogs during the breeding season. Canfield (1991) detected a seasonal increase of koala road fatalities in a population in New South Wales, but found that young males were highly represented. This study has not investigated age as a factor because there was no reliable data available on age in the wildlife records.

A new hypothesis

More male koalas were admitted into care than females and during the breeding season nearly double the number of animals were taken in compared to the non-breeding season. Research also suggest that young male koalas feature prominently in AVC statistics. The reasons for this are likely to be related to the dominance of male koalas and their resultant larger home ranges (Goldingay & Dobner, 2014), and the need for, especially young male koalas, to establish new home ranges particularly during the breeding season (Canfield, 1991).

It is therefore hypothesised that male koalas will exhibit larger home ranges, move more frequently and change trees more frequently than females and that this will be reflected by their increase road crossings and a greater likelihood of being the subject of an AVC. An idea that will be further explored in Chapter 4.

2.5 Conclusion

Even though there may be local differences in the accuracy and type of data recorded for different wildlife carers, and the number of individual koalas admitted to each shelter varies; the reasons for admission for most koalas and the chance of surviving are very similar. Both admission types, AVCs and attacks by dogs, are important contributors to the overall intake of injured koalas into care. However, AVC is the most significant cause of koalas entering a wildlife shelter and also the most important cause of death.

An elimination or significant reduction of this type of incident could decrease the number of koalas needing to be admitted to a wildlife carer by between 59–69%, and therefore reduce koalas dying in care by up to 55–70% depending on which area they are located.

Tribe and Brown (2000) believed that one effort to mitigate threats to wildlife is that the rehabilitation of individual animals which may contribute to the maintenance of a population, and Griffith (2010) concluded that koalas appeared particularly suitable for rehabilitation based, in part, on the research of Lunney, Gresser, Mahon, and Matthews (2004) who found that survival rates of rehabilitated koalas were no different to that of wild controls. These statements cannot be supported by this research as regardless of the type of trauma, most koalas died in care. It is apparent that AVCs play an important role in admissions of koalas into care in Victoria and especially in regional centres like Ballarat. The high death rate associated with these causes of admission may be of some importance in the survivorship of the local koala populations. It is important to investigate whether the high rates of admission into care and death for male koalas reflect the sex ratio of natural populations and even more importantly, whether the high number of female koalas being admitted and killed has an impact on the viability of koala populations. It is important to understand local conditions and other parameters that affect koala populations with the aim of developing effective local management responses.

The findings from this study confirm many other studies (Dique et al., 2003; Gonzalez-Astudillo et al., 2017; Henning et al., 2015; Preece, 2007) and clearly underline the serious impact that vehicles and dogs have on koalas especially when considering the poor prognosis koalas have when submitted into care, indicating that this species is especially susceptible to AVCs.

One obvious solution to prevent the death of so many individual koalas and to the potential threat to koala populations, would be to focus efforts on reducing the total number of vehicle collisions with koalas especially during the breeding season.

The analysis of wildlife carer data bases such as those used in this study have great research potential and can contribute to our understanding of animal biology, anthropogenic impacts on koalas and wildlife in general, and must be considered when making decisions for koala conservation. However, it is important to encourage comprehensive, correct and detailed data gathering to ensure that we can use these to evaluate factors influencing the success of rehabilitation and release.

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Chapter 3. Koala road-kill blackspots

3.1 Introduction

The rate of AVCs causing wildlife deaths, in particular koala mortality, and the limitation that roads pose to the dispersion of animals during migration or breeding seasonal movements, have been discussed in Chapter 2. This Chapter will investigate the potential existence of blackspots on roads, which may be the cause for increased average numbers of AVCs resulting in koala injuries and deaths associated with particular sections of a road.

The impact of collisions with animals has many facets: the direct effect on the animals' lives (as discussed in the previous Chapter), the ecological impact, especially, but not only, in the case of protected species (Fahrig & Rytwinski, 2009; Mumme, Schoech, Woolfenden, & Fitzpatrick, 2000), the financial cost of the accident to the insurance company and/or the owner of the car. For example, in the case of accidents with large animals such as ungulates in United States or Europe (Seiler, Helldin, & Seiler, 2004) the impact to drivers and passengers is both physical (due to injuries) and economical (damage to the vehicle). In Australia, collisions with kangaroos, emus and other wildlife can also be very dangerous to drivers, by resulting in injuries, and damaging to the vehicles (Lee, Klöcker, Croft, & Ramp, 2004). Furthermore, AVCs can have a negative psychological impact on people; Seiler et al. (2004) link the stress caused by AVCs to drivers and passengers due to the injuries or death caused to the animal as well as the damage caused to the vehicle.

Larger car insurance companies (Keogh, 2016; National Roads and Motorists' Association, 2010; Royal Automobile Club of Queensland, 2014) show statistics of accidents caused by animals on their webpages. Reporting of data throughout the country is not homogenous; many accidents involving animals, which have not caused damage to vehicles and/or people, are not reported, hence there is great variation in the data. According to Rowden, Steinhardt, and Sheehan (2008), in Australia, between 2001 and 2005, there were 11 636 accidents caused by AVCs, (both domestic animals and wildlife) of these 632 were in Victoria. In Queensland 67% of the crashes occurred in non-residential areas. The inconsistencies in recording AVCs are underlined by National Roads and Motorists' Association (2010) reporting that in 2009, 20 000 collisions on Australia's roads involved kangaroos. The other wildlife species mentioned is the wombat. Various papers (Canfield, 1991; Dique et al., 2003; Port Stephens Comprehensive Koala Plan of Management Steering Committee, 2010; Prevett, Hives, & Cerini, 1992; Semeniuk, Close, Smith, Muir, & James, 2012) have highlighted the occurrence of AVCs involving koalas in Queensland, New South Wales and Victoria respectively. Hence, the reporting of data throughout the country is not consistent, statistics available from insurance companies only include car accidents that have been reported due to damage to vehicle and/or injury to people, therefore, true numbers of AVCs are probably much greater. The Queensland Government (2006), acknowledges that vehicle related koala mortality has the most significant effect on koalas' conservation after habitat clearing and fragmentation. This has been confirmed by the finding that road mortality was the leading contributor in the dramatic decline in koala numbers within the Koala Coast region of South-East Queensland (Preece, 2007). Lunney (2013) observed similar trends for northern New South Wales over several decades and the Department of the Environment (2009) and Department of Environment and Climate Change (2008) concluded that mortality on roads can form a large component of overall mortality rates in many areas and they considered it to be one of the key threatening processes for the koala.

'Blackspots' or 'hotspots' are defined as segments of roads where conditions are predisposing for accidents to occur more frequently than other similar segments (Elvik, Vaa, Erke, & Sorensen, 2009). The existence of road blackspots for car accidents, causing human injuries or fatalities, is well known. Blackspots are recognised as a problem throughout the world with the WHO (World Health Organisation, 2016) estimating that 3 400 people die and tens of million are injured every day in the world. To establish areas where accidents could occur more often, various studies have been conducted around the world (Elvik, 2008; Geurts, Wets, Brijs, & Vanhoof, 2004; Maycock & Maher, 1988; Wright, Abbess, & Jarrett, 1988); these studies also looked at the best methodology to apply to determine the existence of a black spot.

Establishing the existence, as well as preventing the construction of roads with blackspots is therefore very important to limit the occurrence of AVCs from the animal and the human perspective.

3.1.1 Causes for Collisions. Dique et al. (2003), argued that habitat destruction, koala density and traffic volume are the main contributors to koala road mortalities in South-East Queensland. Studies have shown that the greater number of AVCs occur in areas where there is suitable habitat for a species, in particular when individuals need to access resources (Coffin, 2007; Taylor & Goldingay, 2004). A study by Taylor and Goldingay (2004) has shown that many species of birds and small Australian native mammals are killed on roads that are situated on ridge tops and where trees are planted as wind breaks along the road-side.

Bird roadkill are also associated with the intensity of traffic (Taylor & Goldingay, 2004). Hels and Buchwald (2001) found that diurnal species of amphibians were more likely to be involved in AVCs due to the higher traffic intensity during the day compared to nocturnal species which crossed the road when traffic intensity was lower. They also found that slow moving animals were more likely to get hit than faster moving. Ellis et al. (2016) found that daylight saving time and associated changes to the timing of commuter traffic has the potential to reduce collisions with wildlife especially nocturnal animals. However, other studies have shown that impact of traffic intensity on AVCs is greatly less than the impact of increasing road densities (Rhodes, Lunney, Callaghan, & McAlpine, 2014), especially for more mobile species. Rhodes et al. (2014) showed that AVCs involving male koalas were more frequent than those involving females, mainly due to increased movement during the breeding season, as well as the larger areas of home range covered by males. Furthermore, the construction or widening of roads has a direct impact on koalas through loss of habitat as well as an indirect impact by affecting their home ranges with the need for animals increase or change home range sizes and exposing them to the threat of AVCs (Semeniuk et al., 2012).

The presence of AVCs has also been associated with the different characteristics of the road. An increase in frequencies of roadkill among macropods has been attributed to the presence of curves on sections of roads (Klöcker, Croft, & Ramp, 2006). Brockie (2007), in his study of hedgehogs and possums roadkill in New Zealand, found that many of these animals were killed by cars while walking on bridges to cross a river or falling off these structures if these where built with steep banks. High speed road zones are more susceptible to AVCs (Rowden et al., 2008), in fact, in this study 77.8% of animal collisions occurred at 100 km/h or more.

Some animal species exhibiting antipredator behaviours e.g. birds (Blackwell et al., 2012; Husby & Husby, 2014), elk *Cervus elaphus* and pronghorn *Antilocapra americana* (Brown et al., 2012) are known to apply these responses when avoiding collisions with aircraft or vehicles. While there is evidence of some level of habituation for some animals, the application of antipredator behaviours for vehicle avoidance is often unsuccessful (DeVault, Blackwell, Seamans, Lima, & Fernández-Juricic, 2015). While antipredator behaviour is known in marsupials e.g. kangaroos (Bender, 2006) and Tammar Wallabies (*Macropus eugenii*) (Griffin & Evans, 2003) its relevance in avoiding roads or vehicles has not been widely studied. Some species avoid roads but the extent is subject to a number of aspects among others, the size of roads, traffic volumes and road noise (Rhodes et al., 2014).

Andrews, Gibbons, and Reeder (2005), found that, smaller snake species exhibited higher levels of road avoidance, all species crossed at a perpendicular angle minimising crossing time, and that some species cannot successfully cross highways with high traffic densities. While Kinsella (2014) demonstrated that regular exposure to human activity can actually hypersensitize koalas to human disturbances, there is, however, not yet, any scientific evidence to suggest that koalas are able to actively avoid collisions with vehicles.

In summary, literature lists at least four main causes for collisions of vehicles with wildlife:

- habits of the species (e.g. diurnal, migration, breeding season, speed of movement, size and shape of home range, density of population);
- habitat of the species (e.g. amount and arrangement of habitat in the landscape, topography);
- vehicle traffic (e.g. speed of, intensity, density, type of) and
- the roads themselves (e.g. width of, design of—curves, embankments, density of).

3.1.2 Blackspots for animals. The Australian Federal Government, through its Department of Infrastructure and Regional Development, uses the criterion of 0.13 casualty crashes (a crash where at least one fatality, serious injury or minor injury occurs (Department for Transport Energy and Infrastructure, 2010)) per kilometre per year over 5 years to determine funding eligibility for remedial works on roads to address blackspots where high numbers of car crashes occur (Department of Infrastructure and Regional Development, 2016). However, while it is relatively simple to obtain and analyse data for casualty crashes involving humans and vehicles, it is more difficult to obtain the same data when dealing with animal casualties. Human casualties are recorded by emergency services and insurance companies, while animal casualties are only reported if the collision caused significant damage to the vehicle, if the vehicle involved in the collision is insured and is, indeed, reported to an insurance company; even then, the details are often only imprecise and unreliable. The species of animal involved may not be known or accurately reported, and the individual animal may depart the scene of the accident injured but survive, or possibly die later and in a different location making detailed analysis difficult.

Blackspots for AVCs collisions should be identified and managed where significant numbers of sick or injured wild animals are found (Department of Environment and Heritage Protection, 2012). The National Koala Conservation Management Strategy (Australian Government, 2009), acknowledges that roads and the AVCs are two of the main threats to the long term survival of the koala, and identified the need for research into the threat that roads and traffic exert on the species. Taylor and Goldingay (2010), called for a national strategy to mitigate the impacts of roads on wildlife populations in Australia while stressing the need for more research and increased funding.

Koala populations in southern Australia are not only affected directly by AVCs, but also by the fragmentation effect that roads have on habitat (Lassau et al., 2008). McAlpine et al. (2006), stress that habitat fragmentation forces koalas to travel more frequently to sustain themselves; therefore increasing the risks of being hit by cars or attacked by dogs while on the ground (Dique et al., 2003; Rhodes et al., 2006). Koalas living in developed areas have to cross streets and highways to get to pockets of remaining fragmented habitat (Ramp, Wilson, & Croft, 2006) making them susceptible to road-related impacts (Dique et al., 2003).

Semeniuk et al. (2012), in their investigation of the impact of roads on koalas found that most of the areas with high numbers of koala roadkill were “within a short distance of some form of open corridor (a passage without dense vegetation of shrubs or trees) that leads onto the highway”. Lassau et al. (2008) in an earlier study, also linked koala movement to the use of road corridors and interpreted this as indicating that koalas disperse along tracks (to avoid obstacles) that lead them onto the highway where many are killed in blackspots.

Studies testing for the existence of blackspots for animals are limited especially for koalas. Most studies assume that accumulation of AVCs in certain areas constitute a black spot and compare various parameters to black spot and non-black spot areas or to the presence or absence of roadkill e.g. Ramos, Silva, Santos, and Pires (2015). Further, methods vary between studies; Brockie (2007), found that roadkill of the possum (*Trichosurus vulpecula*) were not distributed randomly along the 60 km of highway ($\chi^2 = 33.1$, d.f. 17, $P = 0.011$) but clustered in six areas along the road. Lassau et al. (2008), depicted koala road kills that were spatially concentrated around junctions of a highway and minor roads. Farmer and Brooks (2012), used logistic regression to compare multiple taxa and variables. Gomes, Grilo, Silva, and Mira (2009), used Crimestat III software to identify global clustering in the spatial arrangement of owls (*Strigiformes*) fatalities before using binary logistic regression and the presence/absence of fatalities along 500-m road segments to develop a model to identify areas of concern for owls colliding with vehicles.

This Chapter aims to establish whether koala road-kill blackspots occur along a section of highway before analysing and ranking the factors that contribute to the occurrence of any such blackspots. Chapter 4 will embark on a more detailed investigation into aspects of koala road-kill ecology in a specific black spot area.

3.1.3 Modelling. In common with most areas of the world, Australia has undergone substantial land clearing and modification due to agriculture and urban development, particularly since European settlement (Barson, Bordas, & Randall, 2000). This has been associated with the loss and fragmentation of koala habitat, especially in coastal regions and a contraction in the koala’s range (Australian Government, 2009; Melzer, Carrick, Menkhorst, Lunney, & St. John, 2000). Therefore, there is a need to develop modelling approaches that can improve our ability to make informed decisions for koala conservation.

Natural resource management often uses models for prediction (Jaeger et al., 2005), but another reason for developing models is to understand processes (Grimm, 1999). However, without understanding the processes, models will tend to be specific to particular case studies and may not be easily transferred to other areas. Statistical models that only focus on relationships may not contribute greatly to the understanding of underlying processes (Hilborn & Mangel, 1997). Predictive models that reflect causative processes rather than correlative relationships between variables are highly recommended (Drew, Wiersma, & Huettmann, 2010).

Malo, Suárez, and Diez (2004), believed that it is essential to utilise predictive models to prevent wildlife fatalities. Roger and Ramp (2009), promoted the benefit of using 'habitat use' to improve the accuracy of predictive road fatality models. They constructed a binary logistic regression model using wombat fatality presences and randomly generated absences. Species-specific habitat variables were included as predictors in the model selection process as well as two spatially explicit measures of wombat habitat use. They concluded that it is essential to incorporate variables that describe habitat use by fauna for predictive modelling of AVCs. Ramp et al. (2006), through their modelling found that the parameters of availability of forage and protective cover were indicative of locations where mammals were most likely to be killed. Ramp, Caldwell, Edwards, Warton, and Croft (2005), in order to identify road-kill blackspots, developed a model approach for both presence and presence/absence data. They recommended that where actual presence data exists, spatial clustering is the preferred method of black spot identification. They promoted the use of predictive models as they enable the identification of explanatory factors which allows for species-specific management strategies to be developed and implemented at black-spot locations.

Another type of model, the source-sink model (Pulliam, 1988), is often used for describing population dynamics. This model makes the assumption that habitat patches are of highly varying quality and further predicts a net flow of individuals from ‘source’ patches (high habitat quality, survival and reproduction success) to ‘sink’ patches (low habitat quality, survival and reproduction success) (Delibes, Ferreras, & Gaona, 2001). The reason for an individual arriving at a habitat sink (considering the potential for negative consequences) may be due to territoriality (i.e. young koalas dispersing away from dominant males), or temporal barrier (i.e. an individual’s choice of a ‘good’ habitat is obstructed by roads or other human developments) (Delibes, Gaona, & Ferreras, 2001). These mechanisms assume that, given no obstructions to habitat choice, individuals would choose the highest quality habitat available. ‘Attractive’ sinks, on the other hand, is a concept where animals actively choose low quality habitats (i.e. sinks). The basis for such disadvantageous habitat choices are attributed to rapid changes in habitat quality (Delibes, Gaona, et al., 2001). In the case of the koala this could be the removal of habitat or the construction of a road. Therefore, ‘attractive’ sinks appear to significantly impact population dynamics, particularly in highly fragmented landscapes and might be a reason for the occurrence of road-kill blackspots.

Prevett, Pope, Smithyman, and Schlagloth (1995), in a study focused on the Western Freeway between Ballarat and Melbourne, found that roadkill occurred where vehicle speeds exceeded 80 km/h and where wide habitat corridors or linear forests occurred on both sides of the road. They hypothesised that the koalas were immigrants from adjacent populations and that a 'source' and 'sink' model was operating at the site.

This conceptual model of population dynamics of source/sink will be explored during the development of the next two chapters.

The habitat mapping associated with the proposed research and the analysis of koala road-kill blackspots might shed some light on the often expressed believe by local residents that the highway functions as a koala sink because of its good koala road-side habitat (Prevett, Hives, & Cerini, 1990; Prevett et al., 1992; J. Lucato, pers. com., July 2006).

Since early 2000, the use of predictive models has become increasingly popular to forecast koala numbers and distribution. Januchowski et al. (2008), tested the importance of multiscale habitat variables on koala occurrence in Ballarat using logistic regression and hierarchical partitioning analyses to rank alternative models and key explanatory variables. They found that it was essential to protect remaining core areas of high quality habitat and scattered habitat patches which provide connectivity and enhance opportunities for safe koala movement between habitat patches intersected by main roads. Johnson and Omland (2004), describe how these models are applied at different scales:

1) Micro-habitat characteristics at the site scale (30 m in diameter) such as topography (aspect, slope, and distance to constant water and roads) can be predictors of presence and absence;
2) Patch size, shape and, condition as predictors of presence and absence. Walker, Novaro, and Branch (2003) found that larger habitat patches in a fragmented landscape supported a higher diversity of species than did smaller patches. Larger patches have also been shown to better support larger sized animals (Fischer & Lindenmayer, 2007);
3) The area of suitable habitat in the surrounding landscape as predictor. For the koala in the Noosa Shire, Southeast Queensland (McAlpine & Eyre, 2002) propose that there is a 50% critical habitat threshold;

4) Landscape configuration, connectivity, and context as predictors. This model predicts that species presence depends on the degree of habitat fragmentation, connectivity, and context. The degree of the effects on species may depend on a species' area and resource requirements (e.g., diet and habitat), sensitivity to edge effects, dispersal capabilities (Townsend et al., 2003). Bennett (1990) found that native mammals were more sensitive to forest fragmentation than introduced mammals and that the presence of corridors was essential for the movement and continued survival of native species;
5) The global model as predictor. This model combines the multiple scale variables outlined in models 1-4 for a most reliable prediction of presence. Mac Nally, Bennett, and Horrocks (2000), postulate that simple models are likely to fail and, that the incorporation of additional relevant measures (e.g. habitat quality) may increase the predictive power. The comparative importance of different variables in forecasting presences and absences is expected to differ between variables. It is important to examine the validity of the chosen model for the target species by testing model results against historical data (Lindenmayer, McIntyre, & Fischer, 2003) or by comparing the performance of multiple models (O'Grady, Reed, Brook, & Frankham, 2004).

Natural resource management increasingly recognises the importance of conceptual models in understanding planning issues, and encourages the integration of such models into daily decision-making. Sanderson, Redford, Vedder, Coppolillo, and Ward (2002), argue that planning for conservation needs to consider all the complicated biological, social and economic factors which affect the ecological integrity of a site. They believe that this is best done by using a conceptual model as it also helps to make the best use of the limited conservation resources. Deblinger, Field, Finn, and Loomis (2004), incorporated population dynamics, landscape ecology, human dimensions, and political and economic variables into their conceptual model to manage beavers. Trexler (1995), draws upon many different biotic and abiotic parameters in his conceptual model including details on individuals, populations, communities, and systems to make conclusions about restoration success of a river.

Given that it is impractical to reverse 200 years of accumulated habitat loss; the identification of factors that cause koalas to be killed on certain sections of roads seems to be a more achievable task with a realistic hope of attaining some reduction in the threats to the long term survival of the koala. This is the overall goal of this thesis.

Key to this is that the findings from this study are relayed to those decision makers who have the ability of implementing them. For example, in Ballarat, with a Koala Plan of Management already implemented in the Planning Scheme (Schlagloth, Thomson, & Mitchell, 2006), there is an opportunity to improve the information already available and to guide the management and development of urban, semi-urban and rural areas, including the planning of roads that connect these areas, for the conservation of koalas and wildlife in general.

This Chapter will address the development of a modelling approach for better understanding the dynamics of koala populations living near roads and determine their conservation requirements.

3.2 Are There Koala Road-kill Black Spots?

The presence of blackspots along the road under investigation needs to be confirmed before attempting to determine the parameters that best define a model for KRB.

3.2.1 Methods. Data on koala road kills on 50 km of roads between Ballarat and Meredith, mostly along the Midland Highway were collected over a period of 18 years (1989–2005). The entire length of the road was driven twice a day (around 6 am and 6 pm) during the period of 1994–2003, by two different people (one person driving seven days a week, the other only Monday to Friday for most of this period). In addition, incidental reports of koala road-kill sightings by the public, council officers and VicRoads crews were recorded and examined. The Midland Highway (A300) is a mostly dual-lane road that forms the main connection between the regional cities of Ballarat and Geelong in Western Victoria (see Figure 1.2 a and b in Chapter 1). The first section of the study site is formed by several roads (Main Road—from where it crosses Victoria St in the centre of Ballarat and Golden Point; Geelong Road—including the mostly treed residential areas of Canadian, Mt Clear and Mt Helen; and Warrenheip Street—in Buninyong) linking the centre of the City of Ballarat to the township of Buninyong and is widely referred to as Geelong Rd (C294). The speed limit varied from 60 km/h to 80 km/h along this section of road. Between the township of Buninyong and the township of Meredith, the speed along the Midland Highway was mostly 100 km/h with a few short sections reduced to 80 km/h and 60 km/h where the highway passed through smaller townships. From Buninyong, the highway passes the townships and localities of Scotsburn, Clarendon and Elaine before reaching Meredith.

Figure 3-1 View of a typical section of the dual-lane Midland Highway. Isolated remnant koala habitat trees on road-side to left.

Dead koalas on or on the side of the road were examined, and details (sex, type of injuries, location, date and time), were recorded where possible. With reasonable accuracy, each location was marked on a set of maps by identifying features on the road, such as intersections, or measuring distances using the car odometer. The bodies of dead koalas were usually marked with spray paint and/or dragged off the road into nearby vegetation to avoid duplications. Many were also collected as samples for further examination for other studies. Additional data were collected from occasional reports from other parties; these reports were usually confirmed on-site and any duplicate reports were eliminated. Records on koala road kills were entered into a Microsoft Excel database and imported into MapInfo for analysis and display purposes.

IBM SPSS Statistics 21 was used to produce a control chart for the koala road-kill data to determine whether there were areas of blackspots that should have undergone further investigations. The road was split into 96 (500 metres) sections as previously used to identify global clustering in the spatial arrangement of owl (*Strigiformes)* fatalities to develop a model to identify areas of concern (Gomes et al., 2009). Statistical significance was determined to be reached at three standard deviations from the mean (Fischer, 1954).

3.2.2 Results. A total of 223 validated reports were found and imported into MapInfo. A map of the distribution of koala roadkill along the Geelong Road from the centre of

Ballarat to the township of Buninyong and along the Midland Highway to Meredith is shown in Figure 3.2.

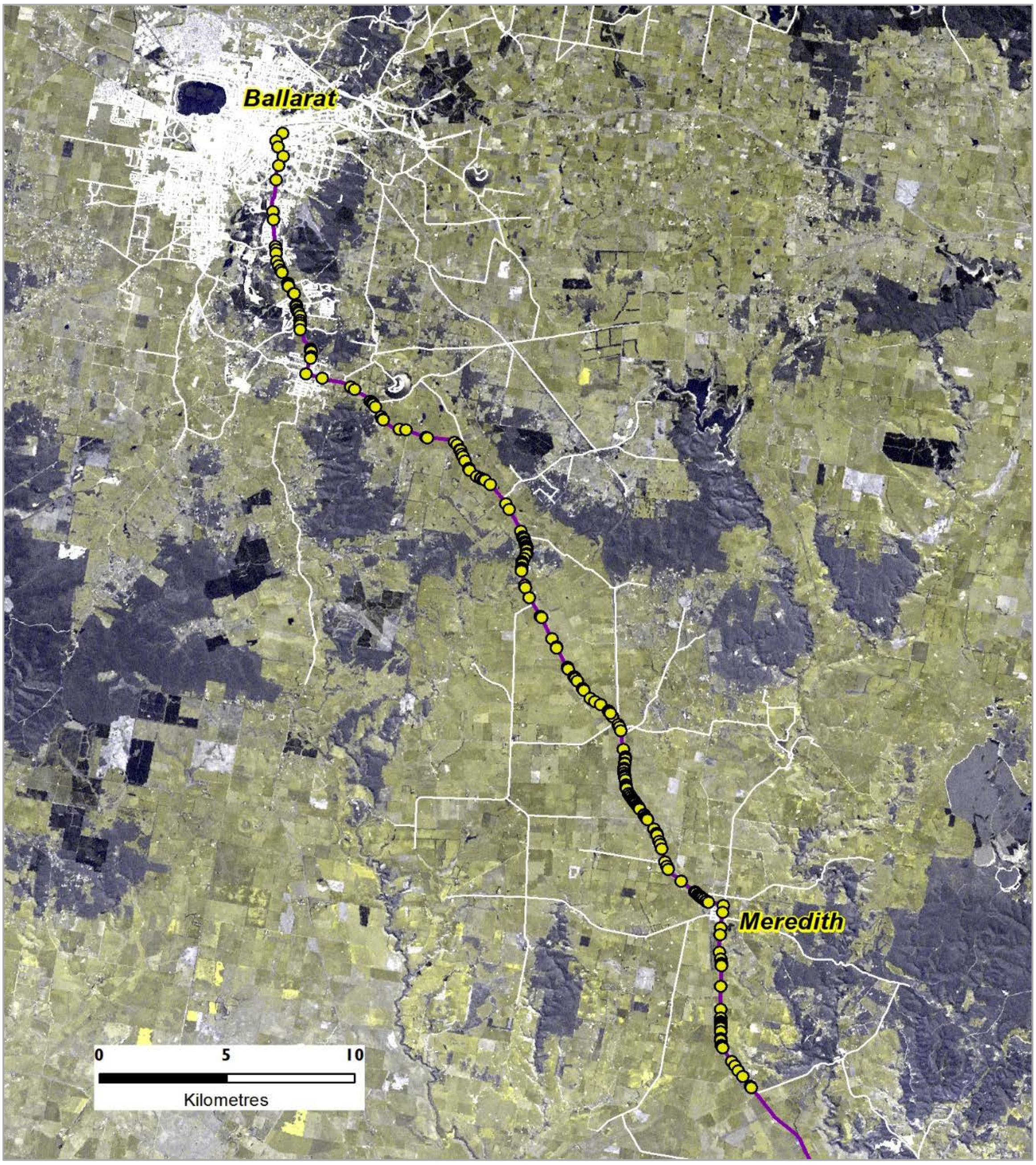


Figure 3-2 Distribution of koala roadkill along Geelong Road and Midland Highway between Ballarat and Meredith (Western Victoria). Background—Landsat 7 image courtesy University of Maryland.

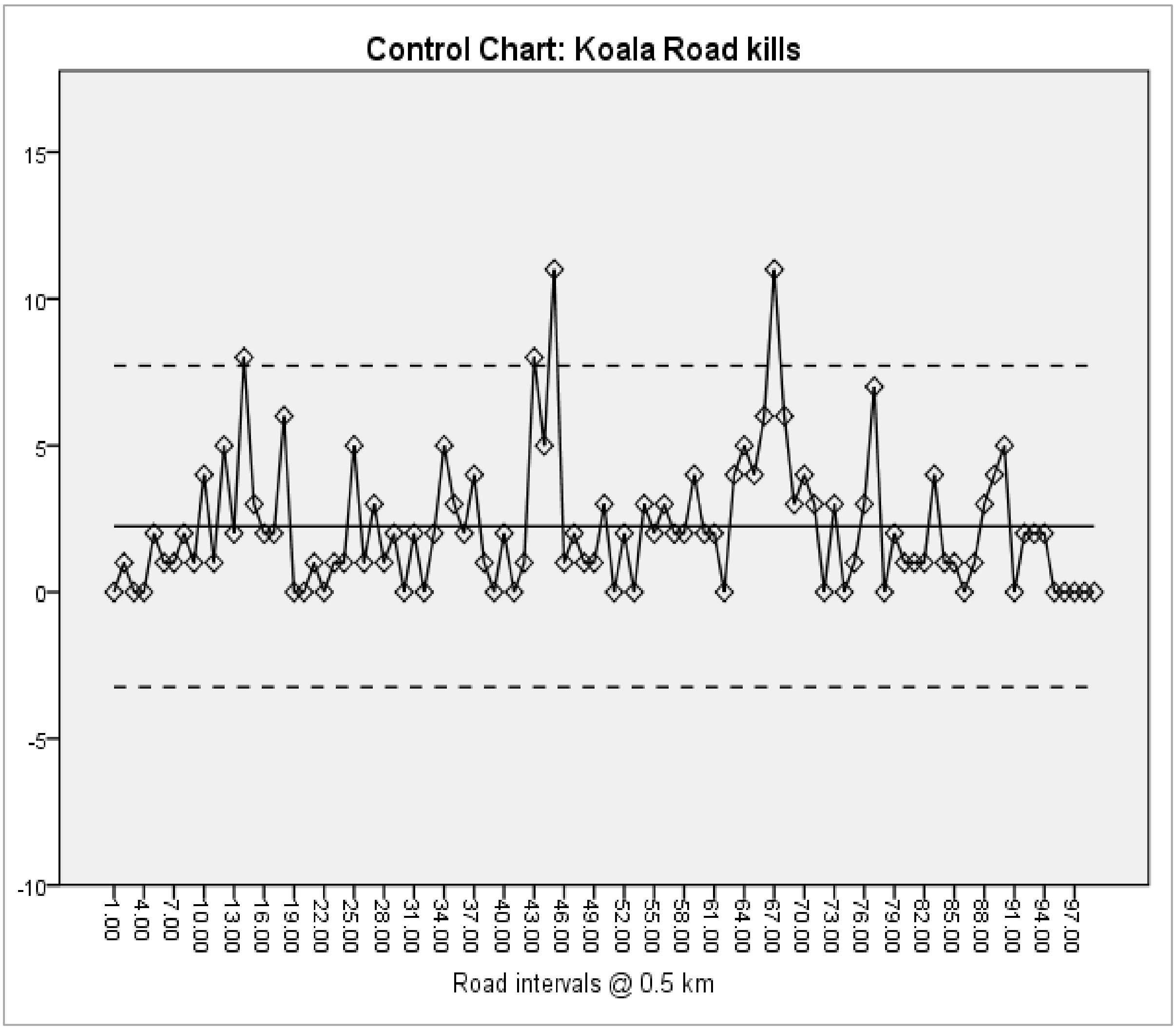


Figure 3-3 Distribution of koala road kills along a 50 km stretch of main road and highway near Ballarat. The horizontal solid line indicates the mean. The two horizontal dotted lines indicate ± 3 standard deviations from the mean.

Statistical analysis in SPSS showed four locations with a positive deviation from the mean in terms of number of koala roadkill; two with eight kills each at 7 km and 21.5 km and two with 12 kills each at 22.5 km and 33.5 km. The graph gives cause to formally examine the four locations (blackspots) that exceed three standard deviation.

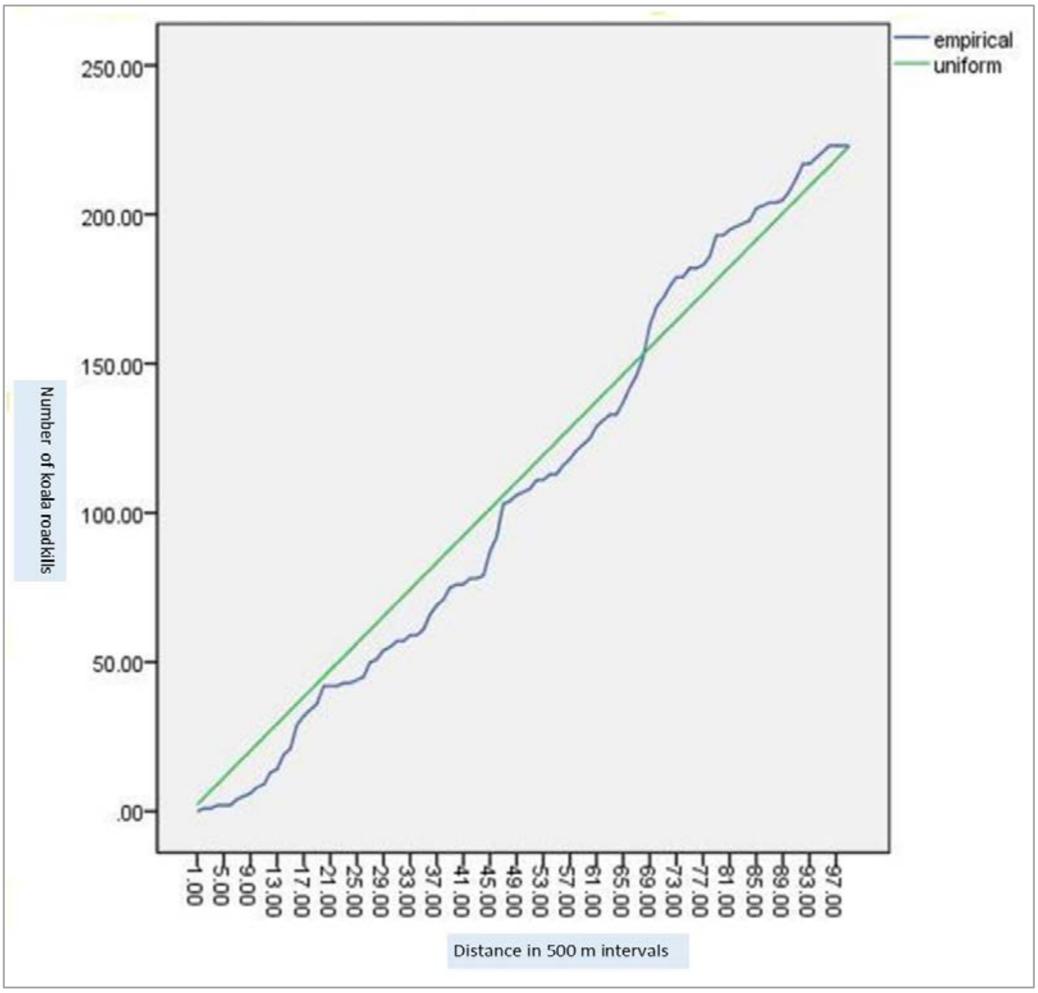


Figure 3-4 Cumulative empirical number of kills along a 50 km stretches of main road and highway near Ballarat in increments of 0.5km (blue line). The green line represents the expected number of kills if the distribution were uniform.

The graph, in Figure 3.3, shows a non-uniform distribution of koala roadkill along the subject road with the greatest divergence from uniformity at the same four points as determined in Figure 3.2. This underlines the existence of four distinct areas of concern (Koala Road-kill Blackspots).

In an attempt to strengthen the finding of areas of concern and blackspots for koala roadkill, all road-kill data were analysed in QGIS (QGIS Development Team, 2015) using the 'heatmap' extension (QGIS Plugin Repository, 2014) and applying 1000 metre radii (see Figure 3.4). The 'heatmap' plugin uses Kernel Density Estimation (Silverman, 1986) to create a density (heatmap) raster of an input point vector layer. It is a process of integrating the number of points that are encountered within the search radius while applying a decaying probability density function to the importance of a point in the final result. The density is calculated based on the number of points in a location, with larger numbers of clustered points resulting in larger values. Heatmaps allow easy identification of “hotspots” and clustering of points. A search radius (or kernel bandwidth) can be used to specify the ‘heatmap’ in metres or map units. The radius specifies the distance around a point at which the influence of the point will be felt. Larger values result in greater smoothing, but smaller values may show finer details and variation in point density.

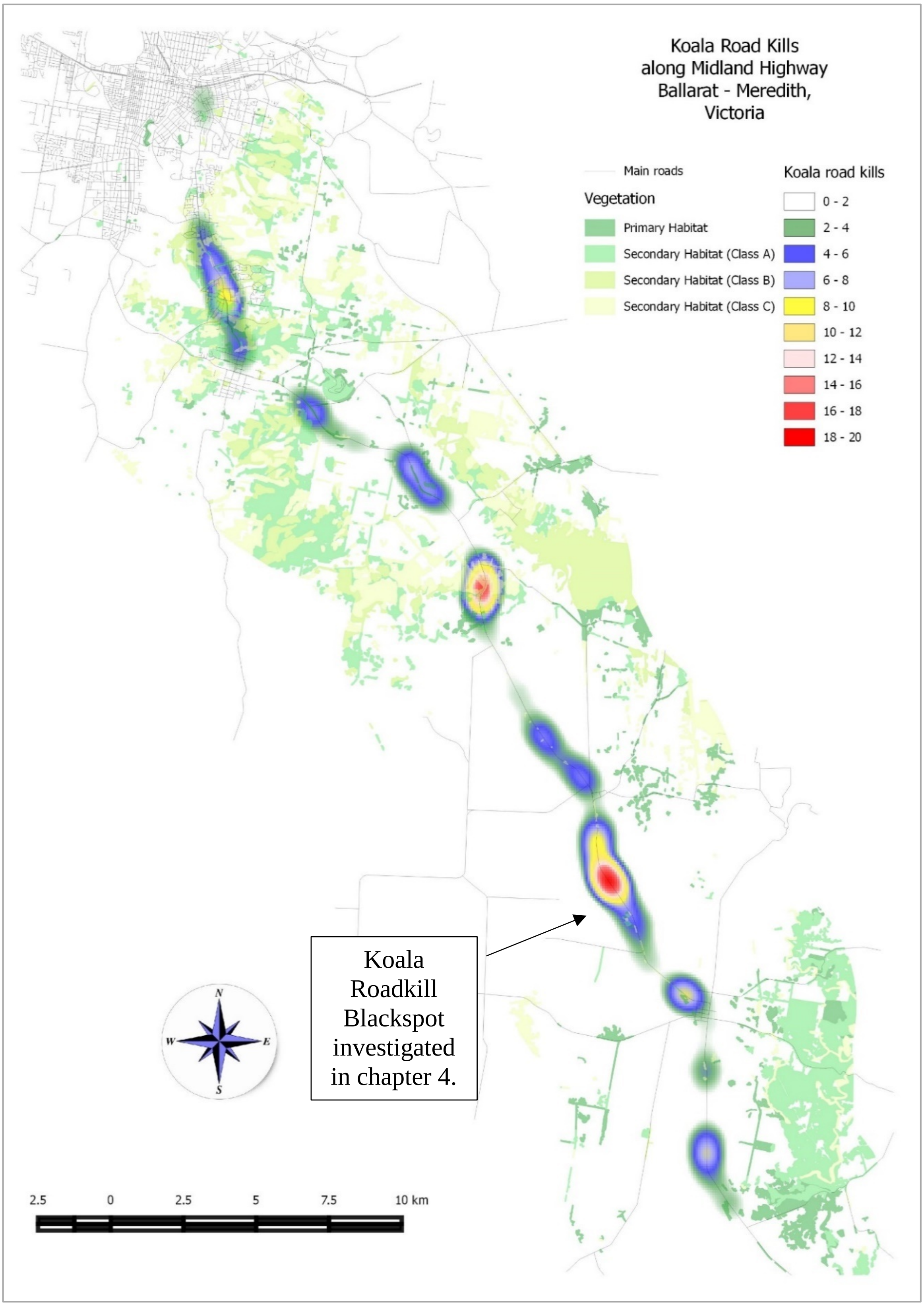


Figure 3-5 Heat map of koala roadkill along the highway dissecting the study site; indicating Koala Road-kill Blackspots and areas of concern. Note: this map does not show the narrow strips of koala habitat found along many sections of road in the study site—such areas are shown in more detail in later chapters and the appendices.

As expected, clustering was identified in the distribution of fatalities for the koala roadkill, meaning that the fatalities occurred in clusters, rather than being randomly distributed along the road (Figure 3.4). Two KRBs can clearly be seen around half way along the length of the road and approximately three-quarters along, reflecting those areas already identified in Figure 3.2.

3.2.3 Discussion/Conclusion. The data represented here justify the classification of the four 500 m stretches of highway as areas of concern or, better known as, koala road-kill blackspots. These four sections clearly show a positive deviation from the mean of three or more points. The two sites at 21.5 km with eight kills and 22.5 km with12 kills are not far apart and possibly may be part of a larger KRB. The fourth 500 m stretch of highway at 33.5 km with also 12 kills is separated from any other areas of concern by ca. 10 km. This is the ideal site to investigate koala movement and aspects of their ecology in more detail. Therefore, this KRB, at and around the 33.5 km mark, forms the site for the integrated study into a koala road-kill black spot covered in Chapter four. The heat map (Figure 3.4) supports the statistical analysis and clearly shows the same black spot areas even when the radius is increased; the sub-study site (KRB) for analysis in Chapter four is highlighted.

3.3 What Makes a Black Spot? The Model

In 3.2 it was confirmed that KRBs, areas where koalas are more likely to be killed or injured by collisions with vehicles (Ramp et al., 2005), exist in four sections along the Midland Highway. This Chapter aims at identifying parameters that may contribute to the occurrence of these KRBs. It is envisaged that the identification of such factors or parameters will assist with attaining some reduction in the threats to the long term survival of the koala locally, but hopefully also nationally.

Physical and biological characteristics of the local KRBs will be established and parameters will be suggested that can be used in a model. Predictive models are an important aspect for ecological studies conducted with future, adaptive, conservation management in mind (Coops & Catling, 2002).

3.3.1 Methods.

Data were collected and analysed from several sources: the Koala Habitat Atlas and associated vegetation maps published as part of the Koala Plan of Management for Ballarat (Schlagloth et al., 2006), from road-kill records obtained from wildlife carers and observations from the public, and from field surveys in the study area.

A predictive modelling approach as used in Coops and Catling (2002), was applied to develop an understanding of the degree to which each variable affects a site on the highway. In this study, the dependent variable is binary (i.e., present or absent) and logistic regression analyses were used to statistically predict the probability of a road-kill occurring. The following variables were measured and recorded; their sources and ownership are recorded in Table 3.1. The locations of koala roadkill and blackspots, identified in 3.2.1, were incorporated into the model.

Table 3-1 Variables, their specifics, acronyms and source.

Variable group	Variable specific	Acronym/ name of specific variables	Source	Source ownership/ access
Koala habitat quality	Primary habitat; Secondary habitat (Class A); Secondary habitat (Class B); Secondary habitat (Class C); Cover of area for each class within various radii (50, 100, 200, 400,	LCover_C1P LCover_C2P LCover_C3P LCover_C4P	AKF habitat atlas—various	CoB/AKF in public domain

Variable group	Variable specific	Acronym/ name of specific variables	Source	Source ownership/ access
	800, 1600, 3200 and 5000 m)			
General	Individual Identification Number Points at 50 m intervals along road Eight different radii around each chainage point Individual identification number—link back to master data base	id chainage buffer_rad XL_ID		Generated by researcher
Vehicular speed	Speed limits (to S or E and N or W—km/h)	Sp_Lim_SorE/ Sp_Lim_NorW	Speed zone data	VicRoads
Driver—visibility	Visibility (distance in m to S or E and N or W)	Vis_SorE/ Vis_NorW	Hawkeye	
Width of road	Width of road (number of lanes (2–4)	Wid_SorE/ Wid_NorW	Data base	
Landscape/Degree of fragmentation, availability of habitat	Landscape proportion Edge length Edge density Number of patches Patch density Greatest patch area Smallest patch area Mean patch area Median patch area Mean patch shape ratio Overall core area	LProp_CxP EdLen_CxP EdDen_CxP NumP_CxP PDen_CxP GPArea_CxP SPArea_CxP MnPAr_CxP MdPAr_CxP MPSRat_CxP OCArea_CxP	AKF habitat atlas	CoB/AKF in public domain
Road-kill	Number of koala roadkill recorded at each chainage point within various radii	No_kills	Road-kill data base	Researcher
	Number of koala roadkill recorded at chainage point not	Kills_50m		

Variable group	Variable specific	Acronym/ name of specific variables	Source	Source ownership/ access
	considering increasing radii			

Variable groups

Koala habitat quality—is defined using the habitat classes

- Primary: *areas of forest or woodland where primary koala food tree species ≥ 50% of the over-storey trees*;
- 2A: *areas of forest or woodland where primary koala food tree species < 50% ≥30% of the over-storey trees; or primary koala food tree species < 30%, but together with secondary food tree species ≥ 50% of the over-storey trees; or secondary food tree species alone ≥ 50% with primary koala food tree species absent*;
- 2B: *areas of forest or woodland where primary koala food tree species < 30% of the over-storey trees; or primary koala food tree species together with secondary food tree species ≥ 30% (but < 50%); or secondary food tree species alone ≥ 30% but < 50% with primary koala food tree species absent;*
- 2C: *areas of forest or woodland where koala habitat is comprised of secondary and supplementary food tree species with primary koala food tree species absent except for possible scattered individual trees, where secondary food tree species comprise < 30% of the over-storey trees.*

… as described in more detail in the Ballarat Koala Habitat Atlas (Callaghan, Mitchell, Thomson, & Bailey, 2004) and the Koala Habitat Atlas for the Golden Plains Shire (Australian Koala Foundation, 2008). Remaining areas of the study site not covered by these two documents, were also classified by using the same methodology.

Vehicular speed is defined as the legal speed limit (km/h) at a chainage point (in this study every 50 m) driving towards north or west and towards South or East, depending on which direction the highway is orientated at that point. No actual speed measurements for all chainage points were available. The assumption was made that, most vehicles would travel on or around the legal speed limit, and that breaches of these limits would most likely apply uniformly across all chainage points.

Driver—visibility is defined as the greatest distance a driver can possibly see at a chainage point driving towards north or west and towards South or East, depending on which direction the highway is orientated at that point. These measurements (expressed in metres), were taken by VicRoads' HawkEye (ARRB Group, 2016) system, similar to Google's street view, during the day only. The system combines a number of cameras in a regular passenger car and continually records while the vehicle is travelling along the road. Cameras allow the gathering of various data in a number of directions. This study was only concerned with the distance the driver's camera could view until it was obstructed by changes in the road (e.g. curvature, elevation). Koalas are known to mostly move at dusk and dawn (Benesch, Munro, Krop, & Fleissner, 2010) when drivers' ability to see in the distance is restricted by a lack of daylight. The average detection distance, of road markers, for drivers of cars with headlights on low-beam, were 124.8 m and 237.3 m on high-beam but differences were found for drivers of different age groups (Debaillon, Carlson, He, Schnell, & Aktan, 2007; Zwahlen & Schnell, 1999). Trucks were not considered separately here; their headlight beam may be greater and the driver's view may also be better, however, their braking distance may also be different; night vision on low-beam and high-beam is considered not much different from cars though with 76 m and 152 m respectively (Trucking Truth Training Company, 2015). Only the daylight visibility was used in the analysis even though the daylight visibility, at many chainage points, was greater than the one at night.

Width of road in this study is defined by the number of lanes (2–4) at a chainage point. Wider roads often carry an increased volume of traffic, therefore the time it takes for koalas to cross would increase their risk of an AVC (Polak, Rhodes, Jones, & Possingham, 2014).

Landscape/degree of fragmentation, availability of habitat is defined using a LecoS plugin for patch and landscape statistics (Jung, 2016) which is based on metrics taken from FRAGSTATS (McGarigal, Cushman, Neel, & Ene, 2002). It identifies class patches and calculates landscape metrics, it allows for the calculation of metrics on rasters and vector layers. These values and metrics are invaluable for studies that focus on the influence of habitat fragmentation on wildlife (Fahrig, 2003). Table 3.3 shows the metrics from the LecoS plugin which considered to be of potential importance and were applied to each of the four koala habitat types:

Table 3-2 Fragmentation Metric Definitions adapted from Elkie, Rempel, and Carr (1999); Wang, Blanchet, and Koper (2014). 'x' will be substituted by 1,2,3,4 in accordance with the category of habitat under investigation.

Name	Code	Description
Edge density	EdDen_CxP	Equals the sum of the lengths of all edge segments involving the corresponding patch type, divided by the total landscape area. Edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size as it reflects the amount of edge relative to the landscape area. It is a measure of landscape configuration. Amount of edge relative to the landscape area.
Edge length	EdLen_CxP	Equals the sum of the lengths (m) of all edge segments involving the corresponding patch type. It is implied that the habitat class/type is made up of small or convoluted patches; the total amount of edge is directly related to the degree of spatial heterogeneity. The metric is to be considered a major correlate of measures of landscape pattern. Justification to include it is that it is a function of the size of an area … the larger the area, the greater will be the probability of occurrence of resources for koalas.

Name	Code	Description
Greatest and Smallest patch area	GPArea_CxP SPArea_CxP	Area of the largest and smallest patch of that habitat type within the particular radius.
Landscape cover	LCover_CxP	Proportion of landscape covered by this particular habitat. Sum of areas of all patches for this habitat type in the landscape within a certain radius. Comparisons are obtained by differences in values, and have direct interpretative value. It is useful for defining a landscape, and comparing class areas within a landscape.
Landscape proportion	LProp_CxP	Proportion of that particular koala habitat category over all koala habitat in the landscape within a certain radius. Comparisons are obtained by differences in values, and have direct interpretative value. It is useful for defining a landscape, and comparing class areas within a landscape.
Mean patch area	MnPAr_CxP	The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. Not only is this information the basis for many of the patch, class, and landscape indices, but patch has area had a great deal of ecological utility in its own right.
Mean patch shape ratio	MPSRat_CxP	The ratio between the perimeter of a patch and the perimeter of the simplest patch in the same area.
Median patch area	MdPAr_CxP	Equals the value of the corresponding patch metric for the patch representing the midpoint of the rank order distribution of patch metric values for patches of the corresponding patch type.
Number of patches	NumP_CxP	Equals the number of patches of the corresponding patch type (class). Number of patches of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. It may be fundamentally important to a number of ecological processes.
Overall core area	OCArea_CxP	Core area is the area that is not influenced by edge effects. Core area index is a relative index that quantifies core area as a percentage of patch area (i.e., the percentage of the patch that is comprised of core area). It is another measure of the level of fragmentation. The more or greater the core area, the lower the level of fragmentation of a habitat type/category.
Patch density	PDen_CxP	Equals the number of patches of the corresponding patch type divided by total landscape area. Patch density is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as number of

Name	Code	Description
		patches as an index, except that it expresses number of patches on a per unit area basis.

Mapping and analysis of the vegetation:

Table 3-3 Process of analysing the vegetation map.

Step	Materials	Software	Methods
1	Aerial photos for entire study site	GIS	Vegetation classes digitised over aerial photos (see Figure 3-5).
2	Vector layers of vegetation classes	QGIS ver. 2.8; Grass R.-> vector	Vector vegetation classes converted into raster vegetation classes.
3	Vector road file	QGIS	Placement of point every 50 m.
4	Point file	QGIS	Buffering of each point with vector poly 50, 100, 200, 400, 800, 1600, 3200 and 5000m. Coded and automated process.
5	Buffer poly file	QGIS	1—selection of single buffer. 2—use of buffer to clip the vegetation class raster. 3—feeding of clip into LecoS plugin for patch and landscape statistics.
6	Buffer file	Python code	Writing of the LecoS results back into the buffer attribute table (*.dbf).
7	*.dbf with vegetation statistics	Excel	Conversion of *.dbf to *.xlsx

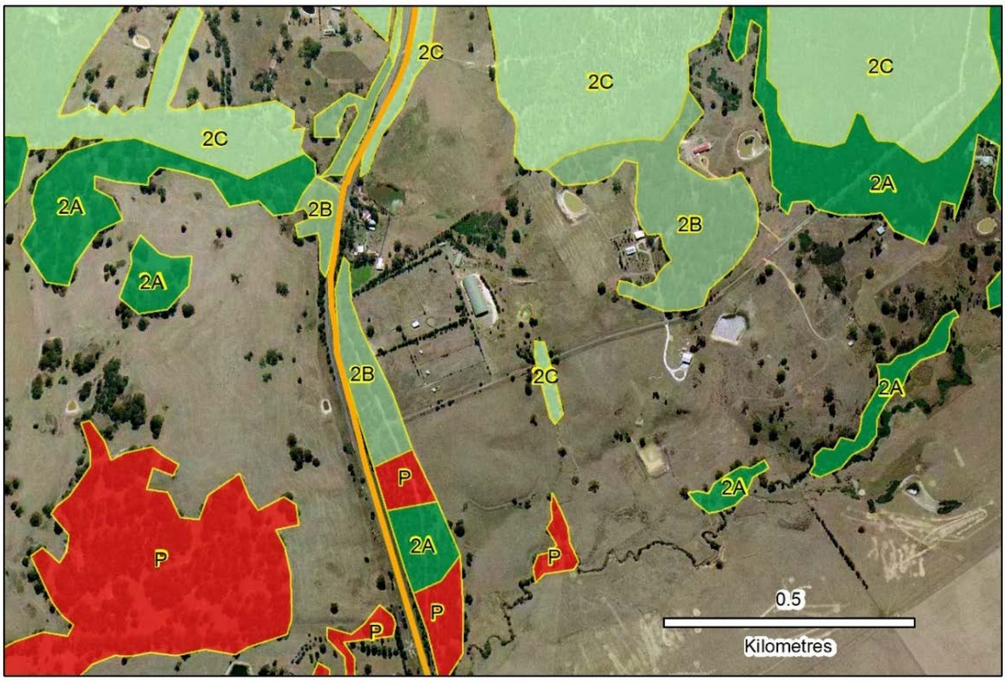


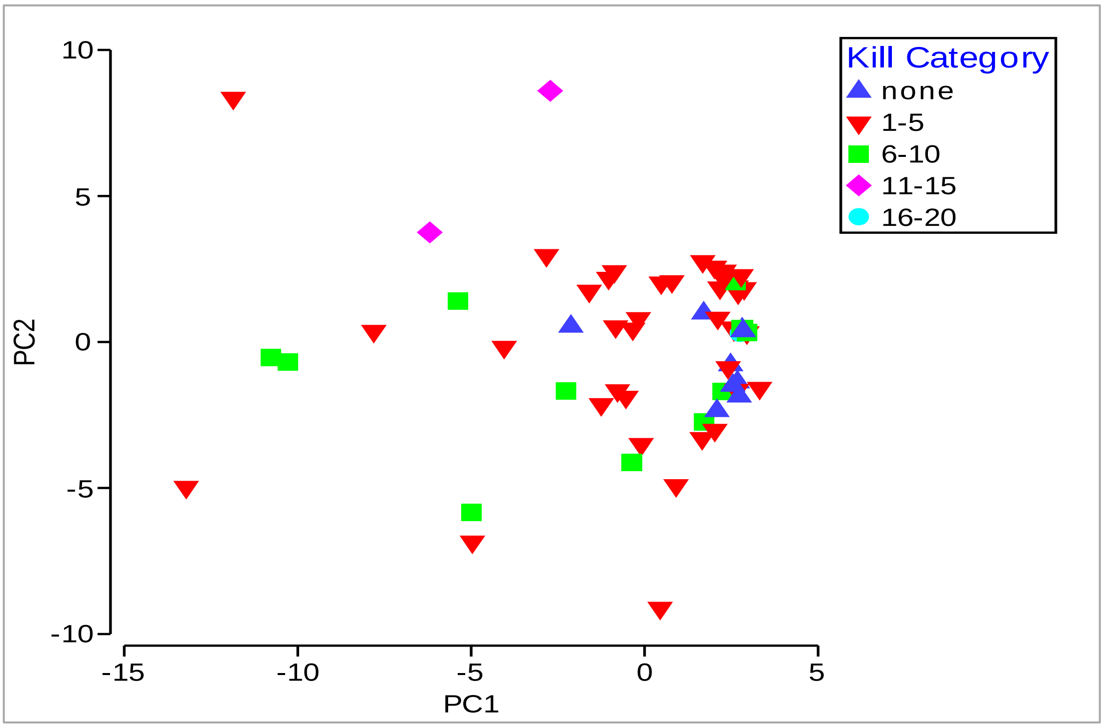
Figure 3-6 Vegetation classes digitised over aerial photos. P = Primary koala habitat, 2A, B and C = Secondary koala habitat A, B and C. Vegetation not captured by polygons consist either of non-native trees or shrubs which are considered non-koala habitat (Callaghan et al., 2004; Schlagloth et al., 2006). This sub-set of a koala habitat atlas is for vegetation, on either side of the road, along a stretch of approximately 1.5 km of the Midland Highway, just south of the locality of Clarendon.

A PCA was undertaken on the full data set using PRIMER 7 (Clarke & Gorley, 2015).

A PCA projection characterises data sets in terms of the orthonormal eigenvectors of the data set's covariance matrix. A covariance matrix finds the correlation between variables in a data set. PCA finds the orthonormal eigenvectors of the covariance matrix as the basis for the transformed feature space. An eigenvalue represents the amount of variance that is accounted for by a given component (Simpkins, 2009). Higher eigenvalues in the covariance matrix point to lower correlation between the features in the data set (Wall, Rechtsteiner, & Rocha, 2003). PCA projections search for uncorrelated variables, it is a variable reduction procedure that results in a relatively small number of components that account for most of the variance in a set of observed variables; it makes no assumption about an underlying causal model (Shlens, 2014).

3.3.2 Results. A principal component analysis was conducted for all parameters within each class of radii. Overlap of radii was avoided and independence of data ensured by only choosing the points along the road with no radii overlap when selecting data for the increasing radii. The analysis in PRIMER, for all the 400 m radii (Figure 3.4), was the one showing the greatest separation of ranked data for the categories of koala roadkill (categories for numbers of roadkill was generated by PRIMER using intervals of five). The two-dimensional plot was rotated by 90^0 in PRIMER (Clarke & Warwick, 2001).

Figure 3-7 PCA in PRIMER @ 400m radius where samples show 'most clustering'. Kill categories are the number of koala roadkill in increments of 5.



It was therefore decided to analyse the correlations for variables within the 400 m radii investigation and progressively exclude variables with multiple correlations of values of above 0.8 (Manly, 2016). The final multivariate PCA analysis incorporated 29 variables, five relating to the road and traffic (Vis_NW; Vis_SE; Wid_NW; Wid_SE; Sp_Lim_NW) and six for each of the four habitat qualities (LProp_CxP; NumP_CxP; PDen_CxP; SPArea_CxP; MPSRat_CxP and MdPAr_CxP). It showed the greatest spread (Figure 3.5).

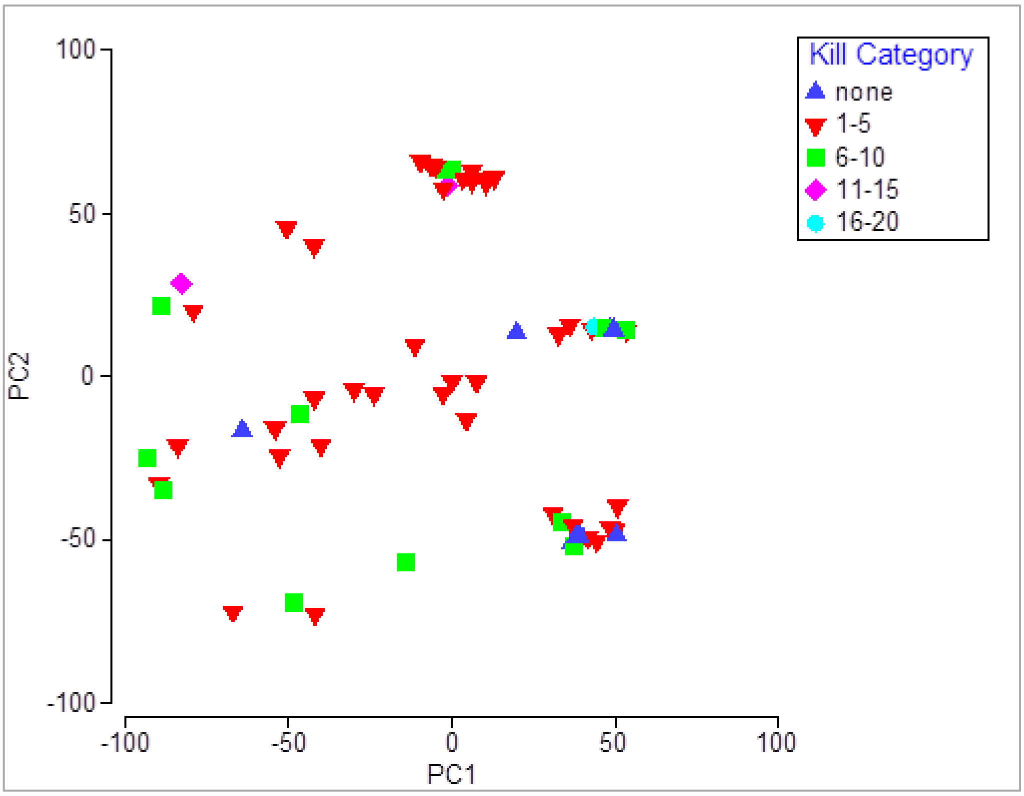


Figure 3-8 PCA in PRIMER @ 400m radius where samples show 'most spread' with number of variables reduced from 54 to 29 after exclusion of highly collineated variables. Kill categories are the number of koala roadkill in increments of 5.

Eigenvalues PC1 (32.4%) and PC2 (26.2%), together accounted for 58.6% of variation and combined with PC3 make up 75% of variation; PC4 (7.9%) (Appendix A). A Scree Test (Cattell, 1966) was performed to determine the place where the smooth decrease of eigenvalues levels off to the right of the plot, the "factorial scree". According to this criterion, factors 1-4 were retained and factor 5 was discarded (Appendix B).

Eigenvectors with a value of above 0.32 can be considered having a strong influence (Costello & Osborne, 2011; Osborne & Costello, 2009; Tabachnick & Fidell, 2001). However, other studies (Chatfied & Collins, 2013; Richman, 1988) have used different pre-established arbitrary values. Richman, (1988) used 0.30 and Chatfied & Collins (2013) nominated 0.25 as the level of significance; both authors suggest these values for ecological studies, and Chatfied & Collins add that the value is most suitable for studies using habitat or abiotic variables. This study also considered 0.25 as the cut-off value as it uses many habitat and abiotic variables.

Table 3-4 Variables and their eigenvector values for the 400 m radii. Only values above the 0.25 cut-off are shown.

Variable acronym	PC1 32.4% variation	PC2 26.2% variation	PC3 16.4% variation	PC4 7.9% variation
Vis_NW	-0.264			
LProp_C1P		0.337		
NumP_C1P		0.309		
PDen_C1P		0.320	0.260	
SPArea_C1P		0.318		
MdPAr_C1P		0.319		
MPSRat_C1P		0.310		
LProp_C2P	0.265			-0.278
NumP_C2P	0.275			
PDen_C2P	0.258			-0.313
SPArea_C2P	0.264			-0.269
MdPAr_C2P	0.273			
MPSRat_C2P	0.265			-0.260
LProp_C3P			0.293	
NumP_C3P			0.280	
PDen_C3P			0.286	
SPArea_C3P			0.271	
MdPAr_C3P			0.281	
MPSRat_C3P			0.263	
LProp_C4P		-0.280	0.256	
PDen_C4P		-0.274	0.264	
SPArea_C4P			0.263	
MdPAr_C4P			0.257	

A subsequent inspection of the Eigenvector tables for the 400 m radii (Table 3.4 and Appendix A) shows that parameters associated with Secondary A (C2P) and Primary (C1P) habitats account for the most variance, cumulatively 58.6 %. Secondary B (C3P) and Secondary C (C4P) habitat variables also show strong variance but with these found on PC4 and PC3 respectively, have a lesser importance than C1P and C2P. In particular, parameters associated with the proportion, and degree of fragmentation, of category C2P koala habitat (Secondary A) have a positive effect (i.e. favouring black spots) while two parameters (L_Prop and PDen) associated with C4P (Secondary habitat, Class C) also show a negative (-0.280 and -0.274, respectively) (favourable) effect in PC2. The driver visibility towards the north or west (Vis_NW) likewise shows a negative (-0.264) (favourable) effect.

Parameters favouring black spots for Secondary A and Primary habitats in order of importance were (Table 3.4): NumP_C2P; MdPAr_C2P; LProp_C2P and MPSRat_C2P; SPArea_C2P; PDen_C2P; LProp_C1P; PDen_C1P; MdPAr_C1P; SPArea_C1P; MPSRat_C1P; NumP_C1P. Primary habitat variable PDen_C1P featured strongly in PC3 but also, to a slightly lower extent, in PC3, while 'Secondary A' habitat variables featured strongly in PC1 and many featured with negative values, in PC4. LProp_C4P and PDen_C4P show positive significance levels in PC3 but even greater negative values in PC2; PC1-3 account for 75% of variation.

If the higher cut-off value of 0.32 is applied (Costello & Osborne, 2011), the primary habitat variables LProp_C1P and PDen_C1P are the only two that remain.

3.3.3 Discussion. The parameters which contribute to the likelihood of koalas being involved in an AVC are those related to the area, quality, and degree of fragmentation, of the habitat available to koalas. Important influence have the proportion (LProp_C1P) and patch density (PDen_C1P) of the primary habitat which is evidenced when applying a greater significance cut-off value of 0.32 (Costello & Osborne, 2011; Tabachnick & Fidell, 2001). Overall, this is expected given that in the Ballarat region and in the study site, primary koala habitat has been cleared and fragmented more extensively than secondary habitats (Callaghan et al., 2004; Januchowski et al., 2008; Schlagloth et al., 2006). However, what is somewhat surprising is that secondary habitat contributes slightly more to the threat of koalas being hit by vehicles. Although, it has been suggested that in some areas, habitat that is classified as Secondary A, might function as primary habitat, in the absence or significantly reduced availability of primary habitat (Schlagloth et al., 2006). However, when applying a lower significance value of 0.25 a trend becomes clear which shows that the greater the extent of secondary habitat class A and to a slightly lesser degree primary habitat, and the greater their fragmentation, the greater the chance of koalas being involved in an AVC. Koala densities are expected to be higher in good quality koala habitat and especially in primary habitat and studies have found that fragmentation of preferred koala habitat exposes koalas to anthropogenic stresses (Rhodes et al., 2006). Of note is that values for parameters associated with lowest koala habitat quality (Secondary C koala habitat) nominally have a larger influence than those associated with secondary habitat B, especially with LProp_C4P and PDen_C4P also featuring with high negative values on PC2. More detailed data for habitat usage by individual koalas, on a 'smaller' scale (individual trees), will be shown in Chapter four, when presenting the results from surveying koalas in one particular KRB.

Koalas are more likely to occur and persist in areas with a higher proportion of patches with contiguous preferred habitat (McAlpine et al., 2006); McAlpine et al. (2005) found that koalas are more likely to persist in landscapes with greater than 50% high quality (primary) habitat configured in large patches. Januchowski et al. (2008) found that it was essential to protect remaining core areas of high quality habitat and scattered habitat patches which provide connectivity and enhance opportunities for safe koala movement between habitat patches intersected by main roads. Smaller patches and lower quality habitat are a likely reflection of habitat loss and a fragmented landscape; these affect the availability of resources and subsequently increase the likelihood of external threats to the animals and its survival (Moon et al., 2014) and it appears, also contributes to KRBs. This is evidenced in this study by the facts that KRBs occur where KH is most fragmented. The results from this PhD research confirm the findings of McAlpine et al. (2006) that the negative effects of landscape configuration are at their greatest when habitat isolation is combined with the occurrence of roads. It is hypothesised that koalas living in lower quality KH show an increase in size of home ranges, number of tree changes and road crossings. Koalas may need to change trees more frequently and spend more time on the ground due to increased fragmentation (Fahrig, 2003); this aspect will be investigated further in Chapter 4.

Ramp et al. (2005) promote the use of habitat parameters, as it allows the identification of explanatory factors which in turn permits for species-specific management strategies to be developed and implemented at black-spot locations; these habitat parameters most definitely showed to be of great importance in the model designed for this study. However, Grimm (1999) pointed out, that without understanding the processes, models will tend to be specific to particular case studies and may not be easily transferred to other areas. Roger and Ramp (2009) promoted the benefit of using ‘habitat use’ by animals to improve the accuracy of predictive road fatality models. Therefore, the use of habitat by koalas living near KRBs needs further and more detailed investigation by radio tracking individual animals and studying their use of individual trees as it appears that broad scale mapping is only able to paint part of the picture of why and where KRBs occur.

The use of 400 m radius has shown to be a reasonable analytical unit based on PCA showing most spread’ at this measurement and considering previous radio tracking data of four koalas on a minor side road of this same highway, indicated the use of strips of vegetation of between 700 and 1000 m (radii between 350 and 500m) in length (Schlagloth, un. pub. data).

More detailed data for home range size for koalas in the study site will be shown in Chapter four when presenting the results from surveying koalas in one particular black spot.

The driver visibility towards the north or west (Vis_NW) also showed a negative effect indicating that less visibility in this direction contributed to KRBs, while parameters for speed limits, road width and visibility towards the South or East for drivers did not contribute to KRBs in this study. However, given the limitations of this study, speed and visibility cannot be totally excluded from contributing to koala roadkill. Greater visibility may result in greater speed and possibly difficulties for drivers to avoid koalas on the road; similar to school children in school zones—higher speed increases braking distance. The actual speed of traffic was not recorded nor was it available for this study site. It was assumed that drivers adhered closely to the advertised speed limits, and if vehicles were exceeding the limit, it would probably apply uniformly along the length of the road due to driver behaviour (Elvik, 2010), the uniform road condition, and surface quality of the road (Goldenbeld & van Schagen, 2007; Mannering, 2009; Warner & Åberg, 2008). The ability of drivers to detect obstacles on a road is difficult to measure, especially when the obstacle is a small, grey koala on a grey background. Brockie (2007) studying roadkill in a number of different species found no correlation between the volume of traffic and the occurrence of blackspots. Prevett et al. (1995), in a study focused on the Western Freeway to the north of this study site, found that koala road kills occurred where vehicle speeds exceeded 80km/h and where wide habitat corridors or linear forests occurred on both sides of the road. They further suggested that narrower roads increased koala mortality and that traffic volume, speed and visibility may influence the collision rate. While parameters relating to speed and width of road did not have strong influences in this study, visibility, especially in one driving direction, appear to be of concern. The fact that most traffic along this highway drives towards the sun in the morning and again in the evening, when koala movement is greatest, may play a role and warrants further investigation.

3.4 Conclusion

The study site along the Midland Highway between Ballarat and Meredith exhibited four distinct areas of high numbers of koala roadkill, the so called KRBs. These blackspots occurred in areas with the greatest degree of fragmentation of higher quality koala habitat (Secondary A and Primary). Areas with large sections of mostly fragmented Secondary Koala Habitat classes B and C (lower quality habitats) still have an influence but are less likely to have a high density of koala roadkill and are less likely to feature KRBs.

Parameters for traffic speed (speed limits) and road width do not appear to be of significance in terms of probability of becoming a road-kill victim for koalas living in this highly fragmented road-side habitat; however, driver visibility might play some role but would need to be investigated further.

It is essential that further habitat loss and fragmentation must be countered and targeted revegetation with strategically placed koala habitat species be implemented to redress the loss in individual animals. New roads should not cross Secondary A and Primary koala habitat and existing roads should be modified at koala road-kill blackspots to prevent further AVCs.

The modelling approach taken in this Chapter appears to be a good tool to predict KRBs; as it incorporates habitat use for the species. It is essential to further include detailed radio tracking of individual animals and studying their use of individual trees to complement the model. Such investigation, examining detailed habitat use, will be conducted in the following Chapter to refine their conservation requirements.

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Chapter 4. An integrated study into a Koala road-kill black spot

4.1 Introduction

The focus of the previous Chapter was on establishing the existence of koala road-kill blackspots along the Midland Highway near Ballarat. This Chapter examines in detail the activities of a group of koalas at one of these blackspots. This group of koalas was studied along the highway in a section of about 2 km south of the township of Meredith. This Chapter looks at habitat and tree use (for rest, shelter and fodder) as well as movement (home range and road crossings) and informs the later conceptualisation of black-spot dynamics.

An extensive description of the characteristics of blackspots was given in the previous Chapter; here I describe the characteristics of the habitat found in areas deemed as blackspots.

4.1.1 Habitat in blackspots. Clements et al. (2014) state that habitat destruction is a major driver of mammal population declines and extinctions; working in tropical forests, they found that construction of roads can be a catalyst for such a threat. Some previous studies e.g. by Brockie (2007) make no reference to the importance or impact that the type of habitat or vegetation present at a black spot has to the number or type of AVCs. However, others point to a relationship between roadkill and fragmentation of habitat caused by the construction of roads, and/or the availability of food close to roads, as in the case of kangaroos (*Macropus* spp.) (Cook & Blumstein, 2013; Klöcker, Croft, & Ramp, 2006). A study on wallabies (*Macropus giganteus*) has shown a link between preferred habitat dissected by roads and an increase in roadkill compared to similar habitats dissected by fewer roads (Clevenger, Chruszcz, & Gunson, 2001; Coulson, 1989; Gomes, Grilo, Silva, & Mira, 2009; Ramp & Coulson, 2002). Barthelmess and Brooks (2010) argue that the feeding strategies of a species may have an effect on road-kill vulnerability; this has also been found by Ford and Fahrig

(2008). Brehme, Tracey, McClenaghan, and Fisher (2013) have shown that micro-habitat use preferences are likely to be a factor affecting species' response to roads. Ramp, Caldwell, Edwards, Warton, and Croft (2005) further suggest that habitat surrounding the road may be acting as a road-kill sink where habitat that becomes vacant due to the resident animals having been killed by vehicles, will quickly be resettled by animals occupying adjacent inferior habitat. In the case of koalas, the presence of fodder versus non-fodder and quality of fodder trees and fragmentation of habitat seem to increase the likelihood of roadkill (Department of the Environment, 2009; Rhodes et al., 2011). However, insufficient fine-scale analysis of habitat variables associated with areas of high numbers of koala roadkill has been completed to date, and Preece (2007) highlights the need for more research into whether it is possible to accurately predict koala road-kill blackspots using environmental or other variables.

4.1.2 Diet. The koala is one of the few species of mammal that is both arboreal and folivorous (Cork, Clark, & Mazur, 2000). Life in trees requires small body size, but small mammals generally have difficulty meeting energy requirements from poor-quality leaf diets (Cork & Foley, 1991). Consequently, the koala's ecology and physiology reflect the need to conserve energy (Hindell & Lee, 1990). Their rate of metabolism and therefore their energy and nutrient requirements are lower than those of most other mammals (Krockenberger & Hume, 2007). Koalas are larger and less mobile than expected for a strictly tree-living animal but are smaller than expected for a mammal that eats only leaves.

Throughout their range, koalas feed on a highly selective diet of leaves from *Eucalyptus* trees but eat only a small proportion of the over 700 species of trees in this genus. Hindell, Handasyde, and Lee (1985) reported that the koala in Victoria is known to feed on only a few species within the *Eucalyptus* genus and that they even showed a preference for individual trees within a species; however, Hindell and Lee (1988) also emphasised that any lists showing koala food tree preference were of little practical use in deciding whether trees from a particular area are palatable. At least 35 species of eucalypts are known to be browsed by koalas (Degabriele, 1981); however, Blanshard (1994) puts the number of *Eucalyptus* species that koalas regularly feed on as high as 40–50 but emphasised that although individual animals may utilise the foliage of other *Eucalyptus* from time to time, most of these are not considered to be a primary food resource. Other literature reports that koalas eat around 80 different *Eucalyptus* species across their range with two to five species being preferred within a certain region (Pahl, Wylie, & Fisher, 1990; Phillips, 1990). In Victoria the most preferred are *Eucalyptus viminalis* subsp. *viminalis* (Manna Gum) and *E. ovata* (Swamp Gum) (Santamaria, 2002). This preference, however, may change seasonally (Hindell & Lee, 1990). Hindell and Lee (1990) observed that captive koalas show a temporal difference in preference. Species preference may also differ between the sexes (Hindell & Lee, 1987); the authors suggest that this may be a consequence of social organisation. Locally, it might be slightly different. For example, in Ballarat, *Eucalyptus viminalis* subsp. *viminalis* (Manna Gum) was relatively scarce and koalas shifted their preference to *E. obliqua* (Messmate Stringybark) (Santamaria, Keatley, & Schlagloth, 2005). Three other *Eucalyptus* species, *globulus* ssp. *globulus* (Blue Gum), *baxteri* (Brown Stringybark) and *viminalis* ssp. *cygnetensis* (Rough-barked Manna Gum) were also used significantly and classified as ‘secondary’ koala food tree species in the Koala Plan of Management for Ballarat (Schlagloth, Thomson, & Mitchell, 2006); often koalas will exhibit a preference for the foliage of individual trees within the same species (Hindell & Lee, 1990). Moore and Foley (2005) found that plant chemistry, in particular nitrogen levels and formylated phloroglucinol compounds (FPC) in leaves as well as size of trees, restrict the use of trees by koalas. In fact, high concentrations of FPCs and low concentrations of nitrogen are limiting factors in the choice of trees within a species (Degabriele, 1983). The author also found koalas using trees of larger-than-average size; in these trees, the mean FPC concentrations were significantly lower and mean nitrogen concentrations were significantly greater than expected. Moore, Lawler, Wallis, Beale, and Foley (2010) also found that there was a positive correlation between size of tree and FPC and a negative correlation with nitrogen. These characteristics could be limiting factors for food availability and may have the potential to negatively affect koala populations. Lawler, Foley, and Eschler (2000) previously found similar principles apply to possums when selecting individual food trees. Moore et al. (2010) found that foliar quality is spatially structured at a scale significant to foraging decisions by koalas and that the spatial structure affects habitat quality. Consequently, the number of koalas that a given area can support is a function of the density of preferred browse tree species and the frequency of palatable or nutritious individual trees of those species. Some researchers argue that this preference has often led koalas to defoliate *E. viminalis* and sometimes *E. ovata*, while leaving other tree species more or less untouched (Hindell & Lee, 1990; Martin, 1985). Exact preferences are difficult to establish as choice of browse can differ between seasons, change over relatively small areas, between individuals and sexes and even the time of day (Ellis, Melzer, Carrick, & Hasegawa, 2002; Martin & Handasyde, 1999; Melzer & Houston, 2001; Woodward et al., 2008).

The highly fastidious nature of koalas is well known (Cork, 1987; Hindell & Lee, 1987); it is considered the most specialised arboreal folivore as almost all of its food and water requirements come from the tree genus *Eucalyptus* (Degabriele & Dawson, 1979). Eberhard, McNamara, Pearse, and Southwell (1975) reported that the koalas consumes approximately 410 grams of leaves per day and that the digestibility of the leaves is approximately 60%. The foliage from *Eucalyptus* species is generally regarded as being of low nutritional value (Hume, Foley, & Chilcott, 1984). By far the majority of browse consumed by koalas comes from the leaves, but they are also known to consume the bark, buds, fruit and flowers from the tree in which they are feeding (Hindell et al., 1985; Lee & Martin, 1988; Melzer, Cristescu, Ellis, FitzGibbon, & Manno, 2014). Mature leaves contribute significantly to the diet of koalas, particularly when the production of fresh, new leaves is low. The koalas eat only one leaf at a time. According to Lee and Martin (1988) each leaf is chewed four to nine times between the molars on one side before it is moved to the other side of the mouth, with the tongue, to repeat the operation. *Eucalyptus* foliage is a poor, but predictable, supply of energy and nutrients. The koala is dependent upon having a consistent supply of foliage of adequate quality. Even though the *Eucalyptus* foliage is such poor food it is remarkably consistent in quality throughout the year. There have been many reports of koalas feeding non-*Eucalyptus* trees and even introduced species like pines. Hindell et al. (1985) point out that koalas were found in acacias but that the most preferred species was still *E. viminalis* when available. Strahan and Martin (1982) also observed ingestion of acacia and tea-tree (*Leptospermum laevigatum*) leaves. Frequent usage of conifers, by koalas in the Ballarat area has been observed by Munro (1989) and this was believed to be for shelter from adverse weather conditions. However, Lithgow (1982) as well as Hindell et al. (1985) have noted the ingestion of non-eucalypt species, especially *Pinus radiata*. Further, they are of the opinion that koalas have occasionally been observed eating the foliage of non-eucalypt species, but believe that except in isolated cases these do not seem to be significantly used as food trees. Other reports of the consumption of non-eucalypts by koalas were made by several researchers; Degabriele (1973) found koalas feeding on Native Kapok (*Bombax malabrica*), Pearse and Eberhard (1978) on Brush Box (*Lophostemon confertus*) and Swamp Mahogany (*Lophostemon suaveolens*), and by Ough, Handasyde, Martin, and Lee (1988) observed them feeding on Swamp Paperbark (*Melaleuca ericifolia*).

Fossil records for the koala extend as far back as 15 million years ago and the genus *Eucalyptus* has been identified in fossil beds dated at 20 million years ago (Hume, 1990). There exists an evolutionary advantage to the koala here because *Eucalyptus* foliage is of such poor food quality that there would be very little competition for the leaves. The trees are also evergreen providing a constant supply of food all year, and the high water content of the leaves meets all the physiological requirements of the koala (Lee & Martin, 1988). Hindell et al. (1985) found that koalas ate nearly all the leaves within their reach, and that young leaves were not actively sought out; however, branches of young foliage were usually stripped bare, but only a proportion of the mature leaves were consumed from branches. Although the koala consumes more mature foliage than do other marsupials, they seem to prefer younger moister leaves (Cork, Margules, & Braithwaite, 1988). This has only been observed in captivity and therefore cannot be assumed to be the same for wild populations.

Due to its feeding specialisation and low content of available energy in the foliage of eucalypts (Cork et al., 2000), koalas must feed frequently and are likely to cope poorly with disturbances that reduce the availability of food or increase foraging effort (Hume & Esson, 1993); for this reason they might be forced to move more frequently and spend more time on the ground.

Habitat fragmentation has also been shown to contribute to the nutritional stress of koalas and increase susceptibility to *Chlamydia* (Hume, 1990).

There is not always a clear association between tree use and diet, as for most of the koala's range it has been suggested that the tree it occupies during the day or night and where its faecal pellets are found underneath, signifies such tree to be a browse tree of that particular animal (Ellis, Melzer, et al., 2002; Hindell et al., 1985; Melzer, MacLennan, & Lamb, 1995; Prevett, Pope, Callaghan, & Bailey, 2001). Melzer et al. (1995) and Melzer et al. (2014) have shown that in Queensland this might not always be the case. This was shown by the use of direct observation of feeding and leaf cuticle analysis of koala faecal pellets.

4.1.3 Soil fertility and foliage. It is thought the trees koalas prefer to browse from may be determined by the quality of the soil beneath the tree. Independent surveys have all concluded that the highest population densities of koalas and other arboreal marsupials were found in forests which grew on high nutrient soils with undulating landform, whereas areas of low nutrient forest have only contained low densities of arboreal marsupials (Cork, Margules, & Braithwaite, 1990). A survey on NSW koala populations has established that 76.4% of these animals browse on *Eucalyptus* species associated with land that supports medium to high grazing densities of sheep and cattle (Reed, Lunney, & Walker, 1991). Radio tracking surveys by Prevett (1989) in the Ballarat area have shown high concentrations of koalas browsing on *Eucalyptus* trees located in domestic gardens which are generally well fertilised and watered. Hindell and Lee (1987) have previously mentioned that well-watered areas produce high quality habitat for koalas. Other studies, however, by Braithwaite, Binns, and Nowlan (1988) show only marginal correlation between soil nutrient levels and foliar concentrations. Cork (1992) argues that fodder quality may have a bearing on habitat selection as well as fodder selection. Under the resource availability hypothesis (Bryant, Reichardt, Clausen, Provenza, & Kuropat, 1992) higher nutrient soils produce fodder with lower concentrations of digestibility reducing polyphenols. Consequently, the better quality soils would support a habitat of better quality for herbivores. Reed et al. (1991) in a broad scale but qualitative examination of the distribution of the koala in NSW, suggests that koala populations might be greater in tree communities that grow in richer soils. Hindell (1984) and Phillips (1990) support this idea but as yet there seems to be no conclusive evidence for it. The foliar nutritional characteristics of *Eucalyptus* communities could be another habitat attribute to use when describing the distribution of koalas. Degabriele (1983) proposed that the availability of nitrogen was the limiting factor for the abundance and distribution of koalas but Cork et al. (1990) argued that it was unlikely for any one parameter to be generally limiting and postulated that koalas prefer *Eucalyptus* communities with high concentrations of foliar nitrogen, phosphorus and potassium and that these concentrations reflect the availability of these elements in the soil. Cork (1992) argued further that the concentration of polyphenolic anti-herbivore compounds in *Eucalyptus* foliage increases as the concentrations of nutrients in the leaves decreases. He considered that the absence of koalas from some *Eucalyptus* communities on poorer soils could be partly explained by relatively high foliar concentrations of polyphenolic compounds. The Koala Preservation Society (1987) believes that occasionally, the koala supplements its usual diet of gum leaves by ingesting earth in order to adjust deficiencies of minerals in its diet. Koalas occasionally ingesting termite mounds (C. and J. Lewis, pers. comm., 2013; Toogoolawah in Melzer et al. 2014) and soil (A. Melzer, pers. comm., Springsure 2013 CQU, F. Carrick, pers. comm., Brisbane 2013 UQ in Melzer et al. 2014) has also been reported. Soil has been used in the rehabilitation of koalas exhibiting gastrointestinal issues (A. Gillet, pers. comm., 2013 Australia Zoo Wildlife Hospital in Melzer et al. 2014).

4.1.4 Koala habitat types. The types of trees that are preferred by koalas determine the types of habitat that koalas favour. Habitat utilisation and tree species preferences of koalas are usually assessed using plot-based surveys and, apart from direct observations of koalas, may involve the detection of koala scats from underneath individual trees (Phillips, Callaghan, & Thompson, 2000).

The survey methodology involves random stratified plot site selection, in conjunction with targeted surveys to sample the range of edaphic and floristic variables to the fullest extent possible and to ensure that statistically useful data sets are compiled for each tree species.

The methodology is detailed in the Ballarat Koala Habitat Atlas (Callaghan, Mitchell, Thomson, & Bailey, 2004) and in Phillips and Callaghan (2000).

The Ballarat Koala Habitat Atlas (Callaghan et al., 2004) identified the extent and distribution of koala habitat in the city based on a categorisation of the forest and woodland communities in terms of the relative abundance of preferred tree species in conjunction with the soil types. It was found that in the City of Ballarat, Manna Gum, *Eucalyptus viminalis ssp. viminalis* was the preferred food source of koalas. However, it was identified that the relative lack of this species within the municipality meant that Messmate Stringybark, *E. obliqua* was utilised extensively by koalas as a substitute food source. These two tree species were described as ‘primary’ koala food tree species and constitute the preferred koala food trees in the City of Ballarat. Using the same methodology as part of a SPIRT project (Rhodes et al., 2008), which mapped koala habitat in the Moorabool Council and Golden Plains Shire within a five kilometre buffer around the Ballarat, and as part of the Koala Habitat Atlas project for the Golden Plains Shire (Australian Koala Foundation, 2008), the additional species of *E. camaldulensis* (River Red Gum) and *E. globulus spp globulus* (Tasmanian Blue Gum) were confirmed as primary food tree species for these areas. *E. ovata* (Swamp Gum) and *E. pauciflora* (Snow Gum) were identified as likely primary species for this area.

4.1.5 Scat analysis. Most studies that focus on the diet of folivorous marsupials are based on observing the animal sitting in a tree of a particular species and consuming leaves of this tree (Tun, 1993) or on captive animals that are fed with a selective diet of leaves of a certain species (Cork, 1986; Pahl & Hume, 1991). Many such studies (Moore & Foley, 2005) focused on leaf composition in an attempt to determine species preference or even preferential selection of individual leaves for marsupials and especially koalas, to browse.

Such studies (DeGabriel, Moore, Marsh, & Foley, 2010; Lawler, Foley, Eschler, Pass, & Handasyde, 1998; Southwell, 1978) often analysed the chemical compounds of leaves and some identified substances that may contribute to their unpalatability (Hume & Esson, 1993; Lawler et al., 2000) and therefore avoidance (Moore, Foley, Wallis, Cowling, & Handasyde, 2005; Moore et al., 2010). For example, Pass, Foley, and Bowden (1998) identified macrocarpals, a sub-group of diformylphloroglucinols, as the likely cause of unpalatability in *E. ovata* for koalas. Some authors argued that such unpalatability or toxicity can influence the distribution of the koala (Cork & Catling, 1996; Lawler et al., 2000). It is erroneous to rely exclusively on daytime observations of individual koalas eating leaves from certain *Eucalyptus* species or animals sitting in certain trees, to determine food tree preferences. Ellis, Melzer, et al. (2002) pointed out that koalas in their study did not always eat from those species that they were observed in during the day, or at least, not to the extent expected when considering the number of times they were detected resting in a certain tree species. Hasegawa (1995) also advised against the use of faecal pellets presence as a determinant of diet preference; however, he recommended the technique to define tree use. Phillips (2000) used faecal pellets evidence found under trees to develop a technique to indicate dietary preference; however, Ellis, Melzer, et al. (2002) believed it not to be suitable to determine dietary preference, indeed they considered indirect evidence for choice of diet such as daytime roost tree selection or presence of scats, only to be useful indicators in heterogeneous habitats such as in studies that Eberhard (1972) or Mitchell (1990) conducted.

Examining faecal pellets using microscopic analysis (Ellis, Carrick, Lundgren, Veary, & Cohen, 1999; Hasegawa, 1995; Tun, 1993) of leaf material, in particular the mean size and density of the stomatal complex, appears to be the most reliable method to discriminate between the various fodder species of the koala.

There is no difference in the digestibility between plant species found in koala scats. Studies have reported differential digestibility only between differing feed groups (grasses, browse, forbs and chenopods) (Herron, 2002) or perhaps with different plant parts (leaves, stems, flowers, roots) (Wu, McAlpine, & Seabrook, 2012). The koala mostly eats from within one feed group and one group of plant parts which are scleriferous leaves, and Cork and Sanson (1990) as well as Foley (1992) pointed out that any differential digestibility may be caused by differential identifiability; something that has been considerably improved upon by the development of scanning electron microscopy (De Munk, 1999).

The amount of expulsion of particulate matter along the digestive tract decays exponentially from the time of consumption, thus it is not possible to say when all of an ingested sample will be excreted. However, according to Cork and Warner (1983) detectable amounts should exist 13 hours to 10 days after ingestion, with 50% of the sample species should have emerged 48 to 78 hours and occasional possible identification at least 15 days after ingestion.

4.1.6 The pro and cons of corridors. The movement of animals among populations is an important aspect of wildlife ecology (Stenseth & Lidicker, 1992) and it has been described as "the glue that holds local populations together" (Hansson, 1991). Without adequate movement of individuals and hence genetic exchange between populations, the likelihood of local extinction increases (Fahrig, 2001). Most metapopulations exist in a dynamic system of local extinction and re-colonisation (Cramer & Portier, 2001), the latter of which depends on migration among populations. In the case of the koala, especially in Victoria (Menkhorst, 2008), this could not be of greater importance.

Roads present a difficult management issue for decision makers in balancing the human needs for an efficient transport system with the need to protect the environment and wildlife. Apart from the many negative issues mentioned in section 2.3, roads can be of value to wildlife. In fact, the vegetation alongside the road can function as wildlife corridor between previously fragmented areas (Downes, Handasyde, & Elgar, 1997; Fortin & Arnold, 1997), but more often have negative consequences (Trombulak & Frissell, 2000).

In the broadest view, wildlife corridors enhance population dynamics by decreasing fragmentation of the habitat via increasing the total amount of habitat in a landscape, as well as linking previously isolated habitat patches. The most commonly studied corridors are facilitated movement corridors that enhance connectivity for a particular species (Pardini, de Souza, Braga-Neto, & Metzger, 2005). Fragmented landscapes are characterised by spatially isolated populations. The establishment of wildlife corridors has become a popular method for increasing connectivity (Pirnat, 2000). The main limitation of wildlife corridors is that they are subject to edge effects and therefore their effectiveness as a corridor in facilitating species movements is very species-specific and is also affected by the nature of the surrounding areas (McAlpine & Eyre, 2002). Native mammals are the most disadvantaged vertebrates in remnants with few species surviving the effects of long term fragmentation (Bender, Contreras, & Fahrig, 1998; Fahrig, 1997, 2001). Bentley and Catterall (1997) argue that for reptile species, there is a strong correlation between remnant area and species number; small remnants are important for bushland-dependent residents that are most abundant in continuous bushland and least abundant in linear remnants. May and Norton (1996) argue that fragmentation influences the potential impact of feral predators on native fauna in Australian forest ecosystems by increasing exposure to the predators. Bennett (1990) found that introduced and native mammals residing in fragmented habitats in south-western Victoria used the corridors for movement between patches, the native species were most affected by fragmentation and therefore he suggested that corridors were an important component when considering conservation strategies for native species. In a study using experimentally fragmented and connected habitat patches, Bowne, Peles, and Barrett (1999) found that although corridors appeared to be the preferred route for the dispersal for cotton rats, there were no statistically significant differences between the number of individuals moving between connected and unconnected patches. Tigas, Van Vuren, and Sauvajot (2002) report on bobcats and coyotes in fragmented urban areas that used corridors as habitat and, less often, as corridors. If such potential corridors are used as permanent habitat by individuals of a species, it will be difficult for other individuals of the same species, or even of other species, to move through the corridors due to reluctance to enter competitor or predator territories. The response to isolation depends largely on the species' ability to traverse the existing matrix, which in urban areas is often hostile for many native species. For example, in the case of the koala, the presence of cars and dogs can impact on their moving from one isolated patch of habitat to another (Dique, Preece, Thompson, & de Villiers, 2004).

One objective, in part at least, of the proposed research, is to examine how koalas use road-side habitat along a highway by investigating whether they use this vegetation as a corridor or as a permanent habitat.

Much of Ballarat's native vegetation has been lost or severely altered since European settlement and now appears in smaller remnants, areas of regrowth and as road-side corridors (Milne, D'Ombrain, & Leversha, 2005); consequently in many parts of Ballarat and surrounding areas, koala habitat is part of a highly fragmented landscape.

This loss of habitat affects species survival by restricting habitat available for colonising and, may have particular consequences for large home range species that require sizeable habitat areas (Siffczyk, Brotons, Kangas, & Orell, 2003).

Habitat fragmentation, on the other hand, is a form of habitat loss that primarily alters the spatial arrangement of habitat patches. The fundamental mechanisms of this process include increases in the total number of patches, patch isolation and shape variation, as well as a decrease in mean patch size. McAlpine et al. (2006) found that the conservation of koalas and other forest-dependent species is negatively affected by habitat fragmentation. Road networks, patchy habitat and the increased distance between these patches all led to a decrease in koala numbers. It is important to understand how koalas use these fragmented landscapes (McAlpine et al., 2006) and this aspect will be investigated in this Chapter.

Mount Buninyong and its surrounds are widely known to contain the largest areas of the small patches of primary habitat left within the Ballarat region (Schlagloth et al., 2006). In these areas, koalas are easily observed because of their presumably high numbers per hectare and it is from here that many young male koalas disperse every year during the breeding season (Prevett, 1989). The areas also contain a network of smaller and larger roads with koala habitat alongside these roads forming corridors colloquially known as 'koala corridors'. The Australian Museum Business Services (Semeniuk, Close, Smith, Muir, & James, 2011) in its investigation of the impact of roads on koalas found that most of the areas with high numbers of koala roadkill were within a short distance of some form of open corridor (a passage without dense vegetation of shrubs or trees) that leads onto the highway. Lassau et al. (2008) interpreted this as indicating that koalas disperse along tracks (to avoid obstacles) that then leads them onto the highway.

This is also an interesting aspect to investigate if koalas actively avoid obstacles, including dense habitat, when moving through the landscape in preference for open space.

4.1.7 Home ranges. Koalas are essentially solitary animals whose home ranges are typically 3 ha in size in Victoria, but can range between 1 and 50 ha in that state, depending on the quality of habitat (Mitchell, 1990). Comparisons of home range between the southern and northern limits of the koala distribution show considerable variation. The home ranges of koalas in Victoria are small and clustered and often overlap (Melzer & Houston, 2001); in contrast, home ranges of Central Queensland koalas are widespread, large and have minimal overlap (Melzer, 1995). Mitchell (1990) postulated that range area was positively correlated with population density and inversely correlated to the density of preferred trees.

Moreover, differences in home range size between males and females have been established (Mitchell, 2008). A dominant male's range usually overlaps with those of several females and young, to which the male maintains access during the breeding season (Lee, Martin, & Handasyde, 1990). In New South Wales, Lassau et al. (2008) describes home ranges for male koalas to be around 23 ha and females nearly 10 ha; Kavanagh, Stanton, and Brassil (2007) have found home ranges of 12 ha and 9 ha for males and females respectively in a *Callitris-Euclayptus* forest; while Ellis, Melzer, et al. (2002) have found home ranges of around 135 ha for males and around 101 ha for females at Blair Athol in Central Queensland. These differences in size of home ranges are generally believed to be related to differences in quality of habitat and availability of preferred fodder species (Goldingay & Dobner, 2014; McAlpine et al., 2006).

4.1.8 Social behaviour and home ranges. Koalas are seasonal breeders with the majority of births occurring in summer (Martin & Handasyde, 1999). Victorian female koalas are sexually mature when they are around six kilograms or 24 months of age. From indirect evidence (Martin & Handasyde, 1999), it appears that male koalas are also sexually mature at around two years of age but, because of competition from larger males, their mating might be limited to as late as four or five years of age. The social behaviour and social organisation of the koala have been studied widely for many years (Eberhard, 1972; Mitchell, 1989; Sharpe, 1980; Tucker, Melzer, & Ellis, 2008). Koalas are sexually dimorphic with males having larger body size and, in the wild, are solitary, showing little association with other koalas

(Mitchell, 1989; Sharpe, 1980). They live in circumscribed home ranges, and may use these during successive years. Home ranges may overlap extensively within both sexes (Lassau et al., 2008; Mitchell, 1989; Sharpe, 1980). Mitchell (1990) reports that during the breeding season movements were more frequent and home ranges were larger. The social structure appears to be organised around a male dominance hierarchy (Ellis, Hale, & Carrick, 2002; Logan & Sanson, 2003; Mitchell, 1989; White, 1999). Vocalisations and scent marking are prominent aspects of koala behaviour and are probably important in maintaining the social structure (Charlton et al., 2011). Mitchell (1990) found that home range sizes were affected by the density of large trees, and possibly by population density.

4.1.9 Home range analysis. Eberhard (1978), Sharpe (1980), Hindell (1984), Hull (1985) and Ellis, Melzer, and Bercovitch (2009) described the home ranges of koalas using a variety of methods, but only Eberhard, Sharpe and Ellis attempted to analyse spatial and temporal overlap between koalas. The preceding authors described koalas as inactive and solitary, with restricted home ranges. Koalas live in trees which can be represented by points on a plane: home ranges can therefore be described by the distribution of sightings at these points over a given period of time, with no mathematical modification (Eberhard, 1978). There are two broad categories of methods used to calculate home range area: non-statistical and statistical. Sanderson (1966) reviewed in detail non-statistical methods such as minimum area method, boundary strip method, and range length. Statistical methods include standard diameter, probability circles and probability ellipses which have been discussed by Metzgar (1972) and Van Winkle (1975). Most animals do not utilise their entire home range area with equal intensity, instead occupying certain areas within their home range with greater frequency (Dixon & Chapman, 1980). This is taken into account by the statistical methods which generate a more refined home range estimate which reflects the intensity of use compared to non-statistical methods. Statistical methods produce contours around the centre of greatest activity based on a statistical distribution of activity loci. The position of each locus can be determined using either the arithmetic or harmonic mean centre (Dixon & Chapman, 1980). The harmonic means is unlike the arithmetic mean centre and is always located inside the area of animal activity, is not strongly biased by extreme locations in the home range, and is not over-sensitive to slight movements within the home range (Dixon & Chapman, 1980). The Ranges IV program (Kenward, 1990) allows the investigator to choose the degree of resolution/accuracy for each analysis, with the maximum resolution being (40m x 40m). Home range size is influenced by the number of locations used to define it. If too few are selected, home range dimensions will be underestimated (Odum & Kuenzler, 1955). Kenward (1990) suggests that the contour selected to define a home range should asymptote when the last 10 fixes are used and increase the home range area by less than 10%. The contour chosen to define an animal's home range is often arbitrarily defined as the 95% isopleth, often with no biological justification (Anderson, 1982).

4.2 Study Area

The study was conducted along a section of the Midland Highway traversing parts of the local government areas of the City of Ballarat, Golden Plains and Moorabool Shires in Western Victoria (Figure 1.2 a & b in Chapter 1). Much of its native vegetation has been cleared since European settlement for goldmining, agriculture and more recently for housing. However, one of the main highways, linking Ballarat with Geelong runs through parts of the most important koala habitat in Ballarat and surrounding municipalities. The focus of this Chapter was on one specific area along this highway close to the township of Meredith. It included all remnant patches of native vegetation on both sides of the road (approximately 1000 metres on either side) along a stretch of four km of the highway. This area was identified in Chapter 3 as a Koala Road-kill Blackspot (Figure 3.3—heat map in Chapter 3 and Maps 1 & 9 in Appendices C & D)

4.3 Question

The demonstrated existence of nodes (KRBs) of relative high frequency of koala road kills was demonstrated in Chapter 3.1 and it raises the question of what causes an increased likelihood of AVCs at these points? In Chapter 3.2 it was found that parameters showing strong influence on the occurrence of KRBs are related to the area, quality, and degree of fragmentation, of the habitat available to koalas and findings from Chapter 2 suggest that male koalas are more likely to be involved in AVCs, probably because they have greater home ranges and change trees more frequently.

In particular, this Chapter addresses the question:

1) How do koalas use habitat near a black spot?

In order to effectively address this question and to contribute knowledge to koala ecology and inform koala management, the objective for this Chapter is:

> To conduct an integrated investigation of koalas living near a black spot and in particular to examine how koalas use the road-side habitat.

4.4 Methods

4.4.1 Procedure for mapping of habitat. As the study area was relatively small, with mainly linear vegetation, and the location and species of each tree was important, an attempted was made to identify each individual tree.

Aerial photographs of the area were scanned into the program MapInfo (various versions up to 12.5.). By enlarging the image on the screen and printing it, individual trees became visible (see Map 1, Appendix C). Accurate maps with road systems of the area were scanned into MapInfo and aerial photos were overlayed with these. High accuracy was achieved by selecting reference points such as fence posts or houses from the aerial photo on the computer and checking them in the field. A Global Positioning System (GPS) receiver hired from the State Data Centre in Ballarat was used to record those points (accuracy ± 5 metres). The computed positions were expressed in Australian Map Grid Coordinates which are based on the Universal Transverse Mercator (UTM) map projection (National Mapping Council of Australia, 1972). The UTM system is based on rectangular coordinate system and is thought to be more accurate than a circular coordinate system, such as latitude and longitude when surveying over a limited area (White & Garrott, 1990, 2012). A triple Pathfinder Basic Plus GPS unit was used to record signals produced by all satellites in view of its external receiver. The receiver's external antenna was mounted on a telescopic range pole to enable accurate readings above any obstructing vegetation.

Two to five metre (circle of error probability) accuracy can be obtained by performing differential correction on the data. This is achieved by using a Base Station which consists of a second GPS receiver stationed over an accurately surveyed point. Since the position of this point is known, any divergence in the computed position for the base station can be attributed to GPS system error both imposed and occurring naturally.

With the help of the staff at the State Data Centre Ballarat and software the collected data were to within a two to five metre accuracy margin. The results were further optimised by taking at least 80 readings for each survey point.

Over a period of two months, every tree in the study site over the diameter at breast height (DbH) of 10 cm was identified on the map as well as on the ground and its location marked on the MapInfo database. Different colours, sizes and symbols were used to display the various species and their sizes. Each tree was assessed for species, DbH, height and maturity (McDonald, Isbell, Speight, Walker, & Hopkins, 1998) as well as numbered and marked. This extensive survey was conducted with future, detailed studies in mind. Each tree was also assessed for evidence of koala use. Proof of usage was determined either by observing an animal in the tree, claw marks on the trunk or scats under the tree. All these details were entered into a spatial (Map 1, Appendix C).

4.4.2 Koala survey.A team of 15 people searched the vegetation in the study site for koalas. During one day, every koala found was captured with pole, flag and noose as well as canvas bag (using a cherry-picker for tall trees). Some trees were also scaled and a tether was secured to the koala encouraging it to descend by waving a flag tied to a pole above the animal's head. The tether was routinely attached to a long pole, by which means it was able to be placed over the koala's head by a person a few metres away. Constant tension placed on the tether by a person on the ground holding a rope attached to the tether ensured that the koala was unable to ascend the tree during the capture process. Once close enough to the ground the koala was held by the nape of the neck and rump, secured in a canvas bag. The koala was fitted with a collar which had a radio transmitter attached (Tidey Electronics, Ballina, NSW) operating in the 150MHz to 152MHz band (Figure. 4.1). The collars were adjusted to ensure an adequate fit (two fingers between collar and neck) for each koala. The transmitters were housed in a double ended aluminium canister with the antenna affixed to the collar with electrical tape or covered in resin. Each transmitter had a battery with an expected life of eight to 12 months. These animals were then monitored for a period of 18 weeks using radio telemetry utilising a Titley Electronics telemetry receiver (Regal 2000) (Figure 4.2). A total of seven koalas were captured and monitored.

Figure 4-1 Koala with fitted radio-collar

Figure 4-2 Researcher using radio telemetry receiver.

For the first six weeks koalas were radio tracked three times per day in order to determine:

- their use of trees during the day;
- the effect of weather on tree preference and movement;
- their home ranges and feeding preferences; and
- the frequency and the outcomes of koalas crossing the road.

For the next six weeks koalas were radio tracked once per day in order to determine:

- their home ranges and feeding preferences; and
- the frequency and the outcomes of koalas crossing the road.

For the last six weeks koalas were radio tracked every third day in order to determine:

- their home ranges only.

All animals were recaptured at the end of the study and underwent a health check; the obtained data were also shared with other studies.

4.4.3 Home ranges. To determine the position of each range locus, the harmonic means was used, since unlike the arithmetic mean centre it is always located inside the area of animal activity (Dixon & Chapman, 1980). Also, using the program Ranges IV (Kenward, 1990) maximum resolution (40x40) was selected which allows for greatest accuracy. The isopleths from 50% to 100% in increments of 5% were displayed, where possible, in order to underline the concentrated use of certain habitat.

The program was not used to determine the percentage overlap of home ranges as the habitat was fragmented and patchy and not comparable to a continuous forest habitat.

4.4.4 Koala habitat within individual home ranges. For the purpose of refined analysis of habitat use and species preferences by individual koalas, habitat within each koala's home range (90% isopleth) was categorised as being comprised of either primary or secondary habitat. The following standard categories of koala habitat were recognised:

Primary habitat

Areas of forest or woodland where primary koala food tree species comprise at least 50% of the over-storey trees.

Secondary habitat

Areas of forest or woodland where primary koala food tree species comprise less than 50% but at least 30% of the over-storey trees;

or

Areas of forest or woodland where primary koala food tree species comprise less than 30% of the over-storey trees, but together with secondary food tree species comprise at least 50% of the over-storey trees;

or

Areas of forest or woodland where secondary food tree species alone comprise at least 50% of the over-storey trees (primary koala food tree species absent).

Primary and secondary food tree species for the study site are outlined in section 4.1.4.

4.4.5 Tree usage and feeding preferences. The numbers of trees of each species, used by each koala, were extracted from the MapInfo database and the frequency of use expressed in percentages. These results were compared to the actual feeding preferences established by scat analysis and to the number of trees available to each koala within its home range.

4.4.6 Scat analysis. Fresh scats from each koala were collected every three days for a total of 12 weeks. Only scats that could be positively identified as coming from a particular animal were used.

A reference collection from all 52 tree species present in the study site was created.

A scanning electron microscope method for identification of plant fragments in faeces was used to establish the relative percentage consumption of each species for each koala. This method was designed by Chris Allen from the University of Sydney and the samples were analysed by him; no observable differential digestibility was expected in this study because of the use of this technique. Even though this technique is very accurate, it is sometimes not possible to determine the species of every plant fragment found in the faeces. Some fragments have characteristics common to two or three *Eucalyptus* species or to several conifers. In the results only those species were considered to be consumed by an animal that could be positively identified to belong to only one plant species. These were expressed by the 'minimum possible percentage consumed over all times'.

4.4.7 Health. Each koala was weighed at the start and the end of the research. The gender and age of each animal was determined using the tooth wear index (Gordon, 1991; Martin, 1981). Each female koala was checked for the presence of pouch and back young and general health assessed using body index measurements (White, 1994).

One millilitre blood samples as well as genital swabs were taken to analyse the level of *Chlamydia* infection in these animals. All samples were taken and analysed by Dr John Emmins from Monash University. Direct immunofluorescence on smear (DIF) and culture tests were performed to demonstrate the presence or absence of *Chlamydia* in the urogenital samples and a positive result indicates that the koala is shedding the organism at that time and it is therefore an indication that the animal is infectious. The antibody ELISA indicates the level of the *Chlamydia* specific antibody in the blood and therefore indicates whether the koala has been exposed to or is infected with *Chlamydia*, and whether or not it is actively shedding the organism at the time.

DIF is analysed on the smear and it detects *Chlamydia* organisms directly by staining the smear with a fluorescent monoclonal antibody. Positive results are indicated when 10 or more organisms are visualised; ± results occur when 8–10 organisms are seen on the slide.

Culture is the growth of *Chlamydia* in cell culture. This is an extremely sensitive test that detects viable organisms in the sample. Positive culture is definitive proof of the presence of *Chlamydia*.

ELISA units represents a linear scale from 0 to 10 with 0 corresponding to the optical density of a known negative control animal and 10 corresponding to the optical density of the highest titre positive control animal ever encountered.

4.4.8 Permits. This research was conducted with a research permit (RP-94-209) under the Victorian Government's Wildlife Act 1975 and the procedures that involved the handling of koalas received ethical clearance from the University of Ballarat.

4.5 Results

4.5.1 Habitat at study site. During the vegetation survey of the study site, approximately 10000 trees were mapped across approximately 800 ha of land of which nearly 8% was covered by trees and shrubs; their distribution is displayed in Map 9 (Appendix D). A total of 52 species were identified, both native and introduced.

Table 4-1 Tree species identified in study site. I = indigenous to the area; NI = native to Australia but not indigenous to the area; W = weed, an introduced species; U = Unknown

Tree species	Common name	Comment
Ecalyptus baueriana	Blue Box	NI
E. botryiodes	Southern Mahogany, Bangalay	NI
E. cladocalyx	Sugar Gum	NI
E. cosmophylla	Cup Gum	NI
E. crenulata	Buxton Gum	NI
E. decorticans	Gum-top Ironbark	NI
E. fibrosa subsp. fibrosa	Broad-leaved Ironbark	NI
E. globulus subsp. globulus	Southern Blue Gum	NI
E. gomphocephala	Tuart	NI
E. kitsonia	Gippsland Mallee; Bog Gum	NI
E. leucoxylon subsp. megalocarpa	Yellow Gum	I
E. melliodora	Yellow Box	I
E. nicholii	Narrow-leaved Black Peppermint	NI
E. occidentalis	Swamp Yate	NI

Tree species	Common name	Comment
E. obliqua	Messmate Stringybark	I
E. odorata	Peppermint Box	NI
E. ovata	Swamp Gum	I
E. pauciflora	Snow Gum	I
E. ployanthemos	Red Box	I
E. porosa	Black Mallee Box	NI
E. radiate	Narrow-leaf Peppermint	I
E. robusta	Swamp Mahogany	NI
E. sideroxylon	Red Ironbark	I
E. viminalis	Manna Gum	I
***E. ssp.* unidentified 1-8**	Unidentified Eucalypts	U
Acacia baileyana	Cootamundra Wattle	NI
A. gunnii	Ploughshare Wattle	I
A. longifolia	Sallow Wattle	NI
A. mearnsii	Black Wattle	I
A. melanoxylon	Blackwood	I
A. pycnantha	Golden Wattle	I
A. sp.	Unidentified Wattle	U
Banksia marginata	Silver Wattle	I
Melaleuca styphelioides	Prickly-leaved Tea-tree	NI
M. wilsonii	Violet Honey-Myrtle	NI
M. sp.	Unidentified Melaleuca	U
Casuarina cunninghamiana	River Sheoak, River Oak	NI
Hakea suaveolens	Sweet Hakea	NI
Exocarpus cupressiformis	Cherry Ballart	I
Pinus nigra	Black Pine	W
P. radiate	Radiata Pine	W
Cupressus macrocarpa	Monterey Cypress	W
C. sp.	Unidentified Cypress	W
Populus alba	White Poplar	W
Populus sp.	Unidentified Poplar	W
Ulmus sp.	Elm	W
Quercus sp.	Oak	W

Tree species	Common name	Comment
Salix babylonica	Weeping Willow	W

These trees were mainly found as linear road and railway-side vegetation. Moreover, a patch of several hundred remnant trees of the species of *E. viminalis, E. ovata* and *E. pauciflora* were found in a paddock between the highway and railway line in the centre of the study site. Other, mostly remnant, *Eucalyptus* trees were scattered across the study site, often in otherwise tree and shrub-less paddocks, or among the regrowth on the road and rail-sides. The road-side vegetation prominently featured a large proportion of native but non-indigenous tree and shrub species, which were planted by road management agencies over many years. There were also a large number of introduced trees of the genus *Pinus*, planted or self-sown, found along fence lines, road and rail-lines throughout the study site (Map 9, Appendix D).

4.5.2 Tree use and diet. The seven koalas were seen in 289 trees of 25 species and some of these were visited multiple times by the animals. The most common species used was *E. viminalis* with 35.7% observations, followed by *A. melanoxylon* (18.9%) and *E. ovata* (16.7%) (Table 4.2). Koalas were also observed using introduced species of which *P. radiata* comprised 11.6%. There was a difference in percentage use of tree species between animals that were using primary habitat and those using secondary habitat. In fact, koalas occupying primary habitat were observed more than 86% of the time in *E. viminalis, E. ovata* and *E. pauciflora*. While koalas in secondary habitat were only observed just over 28% of the time using the same three species; instead, they were observed nearly 60% of the time in non-eucalypts such as *A. melanoxylon, P. radiata* and *P. nigra*.

Table 4-2 Most frequently used tree species by koalas.

Tree species	Percentage use overall	Percentage use for koalas in Primary habitat	Percentage use for koalas in Secondary habitat
E. viminalis	35.7	46.4	24.9
E. ovata	16.7	31.3	2.1
E. pauciflora	5	8.8	1.1
A. melanoxylon	18.9	6.5	31.3
P. radiata	11.6	0.8	22.4
P. nigra	3	0.1	6.0
Others	9.1	6.1	12.2
TOTAL	100	100	100

Koalas were observed 65.8% of the time in 24 trees (Table 4.3). More than one-quarter (26.4%) of all observations were in four trees (Tree numbers: 1462, 1457, 1453, 1458, highlighted in pale grey in Table 4.3) of the species *E. viminalis* found in primary habitat. A number of non-eucalypts were also used multiple times e.g. *P. radiata* (4001 in Table 4.3; 5.1%) and *A. melanoxylon* (5261 in Table 4.3; 2.3%). Three trees (1457, 1453 & 1451 in Table 1.3) were used by five out of the seven koalas.

Table 4-3 Individual tree frequency of use for all koalas (summary). Only trees that were visited more than twice are shown in this table. The first four trees constituted 26.4% of all observations.

Tree ID	Tree species	Koala ID							Percentage of all observations
		1	2	3	4	5	6	7	
1462	*E. viminalis*	3					61		8.3
1457	*E. viminalis*			7	2	15	5	27	7.3
1453	*E. viminalis*			18	3	2	9	11	5.6
1458	*E. viminalis*			18	5		10	7	5.2
4001	*P. radiata*	39							5.1

Tree ID	Tree species	Koala ID							Percentage of all observations
		1	2	3	4	5	6	7	
5254	*E. viminalis*		32			6			4.9
1456	*E. ovata*			31					4
4002	*E. viminalis*	23							3
1454	*E. pauciflora*			9	7			6	2.9
5261	*A. melanoxylon*		18						2.3
3382	*E. ovata*						13	4	2.2
1451	*E. ovata*			3	1	3	3	6	2.1
5259	*A. melanoxylon*		15						1.9
1472	*E. ovata*						12		1.6
1459	*E. viminalis*	3			2		3	3	1.4
5284	*A. melanoxylon*		10						1.3
1467	*E. pauciflora*				3			6	1.2
4004	*C. macrocarpa*	9							1.2
1658	*P. radiata*				7		1		1
3800	*P. nigra*	1		4		3			1
5467	*E. fibrosa*		8						1
1464	*E. pauciflora*				3			1	0.5
1461	*E. viminalis*	2					1		0.4
1470	*E. pauciflora*					3			0.4
	Total	**80**	**83**	**90**	**33**	**32**	**118**	**72**	**65.8**

Tables 4.2 and 4.3 show tree species and individual trees that were used by koalas; however, they were not always observed eating the foliage of the trees they were sitting in. Scat analysis was used to determine the content and percentage of their diet and this showed that koalas consumed a number of *Eucalyptus* and non- *Euclyptus* species (Table 4.4).

Table 4-4 Individual koalas' scat analysis, tree use and tree availability. tr = trace; * at 90% isopleth; nt = not tested for

Tree species	Koala ID																				
	1			2			3			4			5			6			7		
	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available
E. viminalis	26	20.7	1.3	29.9	27.5	8.9	36.3	33.3	1.2	45.4	46.7	1.4	17.8	25.9	1.2	56	76.3	6.1	31.3	61.1	1.9
E. ovata	5.9	3.4	31	0	0	0	27.7	31.6	37.1	11.5	6.7	61.8	30.7	51.6	38.2	30.4	22	54.6	49.5	25	70.2
E. pauciflora	5.9	1.7	17.7	0	0	0	8.5	5.3	17.2	20.1	33.3	18.8	9.8	3.2	14.1	0	1.7	31.3	10.1	13.9	21
E. fibrosa ssp. fibrosa	0	0	0	18.8	12.9	2	0	1.7	0.5	0	0	0.7	0	0	0.4	3.1	0	0	0	0	0
E. crenulata	2.7	0	0	1.7	0	0	0	0	0	2.1	0	0	0	0	0	0	0	0	0	0	0
E. botryoides	0	0	0	0	0	0.5	1.9	5.3	2.3	0	0	0	1	0	0	0	0	0	2	0	0
E. polyanthemos	0	0	0.3	0	0	0	0	0	0.2	0	0	0	3.7	0	0.2	0	0	0	0	0	0
E. globulus ssp. globulusus	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. gomphocephala	0	0	0	8.4	6.4	0.5	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
E. decoritans	0	0	0	6.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. melliodora	0	0	0.2	0	0	0	0	1.7	0.2	0	0	0	2	3.2	0.2	0	0	0	2.8	0	0

Tree species	Koala ID																				
	1			2			3			4			5			6			7		
	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available	% Consumed	% Observed in*	% Available
P. radiata	27	48.3	6.2	2.4	1.6	36.1	0	0	2.9	7.3	13.3	0.5	0	0	4.1	0	0	0	0	0	0
P. nigra	0	1.7	3.6	3.5	1.6	5	7.2	8.8	3.5	0	0	3.5	2	3.2	2.4	0	0	1	0	0	0.3
A. melanoxylon	tr	0	19.1	tr	50	46	tr	12.3	24.3	tr	0	4.4	12.8	12.9	25.2	0	0	7	0	0	2.8
Amyema sp.	0	0	0	tr	0	0	0	0	0	tr	0	0	0	0	0	2	0	0	0	0	0
Cupressus ssp.	nt	24.2	7.3	nt	0	0	nt	0	0	nt	0	0	nt	0	0.5	nt	0	0	nt	0	0
***E. spp*. unable to be determined to species level**	30.2	0	2.3	28.9	0	0	18.4	0	0	13.6	0	0	20.2	0	0	8.5	0	0	4.3	0	0
Others species	0	0	11	0	0	1	0	0	10.6	0	0	8.9	0	0	13.4	0	0	0	0	0	3.8

Data analyses were conducted on species to see which were consumed more than expected given their relative abundance - and hence were preferred, and conversely which were consumed less than expected, given their relative abundance – and hence were avoided. All koalas consumed *E. viminalis* to some degree with the lowest percentage recorded for koala 5 (17.8%) and the highest for koala 4 of 45.4%. Apart from koala 2, all koalas ate leaves of the tree species *E. ovata* and only two koalas did not eat *E. pauciflora*. In fact, the three primary food tree species for the study site, *E. viminalis, E. ovata* and *E. pauciflora* made up the majority of the diet of koalas (3–7) with koala 5 having the lowest consumption of these three species within that group at approximately 58%, and koala 7 the highest around 91%. Koalas 1 and 2 showed a lower consumption of these three species, approximately 30% and 38% respectively. Only four koalas showed evidence of feeding on pines with koala 1 ingesting the highest percentage (27%) of *P. radiata*. Only koala 5 consumed larger than trace amounts (12.8%) of *A. melanoxylon.* Two koalas (2 and 6) consumed *E. fibrosa* ssp. *fibrosa* with 18.8% of koala 2's diet made up of it being the second most important species in its diet after *E. viminalis* (29.9%). Other species of the genus *Eucalyptus* that were consumed to a lesser extent and by fewer koalas, were *E. crenulata*, *E. botryoides*, *E. polyanthemos*, *E. globulus ssp. globulusus, E. gomphocephala, E. decoritans* and *E. melliodora.* A small amount (2%) of Mistletoe (*Amyema sp.*) was consumed by one koala while two koalas showed trace amounts of this species.

Statistical analyses were conducted for the four most widely consumed tree species *E. viminalis, E. ovata, E. pauciflora* and *P. radiata*. The percentage consumed of the four tree species were compared with the percentage of the times the koalas were observed in trees of these species and with their respective availability within the koalas' home ranges. Cases with both variables zero were removed.

E. viminalis

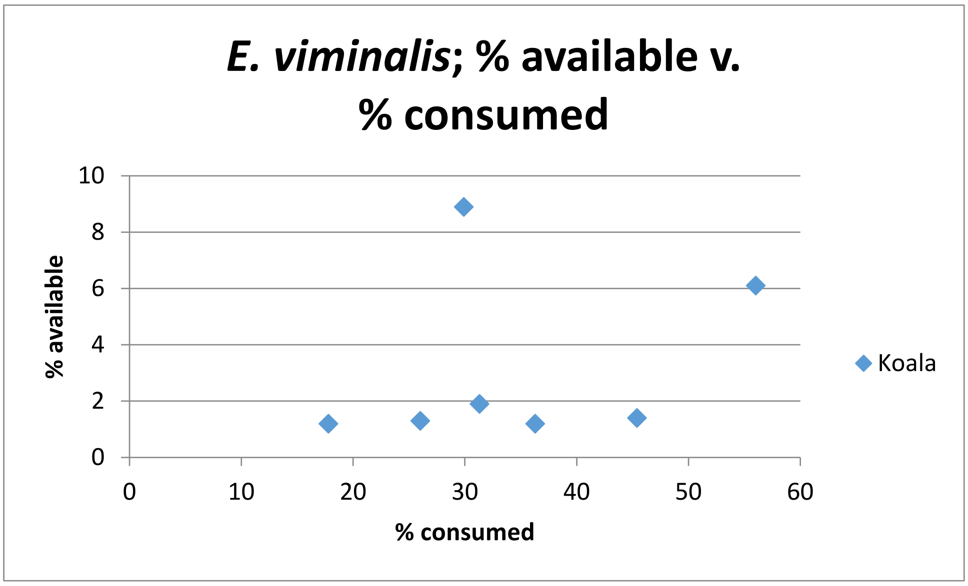

Figure 4-3 *E. viminalis*: Comparison of 'percentage consumed' with 'percentage available' for all koalas.

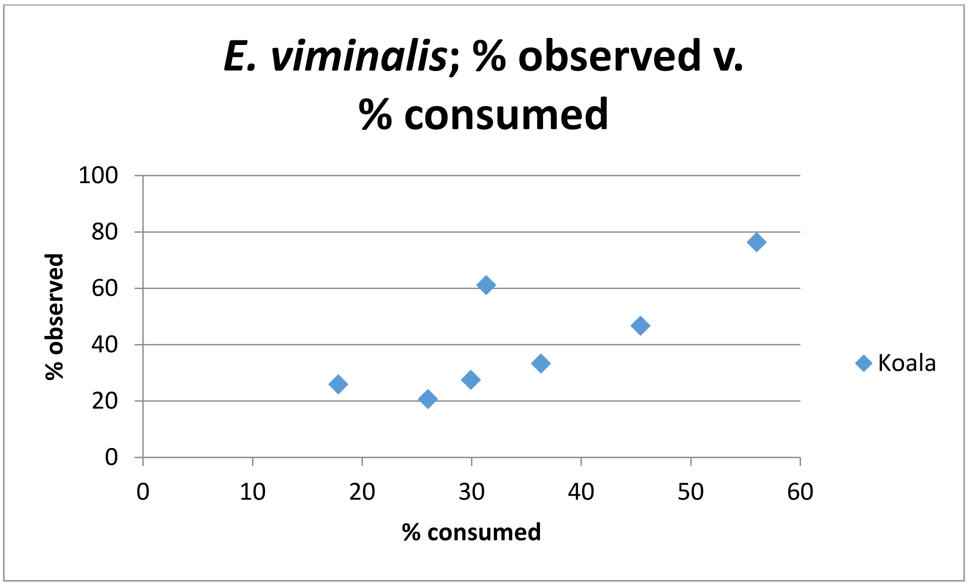

Figure 4-4 *E. viminalis*: Comparison of 'percentage consumed' with 'percentage observed' for all koalas.

A Pearson correlation analysis showed no relationship ($r = 0.28$; $n = 7$; $p = 0.2692$) between percentage consumed and 'percentage available' but a significant positive relationship ($r = 0.78$; $n = 7$; $p = 0.0191$) between 'percentage consumed' and 'percentage observed'.

E. ovata

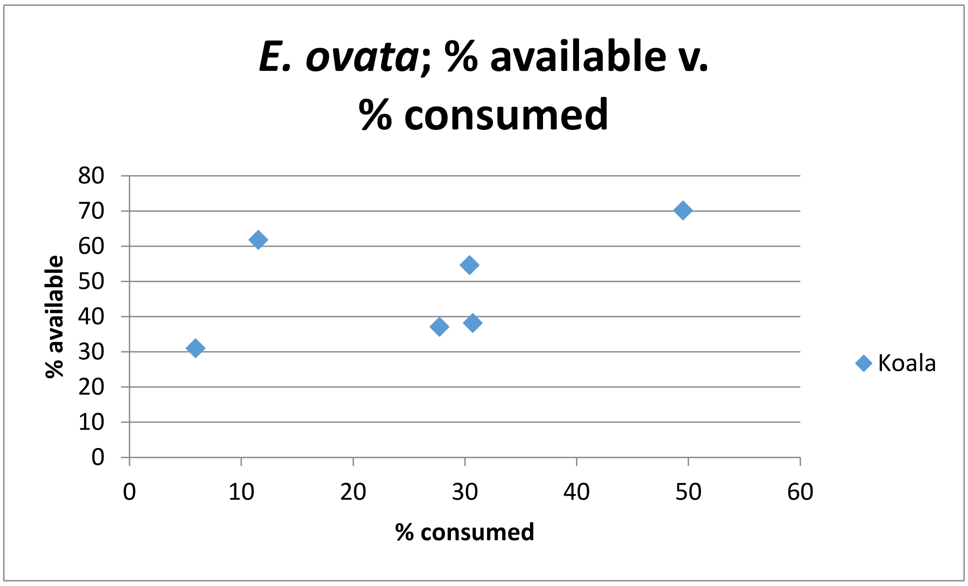

Figure 4-5 *E. ovata*: Comparison of 'percentage consumed' with 'percentage available' for all koalas.

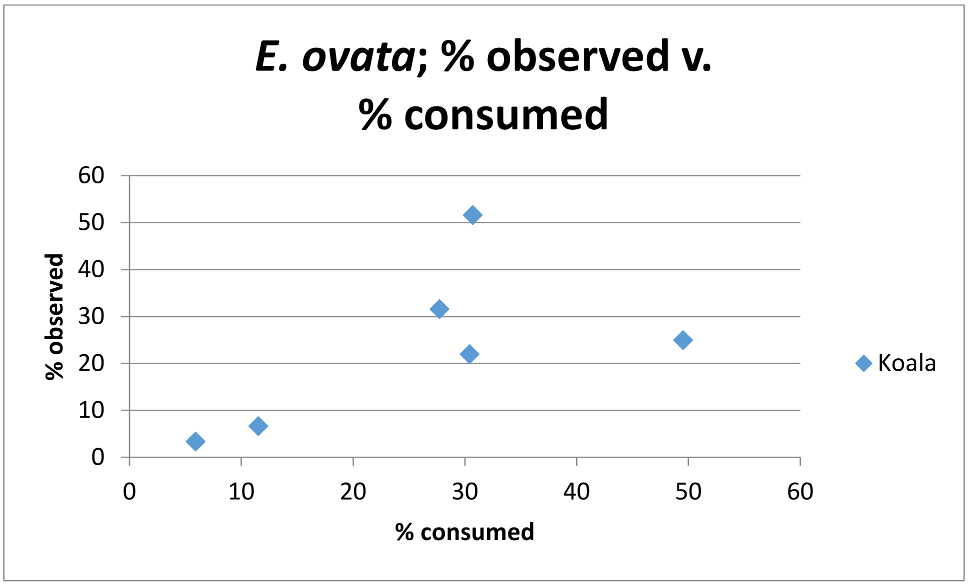

Figure 4-6 *E. ovata*: Comparison of 'percentage consumed' with 'percentage observed' for all koalas.

A Pearson correlation analysis showed no relationship, only a tendency ($r = 0.52$; $n = 6$; $p = 0.1477$) between 'percentage consumed' and 'percentage available' or ($r = 0.6$; $n = 6$; $p = 0.1036$) between 'percentage consumed' and 'percentage observed'.

E. pauciflora

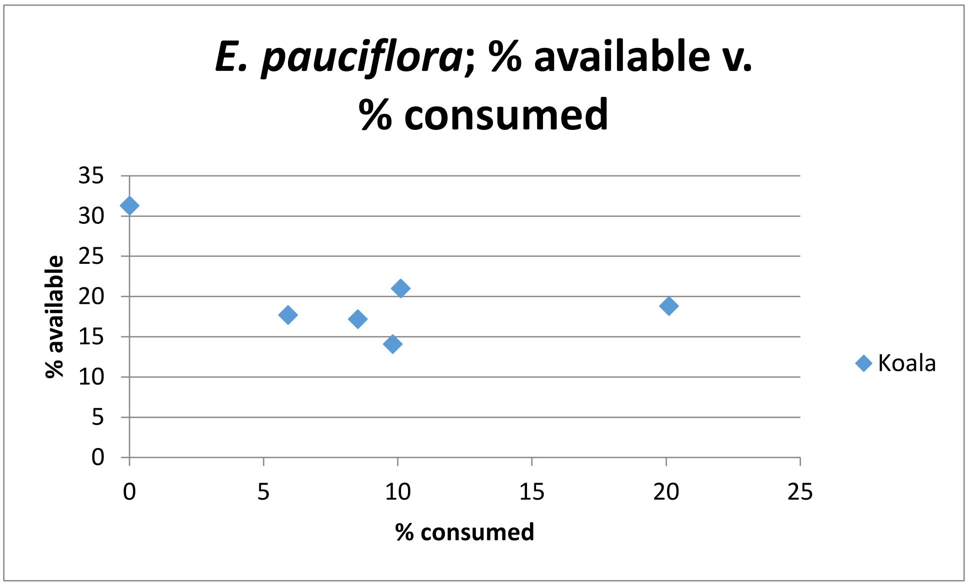

Figure 4-7 *E. pauciflora*: Comparison of ‘percentage consumed’ with ‘percentage available’ for all koalas.

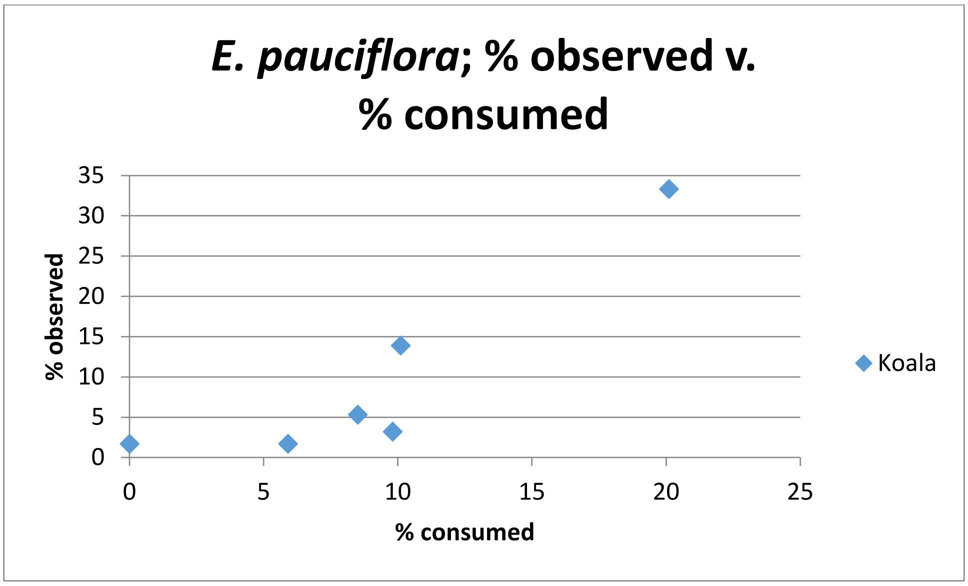

Figure 4-8 *E. pauciflora*: Comparison of ‘percentage consumed’ with ‘percentage observed’ for all koalas.

A Pearson correlation analysis showed no relationship ($r = -0.56$; $n = 6$; $p = 0.8769$) between ‘% consumed’ and ‘% available’ but a significant positive relationship ($r = 0.89$; $n = 6$; $p = 0.0092$) between ‘% consumed’ and ‘% observed’.

P. radiata

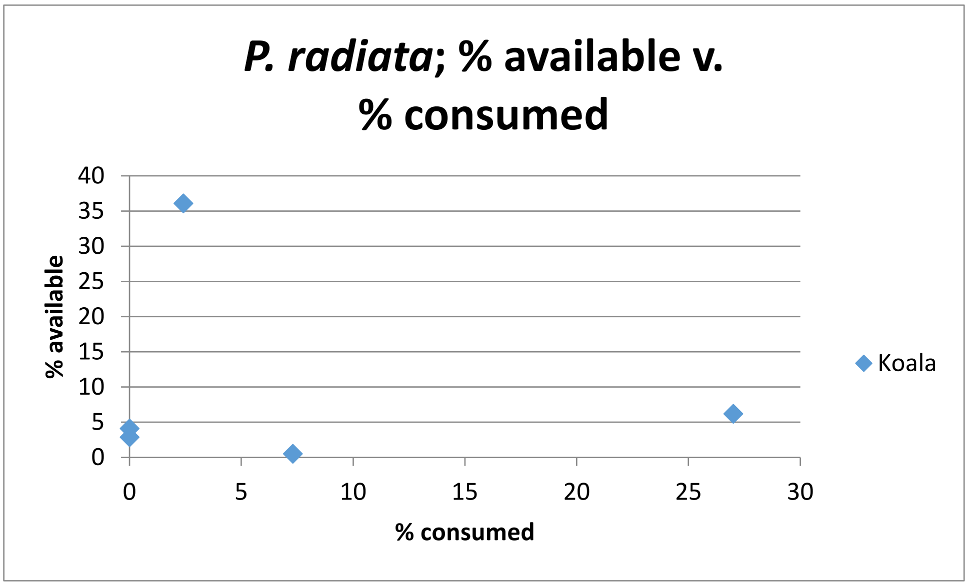

Figure 4-9 *P. radiata*: Comparison of 'percentage consumed' with 'percentage available' for all koalas.

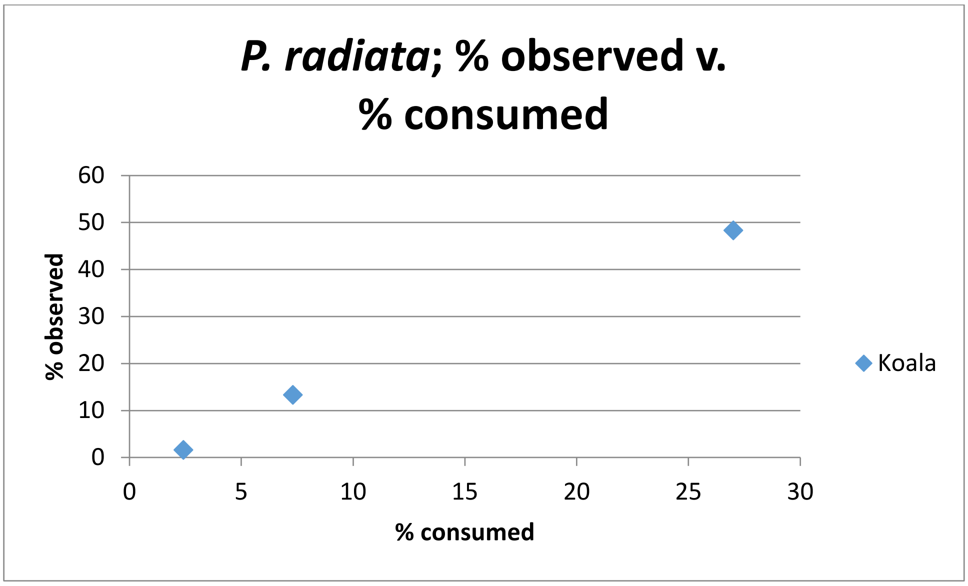

Figure 4-10 *P. radiata*: Comparison of 'percentage consumed' with 'percentage observed' for all koalas.

A Pearson correlation analysis showed no relationship (r = -0.16; n = 5; p = 0.6017) between 'percentage consumed' and 'percentage available' but a significant positive relationship (r = 0.998; n = 3; p = 0.0171) between 'percentage consumed' and 'percentage observed'.

4.5.3 Home ranges. The home ranges for all the koalas are shown on maps 2–8 (Appendices 3 & D). Isopleths at 5% increments are shown from between the 50% and 70% (depending on ability to display smaller isopleths on the one map) to 100% over the vegetation present at the site. For clarity of display, only the three preferred koala habitat species (*E. viminalis, E. ovata* and *E. pauciflora*) are shown in colour.

The home ranges of koalas 3–7 centred on the large remnant of *E. viminalis*, *E. ovata* and *E. pauciflora* in the middle of the study site, while koala 1 took in part of this remnant in its home range. Only koala 2 did not use the remnant at any time as part of its home range. Detailed descriptions of each koala's home range are listed below.

Koala 1: female

This koala's home range was centred on two main areas. One was around an isolated, large, remnant tree of the species *E. viminalis* found next to a large *P. radiata* in the middle of a paddock about 500 metres to the west of the railway line; and the other, focused across both sides of the highway, at the northern end of the study site. This area included some medium to small size *E. viminalis* with otherwise *A. melanoxylon*, some pines and a few introduced *Eucalyptus* species. The home range of this koala also encompassed some part of the remnant stand of *E. viminalis, E. ovata* and *E. pauciflora*, between the highway and the railway line. This home range covered an area of approximately 190 ha of which 25 ha were koala habitat.

Koala 2: female

This koala's home range was centred on two areas located to the northern end of the study site. The main area was centred around seven medium sized *E. viminalis* in a paddock between the railway line and the highway and 12 smaller trees of the same species on the road-side. The vegetation was otherwise dominated by *A. melanoxylon*, some pines and a few introduced *Eucalyptus* species. The second area of its home range focused on a large, remnant tree of the species *E. viminalis* around 100 metres further south along the highway. There were no other trees of the primary *Eucalyptus* food tree species nearby. The home range covered an area of approximately 5 ha of which 1 ha was koala habitat.

Koala 3: male

This koala's home range was centred on the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* and the vegetation along the highway and the railway line alongside the remnant. The vegetation along the railway line contained many trees of *A. melanoxylon* and *Pinus* ssp. but also a number of remnant *E. pauciflora*. The road-side along the highway was dominated by *A. melanoxylon* and *P. radiata* but also some non-local eucalypts. In addition there were good stands of remnant *E. viminalis* on the eastern side of the road and *E. ovata* along the western side, many of which were inside the paddock. The home range covered an area of approximately 40 ha of which approximately10 ha were koala habitat.

Koala 4: male

This koala's home range was centred predominantly around the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* and a small section of the vegetation along the highway and the railway line alongside the remnant. The vegetation along the railway line contained *A. melanoxylon* and *Pinus* ssp., but also a number of remnant *E. pauciflora*. The road-side along the highway was dominated by *A. melanoxylon* and *P. radiata* as well as also a few non-local eucalypts. In addition, there were good stands of remnant *E. ovata* on the western side of the road, many of which were just inside the paddock. The home range covered an area of approximately 9 ha of which approximately 3 ha were koala habitat.

Koala 5: male

This koala's home range was focused in two areas. One centre of activity was around the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* and the vegetation along the highway and the railway line alongside the remnant. The vegetation along the railway line contained *A. melanoxylon* and *Pinus* ssp. as well as a number of remnant *E. pauciflora*. The road-side along the highway was dominated by *A. melanoxylon* and *P. radiata* as well as a few non-local eucalypts. In addition there were good stands of remnant *E. ovata* on the western side of the road, many of which were just inside the paddock and *E. viminalis* to the east of the highway. The second centre of activity was a little further north along the railway line where there was a stand of remnant *E. ovata* on both sides of the railway line and *E. viminalis* on the right side of the line and some trees in the paddock between the railway line and the highway. The home range covered an area of approximately 200 ha of which approximately 35 ha were koala habitat.

Koala 6: female

This koala's home range was centred predominantly around the northern top of the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* and a small section of the vegetation along the highway and the railway line alongside the remnant. The vegetation along the railway line contained *A. melanoxylon* and *Pinus* ssp. but also a number of remnant *E. pauciflora*. The road-side along the highway was dominated by *A. melanoxylon* and *P. radiata* but also a few non-local eucalypts. In addition there were good stands of remnant *E. ovata* on the western side of the road, many of which were just inside the paddock. The home range covered an area of approximately 5 ha of land of which approximately 0.8 ha were habitat.

Koala 7: male

This koala's home range was very similar to that of koala 6 as it was also centred predominantly around the northern top of the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* and a small section of the vegetation along the highway and the railway line alongside the remnant. The vegetation along the railway line contained *A. melanoxylon* and *Pinus* ssp. but also a number of remnant *E. pauciflora*. The road-side along the highway was dominated by *A. melanoxylon* and *P. radiata* but also a few non-local eucalypts. In addition there were good stands of remnant *E. ovata* on the western side of the road, many of which were just inside the paddock. The home range covered an area of approximately 7 ha of which approximately 1 ha was koala habitat.

Range Overlap

The home ranges of koalas 6 and 7 overlapped to a great extent, while those of koalas 3, 4 and 5 also overlapped but to a lesser extent. There was an overlap of home ranges of koalas 3, 4, 5, 6 and 7 at around the 70% isopleths which centred on the northern part of the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the centre of the study site. A detailed analysis of percentage overlap was not performed as the use of individual trees (Table 4-3) shows the intense use of certain individual trees by a number of koalas within the various home ranges.

Tree Changes

It was found that koalas changed trees at different rates depending on whether their home ranges contained mainly primary or secondary koala habitat (Table 4-5).

Table 4-5 Change of tree for all koalas. Koalas 3 – 7 had home ranges that comprised mainly primary koala habitat.

	Koala ID						
	1	2	3	4	5	6	7
Percentage of times moved since last observation n=84	45.4	53.1	34.8	38.2	36.8	22.7	35.6
Percentage of times moved during the day n=42	35.6	40	2.8	8.7	2.3	0	0

Koalas living in secondary koala habitat changed trees more often than those living in primary habitat; they were also more likely to change trees during the day. Koalas were never observed crossing the road; however, when their observed location was across a road from the previous record, a crossing of that road by the koala had clearly occurred.

4.5.4 Home range architecture, road crossings & fate.

The home ranges of all koalas overlapped to varying degrees with both, the highway and the railway. The preferred koala habitat trees and the koala home ranges were in general located alongside these two transport corridors and in a large remnant in a paddock between the highway and the railway. Core areas of each home range were centred on stands of or even individual trees of *E. viminalis*.

Table 4-6 Number of road crossings and fate of koalas.

Koala	Sex	Minimum number of road crossings during this study (18 weeks)	Fate at end of this study (18 weeks)
1	F	5	Alive
2	F	3	Alive
3	M	4	Alive
4	M	1	Alive
5	M	0	Alive
6	F	1	Alive
7	M	0	Alive

There was no evidence of koalas 5 and 7 crossing the road and only one road crossing each for koalas 4 and 6 could be verified. The remaining koalas crossed the road multiple times. All koalas survived for the duration of this study (18 weeks) in contrast to Prevett, Pope, Smithyman, and Schlagloth (1995) who, surveying koalas near another local highway, found that individual animals were unlikely to survive more than 24 days. This may be due to the fact that this study was conducted during the non-breeding season only.

4.5.5 Health. Only one of the koalas was negative to the various *Chlamydia* tests; this was a young, two year old male. Koalas 5 & 6 were found with injuries on the last day of the fieldwork and treated by a veterinarian, Dr Mike Sheedy. Both animals were probably injured during fighting, and koala 5 had his testes removed as he would otherwise have haemorrhaged to death. No samples for *Chlamydia* testing were taken from this animal. All animals, including these, were otherwise in good condition. An older female was found to have never lactated, and her antibody ELISA was also found to be very high.

Table 4-7 Health assessment of koalas at the end of the 18 months project. DIF = Direct immunofluorescence on smear, positive results are indicated when 10 or more organisms are visualised; ± results occur when 8-10 organisms are seen over slide; Culture = growth of *Chlamydia* in cell culture.

Koala	Sex	Weight (kg)	Age	Condition	DIF	Culture	Ab ELISA	Comments
1	F	8.5	8	Good	+	-	9	Never lactated
2	F	8.25	3-4	Good	+++	+	9	
3	M	7.25	2.5	Good	+++	++	8	
4	M	6.5	2	Good	-	-	8	
5	M	11	8-9	Injured	Nt	Nt	4	Testes removed
6	F	8	5	Good	±	-	9	Abrasion/eye
7	M	8	5-6	Good	+++	Nt	7	

4.6 Discussion

4.6.1 Habitat at study site. The survey of the study site revealed a highly fragmented landscape, typical of the rural landscape in the Greater Ballarat area (Schlagloth et al., 2006). Farmland surrounding the highway was found to be mostly cleared of native vegetation, with the exception of the occasional stand of remnant trees, but no regrowth, as this appeared to have been eaten by livestock. Exotic trees such *P. radiata* and *P. nigra* were often found along fence lines as they were originally planted as shelter belts by farmers to replace the native trees which were removed. The only large patch, found in a paddock in the centre of the study site, between the highway and the railway line, included remnant trees of the species *E. viminalis, E. ovata* and *E. pauciflora*. This paddock, and others to the north and south of it, were owned by the State Government and were leased to local farmers. Management prescriptions for these properties have probably saved the native vegetation from being cleared; however, regrowth was limited due to pressure from cattle and sheep grazing. These properties were subject to a decade-long process, by the State Government divesting itself of such assets or restructuring lease agreements for the properties (Government of Victoria, 1999). There was no incentive at the time for leaseholders to invest in protecting the native vegetation. Some native trees remained near the highway, minor roads, tracks, railway and fence intersections, where grazing was excluded and where some regrowth was allowed. The presence of a large number of non-local species found mostly alongside the highway was a result of management directives by the former Roads Department, to plant a variety of exotic species, mostly for aesthetic reasons. Such plantings of native and introduced trees and shrubs, was common alongside many roads in Victoria during the 1970s–80s (personal communication, H. Thomson, October 5, 2013).

4.6.2 Tree species preference (tree use and diet). The fact that during this study the seven koalas were observed 773 times using a total of 25 different species, and that of these, 508 (65.8%) were made in just 24 trees of eight species; four eucalypts *(E. viminalis, E. ovata*, *E. pauciflora, E. fibrosa ssp. fibrosa,* two pines *(P. radiata, P. nigra),* one cypress *(C. macrocarpa)* and one wattle *(A. melanoxylon),* clearly emphasises koalas' use of around half of the breath of species available to them, but also the preferential use of certain species and even individual trees by individual animals. The diet of the koalas studied was made up of eucalypts by 73%–100 % (considering fragments only identified to genus level) depending on the area each animal occupied (primary or secondary habitat). A similar range (83%–96%) was previously found in another study (Tun, 1993) in a more continuous habitat.

E. viminalis and *E. ovata* (Hindell & Lee, 1988; Menkhorst, 2004) and *E. pauciflora*, in order of preference, are considered to be the preferred koala trees for the region around the study site (Australian Koala Foundation, 2008). While this was confirmed to be the case in regards to 'tree use' for those koalas occupying primary koala habitat within the study site (Table 4.5.3), it was not fully reflected by the results for those koalas occupying secondary habitats, where *A. melanoxylon* was the most used tree species, followed by *E. viminalis* and *P. radiata*. This may be partially explained by the limited availability of *E. ovata* and *E. pauciflora* in the secondary habitat, the animal's position within the population or the better shelter qualities of *A. melanoxylon* and *P. radiata*. For example, nearly half (48.3%) of all observations for koala 1 were in *P. radiata*, with that koala spending most of its time in two individual trees (*P. radiata* & *E. viminalis* (Table 4.3)).

The classification of *E. viminalis* as the most preferred koala habitat species in the study area (Hindell & Lee, 1987; Schlagloth et al., 2006) and in Victoria in general (Department of the Environment, 2009; Martin & Handasyde, 1999; Menkhorst, 2004) was confirmed by this study with all koalas observed using this species at significant levels as habitat (lowest 20.7%–highest 76.3%). The fact that 26.4% of all observations (Table 4.3) were attributed to six koalas using four trees of *E. viminalis* further highlights its importance as a habitat tree species. The importance of *E. viminalis* was further noted when its function as a fodder species (% consumed, Table 4.5.1) as part of the koala diet was analysed. *E. viminalis* was the only species preferentially browsed across all koalas in all habitats. *E. ovata* and *E. pauciflora* were eaten where available, mostly at or just below the rate that the species was available in each koala's home range, making them a staple, but not preferentially, consumed fodder species. *E. ovata* was often consumed at high percentages e.g. koala 7 (49.5%); Hindell and Lee (1990) found similar results for koalas in the nearby Brisbane ranges when they concluded that koalas consumed large amounts of *E. ovata* when *E. viminalis* was in short supply. Hindell et al. (1985) also found that koalas in that area only showed a stronger preference for *E. ovata* during summer, a season that was not covered by this study. He also identified differences in species preferences between sexes; males preferred *E. macrorhyncha* and to a lesser extent *E. viminalis* and *E. ovata*. No such differences were found in this study as all koalas preferentially browsed *E. viminalis* (Table 1.4); however, *E. macrorhyncha* was not a species present in the study site. It was interesting to note that, koala 2, in the absence of *E. ovata* and *E. pauciflora*, preferentially consumed *E. fibrosa ssp. Fibrosa* in addition to *E. viminalis*. Other, non-local eucalypts such as *E. crenulata*, *E. botryoides*, *E. polyanthemos*, *E. globulus ssp. globulus*, *E. gomphocephala*, *E. decoritans* and *E. melliodora* were consumed by fewer koalas and at low levels. This may be due to their low availability at the study site, relative plentiful supply of traditional fodder species, non-favourable soil and climatic conditions. *E. botryoides* (Hume & Esson, 1993; Menkhorst, 2004), *E. globulus ssp. globulus* (Betts, 1978; Hume & Esson, 1993; Menkhorst, 2004; Moore & Foley, 2005; Rhodes et al., 2008; Schlagloth, Mitchell, & Rhodes, 2008), *E. melliodora* (Hume & Esson, 1993; Menkhorst, 2004; Moore et al., 2005), *E. polyanthemos* (Hume & Esson, 1993; Menkhorst, 2004; Ullrey, Robinson, & Whetter, 1981) are known to be eaten by koalas in other areas.

However, it was evident, that several koalas, to varying degrees, consumed leaves from non-eucalypts, non-local eucalypts, non-eucalypt native species, introduced species and non-traditional koala tree species. At least one koala, number 5, supplemented its diet with around 12% of *A. melanoxylon*. The same was the case for *P. radiata*, with three koalas (1, 2 & 4) consuming it, and the species was also extensively consumed (27%) by koala 1 who fed on 26% of *E. viminalis*. Koalas eating pines and wattles have been reported in several studies (Lithgow, 1982; Munro, 1989) and it is believed by Southwell (1978) that it is the essential oils that attracts koalas to these species as an alternative or a supplement to their locally preferred *Eucalyptus* browse.

This study confirmed various sources (Hanel, 2008; Norton & Reid, 1997; Troughton, 1938) which suggest that koalas consume mistletoe (*Amyema* species), which was detected at least at trace levels in the scats of two koalas and at 2% for one koala. It was difficult to assess any dietary preference for this species by individual koalas as the plant grows only within the crowns of some eucalypts, and its distribution was not surveyed for during this study. It is not known whether koalas ingest this species by accident, during normal browsing of eucalypts, or if they select it.

In this study, it appeared that any koala that was seen in any particular *Eucalyptus* species for a minimum of 4 out of the 110 observations, could be presumed to have used that species of *Eucalyptus* as fodder. For example, for the seven koalas, there were 21 cases where a koala was observed in a *Eucalyptus* species and found to have consumed that species. The lowest valid ‘percentage observed’ was for *E. pauciflora* in the case of koala 6 or *E. melliodora* for koala 5 with 3.2%. There were 110 observations for each koala and 3.2%for these equates to 3.52–4 observations. Studies by (Ellis, Melzer, et al., 2002; Hasegawa, 1995) for Queensland and Matthews, Lunney, Gresser, and Maitz (2007) for New South Wales found that tree visitation is not an accurate predictor of the diet preferences of koalas. These findings were not supported by this study for this koala population unless sufficient observations were made. Several researchers (Clifton, Ellis, Melzer, & Tucker, 2007; Ellis, Melzer, Clifton, & Carrick, 2010) and Melzer, Baudry, Kadiri, and Ellis (2011) in Queensland, observed the use of various non-food species that were linked to the koala’s ability to better cope with extreme temperature differences. This study highlights the use of *P. radiata* as resting, shelter and fodder trees and it strengthens the argument by Munro (1989) who believed this happens for reasons of shelter from adverse weather conditions. Moreover, this study confirms the findings of Lithgow (1982) and Hindell et al. (1985) who reported the ingestion of non-eucalypt species, especially *P. radiata*.

4.6.3 Analyses of individual koalas within their home ranges. The home ranges for the koalas are shown on maps 2 to 8 (Appendices 3 & 4). Isopleths at 5% increments are shown from between the 50% and 70% (depending on ability to display smaller isopleths on the one map) to 100% over the vegetation present at the site. For clarity of display, only the three preferred koala habitat species (*E. viminalis, E. ovata* and *E. pauciflora*) are shown in colour. The descriptions below all refer to the 95% isopleth.

The home ranges of koalas 3 to 7 centred on the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the middle of the study site, while koala 1 took in part of this remnant in its home range. Only koala 2 did not use the remnant at any time as part of its home range. Hindell and Lee (1990) showed that a small number of trees can be of great importance for a koala population, not only as a shared fodder source but also as part of their social structure. All koalas had well established home ranges for the duration of this study; a situation that may change during the breeding season. They showed a strong focus on areas of remnant *E. viminalis* trees which in this site were located in small numbers along the railway line and the highway as well as in a paddock between these two transport corridors. The proximity of these trees to these transport corridors exposed the koalas to the dangers of colliding with vehicles.

Detailed descriptions of each koala's home range are listed below.

Koala 1

This female koala who was 8 years old used 25 ha of secondary habitat over an area of 190 ha of land. The size of its home range was the second largest among the studied koalas and was within the upper limit for koalas in similar, but more continuous, habitats in other areas in Victoria (Hindell & Lee, 1988). The fragmented distribution of the preferred koala fodder trees (*E. viminalis*) probably accounted for this koala using a larger area of habitat, distributed over an even larger area of land. This animal was the oldest female koala in the group and second oldest animal overall; she showed signs of never having lactated, probably because she had become infertile due to *Chlamydia* (Table 4.7). The koala's age and likely lower position within the hierarchy of the local population (Hindell, 1984; Houlden, England, Taylor, Greville, & Sherwin, 1996; Martin, 1981) probably contributed to this animal being excluded from utilising the trees of the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the middle of the study site. Within its home range, koala 1 had access to only a few large, remnant, preferred fodder trees of *E. viminalis.* This may have contributed to this animal changing trees nearly every second day (45.4%) and even around one-third of the time (35.6%) during the day. Pfeiffer, Melzer, Tucker, Clifton, and Ellis (2005) postulate that reasons for frequent tree change for koalas on a Queensland island are the differences in shelter and fodder qualities between different species of trees. Also, the proximity of the chosen trees to the highway, may have contributed to it having the highest recorded road crossings for all koalas. This is especially the case when considering that koalas that mainly occupy the large remnant in the centre of the study site were recorded with no or just one road crossing. It is interesting to note that this koala was observed around 53% of its time, alternating between two large trees (a remnant *E. viminalis* and *P. radiata*); and for its diet to be composed of the same species at similar percentages (*E. viminalis* 26% & *P. radiata* 27%). This supports earlier findings by Prevett (1991) which highlighted the use of *P. radiata* as resting, shelter trees in the Ballarat area, however, it also shows that koalas consume this species.

Koala 2

This female koala was 3, possibly 4 years old and used 1 ha of secondary habitat over an area of 5 ha of land. The size of its home range is on par with limits for koalas in similar, but more continuous, habitats in other areas in Victoria (Hindell & Lee, 1988). This koala had the smallest overlap of home range of any of the study animals as only its 100% isopläths overlapped with two other koalas (1 & 5) and it only used one tree (5254 *E. viminalis*) in common with another koala (5). It is not known why this koala never ventured to the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the middle of the study site. Maybe its position within the broader local population of a 3–4 year old female meant that this was its established home range and habitat. Within its home range, koala 2 had access to only a few large, remnant, preferred fodder trees of *E. viminalis;* this may have contributed to this animal changing trees every second day (53.1%) and 40% of the times during the day. Both of these percentages for frequency of tree change represented the highest records for all koalas in this group. The majority of *E. viminalis* within its home range occurred on the west of the road; although it occupied habitat on both sides of the highway, it only had three confirmed crossings of the road. This koala did not consume *E. ovata* and *E. pauciflora* as they were not available within its home range and only less than one-third (29.9%) of its diet consisted of *E. viminalis*. Instead it was found to have ingested other eucalypts (*E. fibrosa* *ssp. fibrosa* 18.8%; *E. gomphocephala* 8.4%; *E. crenulata* 1.7% and *E. decoritans* 6.4%) and pines (*P. radiata* 2.4%; *P. nigra* 3.4%); all these species were planted along the highway.

Koala 3

This male koala was 2.5 years old and used 10 ha of primary habitat over an area of 40 ha of land. The size of its home range is within the limits for koalas in similar, but more continuous habitats in other areas in Victoria. This animal was a young koala whose home range encompassed a slightly greater part of the large remnant of *E. viminalis*, *E. ovata* and *E. pauciflora* in the middle of the study site compared to the other koalas using it. This could be related to koala 3 not having fully settled into a permanent home range and position in the hierarchy within the local population. Hindell and Lee (1988), for the Brisbane ranges, report of larger home ranges for males and particularly young males that have recently become independent from their mother (Mitchell & Martin, 1990). This animal, like all other koalas in this study, showed a distinct preference for *E. viminalis* with more than one-third (36.3%) of its diet being attributed to this species. However, *E. ovata* also made up a large percentage (27.7) of its diet and *E. pauciflora* to a lesser (8.5%) extent, but both species were more readily available within the large remnant and within its home range. This koala occupied better quality habitat compared to koalas 1 and 2 and this might be the reason for it having fewer changes of trees between observations (34.8%) and during the day (2.8%) however, the fact that its home range included large sections of road probably accounts for the four recorded road crossings for this animal. It is interesting to note that this koala was one of five animals which intensely used three *E. viminalis* trees (1457, 1453, and 1458, shown in Table 4-3) in the large remnant at the centre of the study site. This underlines the importance of this remnant stand of *E. viminalis* for the population of koalas in the study; the importance of such remnants for koalas was previously found by Lunney, O'Neill, Matthews, and Sherwin (2002) and Garden, McAlpine, Peterson, Jones, and Possingham (2006).

Koala 4

This male koala was 2 years old and used 3 ha of primary habitat over an area of 9 ha of land. The size of its home range is within the limits for koalas in similar, but more continuous, habitats in other areas in Victoria. This animal was a young koala in the group and its size of home range was comparable to other koalas using the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the middle of the study site. It is likely that this koala was the offspring of one or both of the koalas 6 and/or 7 whose home ranges centred on the same area and particular trees. It was a young animal that possibly had not yet fully separated from its mother or established an independent home range. This animal, like all other koalas in this study, showed a distinct preference for *E. viminalis* with more than one-third (45.4%) of its diet being attributed to this species. However, *E. ovata* also made up a large percentage (20.1%) of its diet and *E. pauciflora* to a lesser (11.5%) extent, but both species were more readily available within the large remnant and within its home range. This koala occupied better quality habitat compared to koalas 1 and 2 and this might be the reason for it having fewer changes of trees between observations (38.2%) and during the day (8.7%) Its home range included only a very short section of road on the perimeter of its home range, and this probably accounts for the only one recorded road crossings for this animal. This koala is another one of five animals that intensely used three individual trees of *E. viminalis* (1457, 1453, and 1458, shown in Table 4-3) in the large remnant in the centre of the study site. This underlines the importance of this remnant stand of *E. viminalis* for the population of koalas in the study site.

Koala 5

This male koala used 35 ha of primary habitat over an area of 200 ha of land. The size of its home range is exceeding the limits for koalas in similar, but more continuous, habitats in other areas in Victoria. The increase in home range is also partially due to the animal establishing two centres of activity, approximately one kilometre apart from each other. Sharp (1980) determined that home ranges of males tended to have more complex shapes and at least two centres of activity. While this theory applied to koala 5, it did not apply to the other male koalas in this study; in fact, two female koalas, 1 and 2, exhibited two centres of activity as well. Koala 5 was an older male of 8 or 9 years old in the group and its larger size of home range, compared to other koalas using the large remnant of *E. viminalis*, *E. ovata* and *E. pauciflora* in the middle of the study site, could be related to it being older and being excluded from the best habitat or conversely, it could be a sign of dominance. This koala was the only animal whose home range overlapped, to some extent, the ranges of all other koalas. It was also the one koala who suffered a severe injury to his testicles at the end of this research, most probably as a result of a territorial fight. However, the relative low percentage consumption (17.8) of *E. viminalis*, the lowest percentage for all koalas, and the high percentage (30.7) consumption of *E. ovata*, combined with the consumption of 12.8% *A. melanoxylon*, suggest that this koala might not have been a dominant male at that time. Both Hindell and Lee (1990) and Sharpe (1980) found that the home ranges of male koalas were on average 50% larger than those of female koalas; a finding that is not supported by the findings from this study, probably because of the fragmented habitat found at this site. This koala occupied better quality habitat compared to female koalas 1 and 2 and this might be the reason for it having fewer changes of tree between observations (36.8%) and during the day (2.3%). There were no confirmed road crossings recorded for this animal. This koala shared two of the three *E. viminalis* trees that were intensely used by five animals in the large remnant in the centre of the study site. This underlines the importance of this remnant stand of *E. viminalis* for the population of koalas in the study site.

Koala 6

This female koala used 0.8 ha of primary habitat over an area of 5 ha of land. The size of its home range is within the limits for koalas in similar, but more continuous, habitats in other areas in Victoria. This animal was a five year old koala and the size of home range was the smallest of all koalas and restricted to a few trees in the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the middle of the study site. It focused extensively on one *E. viminalis* tree (1462, shown in Table 4-3) with the 60% isopleth surrounding this one tree. Its reliance on *E. viminalis* as a fodder species was highlighted by the 56% consumption rate of it, the highest percentage for all koalas. Very few additional species, other than *E. viminalis* and *E. ovata* (30.4% consumption), were either used or consumed by this koala. While its home range was focused nearly exclusively on the remnant in the centre of the study site, a very small part of it included the highway and subsequently, one only crossing was confirmed for this koala. Probably because of the fact that this koala occupied the best available habitat in the study site, it had the lowest percentage of changing trees and was never recorded to have changed its tree during the day.

Koala 7

This male koala used 1 ha of primary habitat over an area of 7 ha of land. The size of its home range is within the limits for koalas in similar, but more continuous, habitats in other areas in Victoria. This animal was a 5 to 6 year old koala and its size of home range was the second smallest of all koalas and restricted to a few trees in the large remnant of *E. viminalis, E. ovata* and *E. pauciflora* in the middle of the study site. It was very similar to that of the female koala, 6, who focused extensively on a few large, remnant *E. viminalis*, *E. ovata* and

E. pauciflora trees. It preferentially browsed on *E. viminalis,* but *E. ovata* was also important in its diet as it made up half (49.5%) of it, the largest percentage consumption for any koala for this species of tree. Very few additional species, other than *E. pauciflora* (10.1% consumption), were either used or consumed by this koala. There were no road crossings confirmed for this koala. Probably because of the fact that this koala occupied, and shared with koala 6, the best available habitat in the study site, it also had a low percentage of changing trees and was never recorded to have changed its tree during the day. This koala was probably the dominant male in that area. Although this is contrary to Logan and Sanson (2003) who suggest that dominant males may be expected to use more trees than subordinate males. This might apply to koalas living in a continuous, more uniform habitat and may not quite fit the fragmented habitat at this site.

While this study draws some comparisons between the 'availability' of certain species to koalas, the percentage of this species consumed by individual koalas and the percentage that koalas are observed in these species, I acknowledge that these percentages are not fully compatible. Observations refer to a sighting of a koala in that species. Trees of that species may differ in size, height, age and condition and may therefore also differ in size of canopy and available browse. There may be differences for these parameters between species. The same concern applies to the availability of a species. However, by koalas concentrating on a few key areas e.g. the large remnant, these concerns are minimised. Trees of the three main species *E. viminalis, E. ovata* and *E. pauciflora* were of similar size, age and structure as, because of grazing pressure, no regrowth of these species was observed in that area. Percentages 'observed in' and 'consumed' were mostly matching each other for all three species for most koalas. Even if records had been made of canopy cover, there is no guarantee that a larger canopy necessarily implies more availability for, or intake of browse, by a particular koala.

This study was conducted during winter, the non-breeding time for koalas in Victoria. Ellis et al. (1995) found that male koalas, in particular, in Central Queensland, exhibited seasonal changes in diet selection which the authors related to increased energy requirement in winter and greater water requirements in summer. It is recommended that a similar study over a longer time frame be conducted, e.g. three years. This would allow for observing changes in home ranges and feeding preferences across seasons and breeding seasons. All koalas displayed well established home ranges during this study. There were no indications of any koala being transient; there were also no additional koalas sighted within the study area during the vegetation survey or radio tracking. Therefore only limited comment can be made on the potential of the habitat in this study site that functions as corridors for koalas. At the end of the study, two more koalas were sighted, captured and tested for a separate study. The suggested longer-term study, with a more rigorous and repeated survey to find koalas, has the potential to shed light on the question of the use of the vegetation as a koala habitat corridor, and better address the issue of transient koalas. This will inform us in more detail about the interactions between individual koalas in this population.

4.6.4 Health. Apart from the physical injuries to two animals, as a result of a fight, all koalas showed a good body condition index, suggesting that they had sufficient nutritional resources. Only one of the koalas tested received an all-clear on the various *Chlamydia* tests conducted. This 2 year old male koala, number 4, had probably not yet reproduced and was therefore not yet infected by a female koala. Female koala 1 was probably rendered infertile by a chlamydial infection (pers. comment J. Emmins) and at the age of eight, it appeared that she had never lactated. It is evident that this koala population is extensively infected with

Chlamydia. These results are in line with findings for most mainland koala populations in Victoria (Polkinghorne, Hanger, & Timms, 2013).

The koala population on French Island is found in isolation, and it was established that animals there are free from *Chlamydia*. There were no clinical, external signs of *Chlamydia* in these animals such as conjunctivitis or “wet bottom”. Such signs are unusual for populations infected with *Chlamydia* (Jackson, White, Giffard, & Timms, 1999), but do not always show, especially when koalas occupy good quality habitats, such as this population, and are not exposed to excessive stress associated with competition for limited resources (Phillips, 2000; Woodford & Rossiter, 1993).

4.6.5 Habitat sink. Prevett et al. (1995), in a study focused on koala roadkill along a section of the Western Freeway to the north of this study site, hypothesised that the koalas living near the road were immigrants from adjacent populations and that a 'source' and 'sink' model was operating at the site. Pulliam (1988) described the source-sink model in order to describe population dynamics. This model makes the assumption that habitat patches are of highly varying quality and further predicts a net flow of individuals from ‘source’ patches (high habitat quality, survival and reproduction success) to ‘sink’ patches (low habitat quality, survival and reproduction success) (Delibes, Ferreras, & Gaona, 2001). While this study was too short to monitor population changes and movements over time or seasons, it appears that koalas occupying primary habitat nearly exclusively used few, large trees of the preferred browse species *E. viminalis*, changed trees infrequently, and had much smaller home ranges than koalas occupying lower quality habitat; it appears that the more dominant koalas in the area occupied the better quality habitat. None of the koalas studied were subjects of AVCs during the duration of this research or left the area, and it was therefore not possible to observe any potential effect of the loss of individuals on the local population.

A larger study involving the monitoring of more koalas from a wider area for a longer period of time might be able to shed more light on the question if the entire road habitat works as a series of habitat sinks depending on the distribution of remnant koala habitat across the area.

Hypothesis from Chapter 2

In Chapter 2 it was hypothesised that male koalas would exhibit larger home ranges, move more frequently and change trees more frequently than females and that this would be reflected by their increased numbers of road crossings and a greater likelihood of being the subject of an AVC.

This hypothesis could not be supported by the results. Several female koalas had larger home ranges than male koalas. Indeed, the extent of movement, tree change and size of home ranges was clearly related to the quality of habitat occupied by individual animals. The better the habitat, the smaller the koalas' home range and the fewer tree changes and road crossings they exhibited. These findings may be restricted to koalas occupying heavily fragmented habitat as found in this study site. The significance of the preferred fodder species *E. viminalis* is also underlined by these findings; koalas in areas where such single-species importance does not exist, e.g., in Queensland, might exhibit different use of habitat near a KRB. It is possible that a study involving a larger number of koalas might help to differentiate more between movement patterns of male and female animals.

Hypotheses from Chapter 3

In Chapter 3.1 several KRBs were identified and in this Chapter, koalas in one of these KRBs, were radio tracked. Several road crossings by some koalas were recorded but no AVCs were observed. The lack of AVCs is possibly due to the timing of the survey (non-breeding period), the length of survey (4 months) or chance. It was hypothesised in 3.2 that

KRBs are due to the amount and degree of fragmentation, of Secondary A and Primary koala habitat. Radio tracking, as part of this Chapter, supports this hypothesis and confirms the importance of these two types of koala habitat in attracting koalas but it also shows that, where preferred habitat trees occur in a fragmented state, koalas will change trees more frequently, travel more often and further, and are more likely to cross the road or railway line and therefore, are exposed to an increased risk of being involved in an AVC.

4.7 Conclusion

Koalas living near this koala road-kill black spot highly favoured remnant stands of their preferred browse species of *E. viminalis*, followed by *E. ovata* and *E. pauciflora* in the primary habitat. Where these habitats were already occupied by individual koalas, other koalas used secondary habitats where *E. viminalis* was available, at varying (remnants and regrowth), but overall lower levels, compared to the large remnant in the centre of the study site. In addition, koalas in secondary habitats used and consumed a variety of non-local eucalypts, non-*Eucalyptus* native species and introduced species depending on their availability, the koalas’ individual preferences and their individual needs.

This research supports earlier findings by Prevett (1991) which highlighted the use of *P. radiata* as resting, shelter trees in the Ballarat area, however, it also shows that koalas consume this species probably to supplement their diet when their access to preferred browse is limited.

Studies have found a link between preferred habitat dissected by roads and an increase in roadkill compared to similar habitats dissected by fewer roads. This study showed that koalas living in a secondary habitats changed trees more frequently than those living in a primary habitat, and if a road crossed that habitat, they were therefore more likely to cross that road compared to koalas living in the large remnant.

It has been shown that feeding strategies of a species may have an effect on road-kill vulnerability; this Chapter has highlighted the very high importance of large remnant *E. viminalis* trees and to a lesser extent, *E. ovata* and *E. pauciflora* trees for koalas in this area and how the position of these trees in the landscape, especially in their proximity to roads, may expose koalas to an increased risk of colliding with traffic.

Prevett et al. (1995) who, surveying koalas near another local highway, found that individual animals were unlikely to survive more than 24 days and suggested that the highway and its linear vegetation may function as a road-kill sink. There was no evidence found that any of the koalas in this study, used the linear habitat around the black spot as a corridor or that the overall koala habitat in the area may function as a habitat sink; a possibility that warrants further investigation trough a larger and longer-term study.

A hypothesis

Why do koalas cross the road and why do KRBs occur? In Chapter 3 it was found that KRB occur where good quality koala habitat (Secondary A and Primary) is found in the most fragmented state. The results of Chapter 4 allow us to refine this hypothesis; *E. viminalis*, the preferred koala fodder species (the percentage presence of which is used to determine the koala habitat quality categories), its abundance and distribution in the landscape has the greatest influence on how often koalas, occupying habitat near the road in this study site, change trees, how large their home ranges are and subsequently, how often they might cross a road or railway line, and ultimately how likely they are of being involved in an AVC.

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Chapter 5. Key findings, conclusion, discussion and recommendations

This study commenced with a consideration of the literature on the ecology, conservation, history and threats to the koala. Past management was explored with a focus on koala wildlife carer records and the impact of roads on different species. The subsequent research focused on roads in the Ballarat area with high numbers of koala roadkill and the establishment of patterns that might lead to define blackspots. After examining the significance that AVCs have for local koala populations by exploration of local wildlife carer data files, the goal was to assess whether koala road-kill blackspots exist by analysis of detailed information on koala roadkill data and the development of a model based on multiple influences on koala road-kill occurrences. The model, followed by a detailed investigation of koalas living near a black spot, was to illuminate local koala ecology and inform management including the design of a conceptual model.

Initially three hypotheses were proposed:

1) Collisions between vehicles and koalas pose no risk to the longevity of koala populations in the Ballarat region:

   This hypothesis was rejected. Animal-vehicle collisions were the most important cause of koalas entering a wildlife shelter and also the most important cause of death, most likely posing a great risk to the persistence of local populations.

2) Most of these collisions do not occur in so called ‘blackspots’ along roads, but could occur anywhere:

   This hypothesis was rejected. Road-kills were not randomly distributed and four koala road-kill blackspots were identified.

3) … and that in relation to perceived blackspots, visibility by drivers and availability of koala habitat are not important variables which could determine the likely occurrence of 'blackspots'.

This hypothesis was rejected in regards to availability of habitat and partially in regards to visibility by drivers. The most important factors contributing to the occurrence of koala road-kill blackspots were the fragmentation of preferred koala habitat. Visibility by drivers travelling towards the sun may have some influence as well.

5.1 Key findings and conclusions

This research found that:

1) Mortality due to road collisions is important in Ballarat and Victoria in general.

   Not surprisingly, AVCs were the most significant cause of koalas entering a wildlife shelter and also the most important cause of death (Chapter 2). This agrees with other studies from NSW and Qld; clearly underlining the nationally significant impact that vehicles have on koalas.

2) While roadkill may occur anywhere along the highway study area, they did not occur randomly, but occurred with greater frequency in discrete nodes termed blackspots.

   This clustering enabled analysis of the drivers of higher frequency kills within a koala habitat (Chapter 3).

3) Although there was only limited influence from driver visibility (field of view), the most important components were related to koala habitat features. Koala habitat

features have been linked by other studies to the ability of koalas to persist in areas and been linked to the threat that roads pose to the species.

The parameters which had the greatest contribution to the likelihood of koalas being involved in a vehicle strike are those related to the area, quality, and degree of fragmentation, of the better koala habitat. Driver visibility towards the north or west was the only road/driver related parameter that contributed to an explanation of black spots – albeit a lesser effect than the habitat parameters. This might be associated with the fact that most traffic along this road travels towards the rising sun in the morning, and the setting sun in the evening; a proposition that needs further investigation (Chapter 3).

4) An understanding of the local koala ranging behaviour and habitat structure suggested that the juxtaposition of the road to koala ranges, together with aspects of koala natural history, were most likely driving the frequency of roadkill – not driver behaviour; this is in contrast to other studies.

   In the one black spot where koalas were studied intensively, koalas highly favoured remnant stands of their preferred browse species of *E. viminalis*, and the position of trees of this species in the landscape, especially in proximity to roads, exposed koalas to an increased risk of colliding with traffic (Chapter 4).

5) The key management implications were that:
   a) attempting to influence driver behaviour was unlikely to be effective in reducing the risk of collision, and consequently
   b) management should focus on avoiding risk by directing new roads away from preferred koala habitat, and on existing routes installing diversionary and protective infrastructure; this is supported by other research.

Literature suggests that, at a population level, drivers do not regulate their driving style to account for koalas; consequently koalas need protection from vehicles via pre-emptive planning, hard, protective infrastructure, or potentially, rescheduling peak traffic flows (Chapter 5).

6) The koala, as a species, was vulnerable to roadkill as it fell into a class of animal that would be vulnerable to these risks due to its feeding strategies.

   Koalas move overland in search of new trees within their range–increasing vulnerability to vehicle collisions where roads intersect home ranges. The preferential browsing of *E. viminalis* by koalas in this study site, the distribution of this fodder tree species in the landscape and the resulting differences in home range sizes between individual animals, have shown that their feeding strategy had an effect on road-kill vulnerability (Chapter 4).

7) Analysis should use a global model approach incorporating parameters from different scales as predictors, especially habitat quality. The inclusion of koala home range size represented by different radii in the model, for animals occupying lower quality habitats, is an essential analytical tool and has not been used in this way for the determination of koala road-kill blackspots before.

5.2 The Modelling Approach

The final model chosen incorporates no road specific parameters, instead featuring parameters associated mostly with the quality and fragmentation of koala habitat and supplementing them with data on the ecology of local koalas. This allowed the processes to be understood. As the approach is independent of road design and construction specifications, it should be easily transferred to other areas (Grimm, 1999). The model reflects a causative process and allows the prediction of KRBs, such models are highly recommended because of its prognostic abilities (Drew, Wiersma, & Huettmann, 2010). Januchowski et al. (2008), in their modelling, found that multiscale habitat variables were important to determine koala occurrence, and they found that it was essential to protect remaining core areas of high quality habitat. Ramp, Wilson, and Croft (2006) found that the parameters of availability of forage were indicative of locations where mammals were most likely to be killed. This research confirms both of their findings but qualifies it by underlining that, in this case, it is the fragmentation of the preferred fodder trees that causes an increased risk. Townsend et al. (2003) promoted a model that considered landscape configuration, in particular patch size and shape, as the predictor of presence and absence, and stressed the negative effect of habitat fragmentation; conclusions fully endorsed by this research and incorporated into the design of the conceptual model to be applied at other sites. Mac Nally, Bennett, and Horrocks (2000) encourage the use of global models that use parameters from different scales as predictors. They promote the incorporation of additional relevant measures such as habitat quality. The final model chosen uses several habitat variables, and by including koala home ranges for the specific site as one analytical tool (radius), not only looks at the landscape scale but considers the influence of small-scale habitat use by koalas (which can be at a micro scale).

The developed predictive model, which focuses on specific fragmentation parameters, allows for the identification of explanatory factors which enables species-specific management strategies to be developed and implemented at black spot locations.

Delibes, Ferreras, and Gaona (2001) argued that individual animals occupy habitat near blackspots due to territoriality with the assumption been made that, given no obstructions to habitat choice, individuals would choose the highest quality habitat available. Here, while the number of animals and restricted time frame of the research make it difficult to express firm comments on territoriality, it was obvious that some koalas occupied very small home ranges centred on preferred habitat trees. This information feeds into the model by influencing the size of radius used when analysing the amount of habitat and degree of fragmentation; as it is the koala, with the larger home range, occupying fragmented preferred koala habitat, which is more likely to cross a road. While some models utilise micro-habitat characteristics at the site scale (30 m in diameter) to predict presence and absence (Johnson & Omland, 2004), the findings from the Ballarat study suggest that for this specific location, a 400 m radius is most predictive.

It is important to apply the model not only conceptually but to test its validity at a new site, using historical data (Lindenmayer, McIntyre, & Fischer, 2003). It is envisaged that this can be achieved at the Nebo-Eton Road-side in Central Queensland where koalas exhibit preference for different eucalypts and have much larger home ranges compared Ballarat and Victorian koalas.

5.3 Conceptual Model

This thesis contained some fundamental research (International Union for Pure and Applied Biophysics, 2016) (e.g. diet of, and home range sizes for, local koalas in a fragmented, road-side habitat). In cases where the aim is to conserve a species like the koala, we need to apply the findings from such research conceptually in order to make efficient use of resources.

A conceptual model has been developed (Figure 5.1) to illustrate the key factors contributing to black spots, and facilitates the development of hypotheses regarding the causes of the high relative frequency of koala mortality at these localities. Figure 5.2 illustrates the relative contribution of key habitat and fragmentation parameters on defining the black spots.

This model facilitates consideration of the key drivers of (a) the development of black spots, and (b) facilitates the understanding of regional koala ecology that drive the increased frequency of roadkill at these points and can be described through diagrams (Figure 5.1 & 5.2).

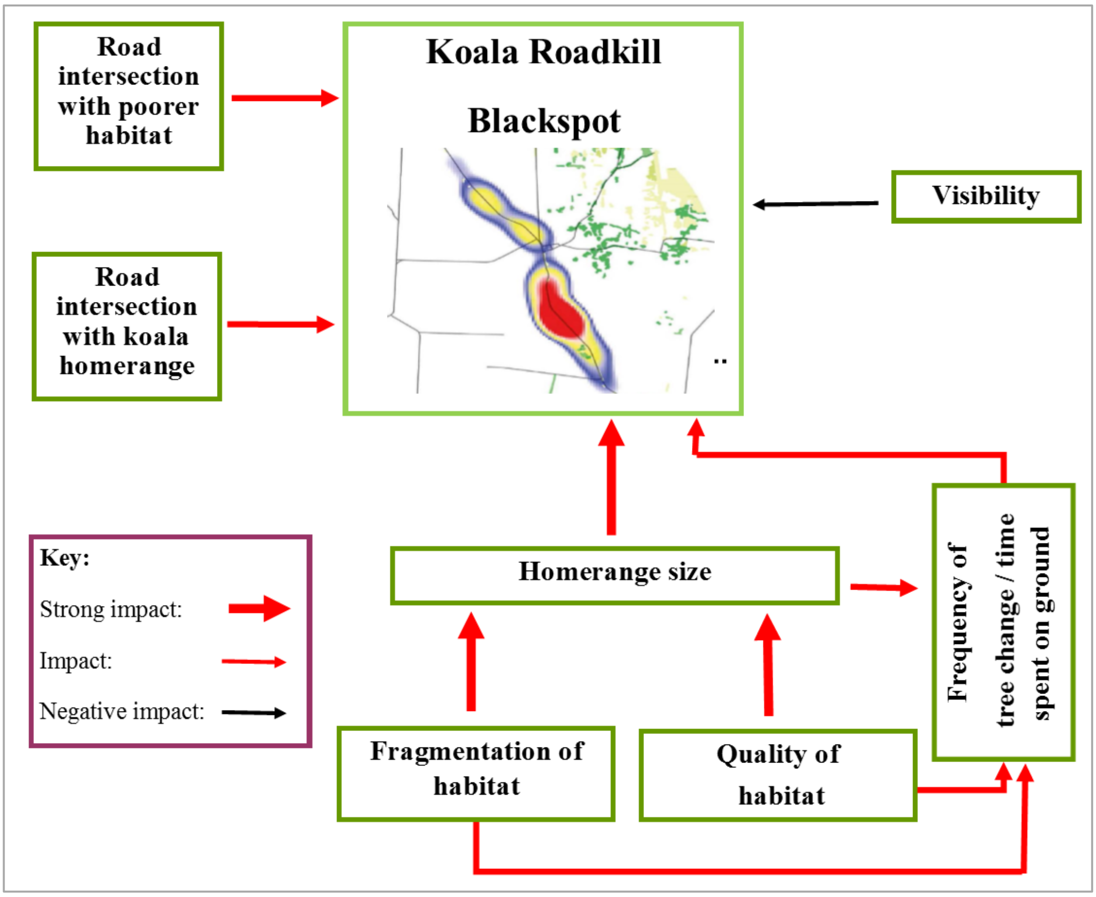

Figure 5-1 Koala Road-kill Black-spot Concept for this study site only.

The general concept for the determination of Koala Road-kill Blackspots along the Midland Highway (Figure 5.1) features, as the strongest influences, the quality and the fragmentation of 'Secondary A' and 'Primary' koala habitat. These two drivers show strong positive influences in the spatial classification (Chapter 3), while the radio tracking study (Chapter 4) found that koalas occupying home ranges with fewer primary food trees, had larger home ranges, moved further, changed trees more often and where their home range intersected with the road or railway line, resulting in more frequent crossings of these. Parameters associated with the road e.g. driver visibility, speed limit and width of road, show little impact, however, driver visibility towards north or west (Vis_NW) showed a negative (-0.297) (favourable) effect.

It is important to consider scale when examining koala habitat to determine the likelihood of road-kill blackspots to occur. A lower quality, fragmented habitat will influence homerange size and force koalas to change trees more frequently and spend more time on the ground. Both homerange size and frequency of tree change/time spend on ground will affect the likelihood of koalas falling victim to a collision with a vehicle in a black spot. It is difficult to understand how koalas use a given habitat and a coarse scale habitat mapping exercise will most likely be unable to pick up koala movements in areas of mixed habitat quality unless it is supported by detailed radio tracking studies.

The koala is a multi-habitat species that moves through the landscape, is sensitive to loss of, and the spatial configuration of its habitat (McAlpine, Bowen, et al., 2006). From the model, it is hypothesised that, koalas which use only parts of primary habitat and supplement it with lower quality fragmented habitat have larger home ranges, these koalas will have to spend more time on the ground moving between trees (Melzer & Houston, 2001), and consequently, where the home range is intersected by the highway, koalas will cross the highway at a relatively high frequency, and with that comes an increased likelihood of a road strike.

Conversely, where habitat is of relatively high quality and not fragmented, koalas will have to spend less time on the ground moving to new trees. Consequently, the likelihood of a road strike is relatively low.

In this study site (Chapter 4), the lower quality habitat was closer to the road and therefore, the intersection of the road with the lower habitat, and generally, the road intersecting with koala homeranges, increased the chances of koalas crossing the road and the potential for a road-kill to occur. Conversely, where the primary habitat occurred, in the least fragmented state, homeranges were smaller, tree changes were fewer, homeranges were less likely to cross the road and therefore the chances of a koala road-kill black-spot occurring, was very low.

Such relationship was greatest at the 400 m radius which is approximately the size of homeranges of koalas occupying the lower quality habitat in this study site. A detailed look at the influences of habitat factors for all 68 of the 400 m radii is shown in Figure 5.2.

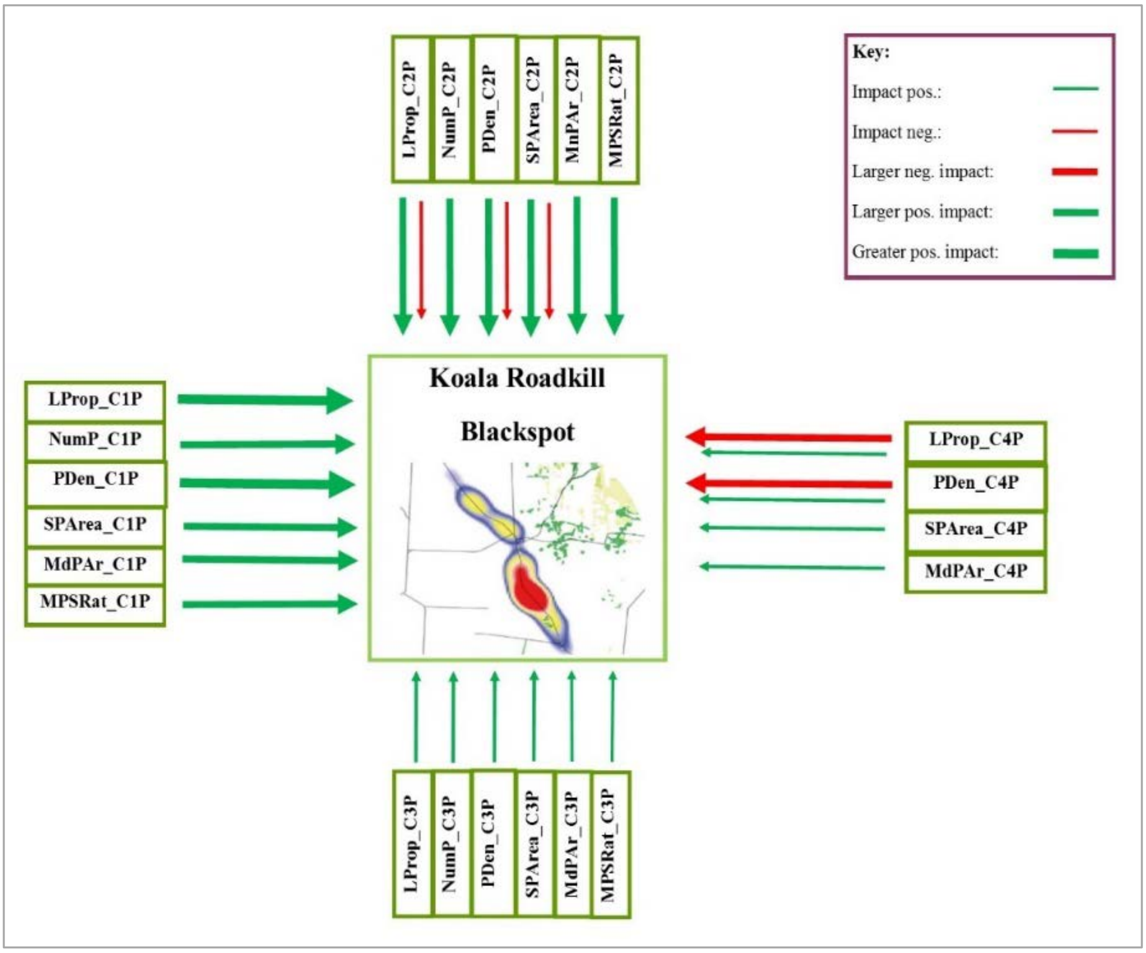

Figure 5-2 Impact of habitat/fragmentation parameters on koala road-kill blackspots for 400m radii. (Table 5.1 gives specifics and definitions for all remaining parameters).

Table 5-1 Fragmentation Metric Definitions for parameters remaining for the 400 m radii analysis; adapted from Elkie, Rempel, and Carr (1999); Wang, Blanchet, and Koper (2014). 'x' will be substituted by 1, 2, 3, 4 in accordance with the category of habitat under investigation.

Name	Code	Description
Smallest patch area	SPArea_CxP	Area of the smallest patch of that habitat type within the particular radius.
Landscape proportion	LProp_CxP	Proportion of that particular koala habitat category over all koala habitat in the landscape within a certain radius. Comparisons are obtained by differences in values, and have direct interpretative value. It is useful for defining a landscape, and comparing class areas within a landscape.
Mean patch area	MnPAr_CxP	The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. Not only is this information the basis for many of the patch, class, and landscape indices, but patch has area had a great deal of ecological utility in its own right.
Mean patch shape ratio	MPSRat_CxP	The ratio between the perimeter of a patch and the perimeter of the simplest patch in the same area.
Median patch area	MdPAr_CxP	Equals the value of the corresponding patch metric for the patch representing the midpoint of the rank order distribution of patch metric values for patches of the corresponding patch type.
Number of patches	NumP_CxP	Equals the number of patches of the corresponding patch type (class). Number of patches of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. It may be fundamentally important to a number of ecological processes.

In summary: It is hypothesised that the primary cause of localised incidences of a relatively high frequency of koala roadkill was the increased frequency of koala road crossings. In the Ballarat example, this was a consequence of the accidental coincidence of a highway with koala home ranges in fragmented habitat.

Replication, at least in concept, in other sites is required to provide the data that could be used to assess and further develop management strategies, and to refine the predictive model of species–environment relationships (Guisan et al., 2006), and to identify any general principles that may apply across sites or regions.

This study has developed a model that identifies black spots and facilitates the understanding of factors potentially driving the roadkill at these black spots on a highway near Ballarat. Questions remain as to whether (a) the investigative approach is widely applicable, and (b) whether the conceptual model will apply to other parts of the koala's range. Studies of koalas and koala road kills along a portion of highway in Central Queensland provide an opportunity to test this hypothesis, at least conceptually. Unfortunately project scheduling precluded a quantitative replication of the approach here.

However, this analogous situation is considered briefly to set the scene for future work. The general description of the analogue and the methodological approach is outlined in Appendix E.

Based on the findings from chapters 3 and 4, it is hypothesised that KRBs will be located along sections of the road that feature mostly highly fragmented koala habitat of Secondary A and primary categories within radii reflecting the home ranges of koalas occupying the lower quality habitats. This might explain why there appears to be a KRB, as identified in the report by the Department of Transport and Main Roads (2015), away from areas considered to feature high levels of koala activity, located in flatter sections of the highway, at the top of the range. High levels of koala activity or better high density of koalas, will be found in areas that contain the primary koala habitat in the least fragmented forms, therefore requiring koalas to spend less time changing trees (Thompson, 2006), and potentially exhibiting fewer road crossings compared to koalas in the lower quality KH areas. However, there are some critical differences in ecology between the koalas at the Queensland analogue and those at the Victorian Ballarat site. Notably the Queensland koalas have much larger home ranges on average than Victorian koalas (Melzer, Cristescu, Ellis, FitzGibbon, & Manno, 2014). Queensland koalas usually change trees at least once per night and frequently more, and can travel considerable distances overnight, irrespective of habitat quality, relative to Victorian koalas. Sanderson, Redford, Vedder, Coppolillo, and Ward (2002) argue that planning for conservation needs to consider all the complicated biological, social and economic factors which affect the ecological integrity of a site and they promote the use of conceptual models as this also helps to make the best use of the limited conservation resources. The Nebo-Eton Road site makes a perfect study site to test the concept before engaging in the construction of mitigation devices near KRBs areas.

5.4 Implications for Management

Roads are not just a symptom of universal habitat loss, they play a specific role in reducing biodiversity and can threaten individual animals and even populations (Ahmed et al., 2014), koalas are no exception. Small and isolated populations are particularly at risk of extinction due to anthropogenic influences and environmental catastrophes (Cardillo et al., 2005). Effective conservation solutions for wildlife populations living in fragmented habitats requires integrated landscape-level management to reduce mortality risk, protect core areas and corridors (Moqanaki & Cushman, 2016), and in the case of koalas living in this road-side habitat in the study side, requires measurements to re-establish primary koala habitat. In many cases, conservation measures only focus on maximizing short-term persistence (Traill, Brook, Frankham, & Bradshaw, 2010), as financial and political realties often prevent targeting long term solutions. In section 1.5 broad koala management issues have already been discussed. This Chapter will mainly discuss the findings from this research where they can affect local and site specific management actions.

5.4.1 Injured koalas.

The outcomes of Chapter two clearly show that attacks by dogs and collisions with vehicles are serious threats to the local Ballarat, regional, but also Victorian koala populations in general; these findings are in line with research for all of the koala's range (Department of Environment and Energy, 2016; Melzer, Carrick, Menkhorst, Lunney, & St. John, 2000; Menkhorst, 2004). Collisions with cars are mostly fatal and if not killed by the initial impact, many koalas succumb to their injuries, even if admitted to a wildlife carer. Tribe and Brown (2000), suggest that one way to mitigate threats to wildlife populations is the rehabilitation of injured and orphaned wildlife which may contribute to the conservation of some wildlife populations. However, it appears that, in the case of the Ballarat koala population, many animals are less likely to survive rehabilitation. While it is understood that recordkeeping and wildlife training has improved in Victoria since completion of this research through the establishment of more structured carer organisations and networks.

However, they are still lagging behind better resourced and supported facilities of New South Wales and Queensland.

Figure 5-3 Koala (♀) found injured through collision with car near another black spot. Discovered during survey work, taken to veterinarian/wildlife carer. Died after 5 weeks.

Monitoring studies of rehabilitated and released koalas are essential (Ellis, White, Kunst, & Carrick, 1990; Jones, 2008). Tribe, Hanger, Nottidge, and Kawakami (2005), found that 70–100% of rehabilitated koalas survived over 2–11 months monitoring and survival rates were no different to that of wild controls (Lunney, Gresser, Mahon, & Matthews, 2004). However, no such surveys exist for the Ballarat populations. Release of rehabilitated animals into road-side habitat, as required by law, where they originally were injured by vehicular collisions, is a questionable practise.

In Chapter two, it was also shown that in Ballarat, male koalas were admitted into care at a ratio of 55:45. Over-representation of male koalas has been observed by other studies e.g. Department of the Environment (2009), Dique et al. (2003), and may suggest that there is a potential for limiting the gene flow and thereby may contribute to a decline in local populations (Holderegger & Di Giulio, 2010). Anecdotal evidence exists, showing that numbers of koalas are decreasing in the Ballarat population; a theory that needs exploring through a larger study over longer time. The impact of a reduction in numbers on the genetic and overall viability of the population needs further investigation, especially in light of existing habitat fragmentation issues and the threat that AVCs pose to koalas in the region.

5.4.2 Koala habitat. In landscapes where the extent of primary habitat has been reduced by removal and fragmentation, secondary habitat can assist in facilitating koala movement (Smith et al., 2013). In Ballarat, historical and continued loss of koala habitat impacts negatively on local populations, a fact that is underlined by the findings of this research that show the importance of both Secondary A and Primary habitat in relation to the occurrence of KRBs. Secondary A habitat emerges as ecologically slightly more important than primary habitat which is a reflection of the fact that Secondary A habitat is more extensive than primary in Ballarat because of historical clearing (Januchowski et al., 2008; Schlagloth, Thomson, & Mitchell, 2006). Hence, both Secondary A and Primary habitats are vital for the survival of the koala in Ballarat especially near KRBs.

Radio tracking of koalas in the study site has demonstrated that establishment of habitat corridors is less important than quality, total area and connectivity of habitat, and koalas that occupy lower quality habitat have larger homeranges, use more trees and change trees more frequently. Consequently, efforts to reduce koala vehicle collisions along the Midland Highway need to focus on providing a mosaic of large and unaugmented parcels of preferred (Primary and Secondary A) habitat. In urban areas, preferred koala habitat needs to be excluded from development (housing and roads), which has already been, at least in part, addressed by the implementation of a Koala Plan of Management for Ballarat; other municipalities need to follow this example. It is also important to protect individual habitat trees within urban areas to reduce koala movement. Even though, koalas in suburbia are exposed to dog attacks, measures to reduce such threats would also best be addressed through a Koala Plan of Management. Protection of koalas near the roads surveyed in this research, cannot rely exclusively on traffic calming efforts such as speed reduction signs or koala warning signs.

Large sections of koala habitat in the study site, especially primary habitat and individual primary habitat trees were found on the actual road-side, within the gazetted road reserve. Suitable management of road-side vegetation may assist in reducing the threat to koalas from approaching vehicles. Maintaining grass on road verges to a low level improves the visibility of koalas for approaching vehicles especially at night. However, the roadsides in this study were also often the only area to support significant koala habitat and care needs to be taken for management not to reduce the quality of this vegetation during maintenance operations.

A special case in point is the large remnant stand of *E. viminalis*, *E. ovata* and *E. pauciflora* in a paddock situated between the highway and the railway line. This land is owned by the State Government and leased to farmers for grazing. This parcel of land contains the most significant koala habitat in the study site and its protection is of the highest priority. There are similar parcels in many sections along the road and railway line. Most have remnant vegetation with little regrowth of native vegetation due to grazing pressure but show evidence of greater densities of koalas with smaller homeranges and fewer changes of trees for the animals that occupy such primary habitat refuges. Such parcels of primary habitat need to be protected, managed to allow for regrowth and re-vegetated with indigenous tree species.

5.4.3 Road-side vegetation as corridors. Prevett (1991) found little evidence that koalas use continuous corridors of vegetation as conduits in the Ballarat area. Studies of koalas in urban areas have established that provision of habitat corridors and patches are less important than total area and connectivity of habitat (White, 1999). The findings of this research support these findings as none of the surveyed animals left the study site during the

18 weeks of monitoring. However, a longer monitoring period, encompassing breeding and non-breeding periods, as well as ongoing surveys for new koalas in the area, and the capture and monitoring of more animals are suggested to strengthen this theory. Koala habitat near the highway, along many section of the highway, is the only koala habitat remaining in many areas, albeit in narrow strips and very close to the road. It would be, in most cases, very difficult and costly to fence off these areas. It is instead suggested to encourage neighbouring, private and public, property owners to retain, manage and revegetate their remnant stands of koala habitat and facilitate connection of these to the road-side habitat and with that, decreasing the fragmentation and reduce the overall edge length of patches.

5.4.4 Koala Road-kill Blackspots and road design. One finding of this work was the contributing factor of reduced driver visibility (field of view) and probably associated road speed, with koala vehicle collisions. However, ecological parameters had a bigger effect. Further the literature suggests that attempting to influence driver behaviour through speed controls is unlikely to significantly reduce road deaths at blackspots (Dique et al., 2003). If this is correct, then the management focus should be on risk avoidance measures—separating the koalas and the vehicles. This can be done at the planning phase by trying to avoid koala habitat, or by constructing or retrofitting protective and diversionary infrastructure.

Road features and driver behaviours

Vehicles travelling at night have been identified as a risk factor for AVCs (Rowden, Steinhardt, & Sheehan, 2008), and at dawn and dusk especially for koalas (Department of the Environment, 2009). Ellis et al. (2016) found that daylight saving time has the potential to decrease the occurrence of AVCs and Rhodes, Lunney, Callaghan, and McAlpine (2014) found that wider roads feature an increase in number of roadkill; while studies investigating different speed zones at night did not find a reduction in vehicular speed or a decrease in AVCs (Dique et al., 2003). Driver visibility towards the north or west (Vis_NW) was the only parameter in this group that showed a strongly negative (favourable) effect; it might be associated with the main traffic along this road travelling towards the sun in the morning and again at night; a proposition that needs further investigation. In general, in this Ballarat case study, visibility by drivers, speed limits and width of road only showed a limited impact but cannot be fully excluded from consideration, however, the quality and degree of fragmentation were the strongest parameters affecting the occurrence of koala road-kill blackspots.

Ecological parameters

Ecological parameters had a bigger effect than those related to the road and drivers. In fact, identifying specific collision 'hotspots' based on these parameters is essential in implementing tailored interventions that contemplate all applicable impacts on koalas (Huijser, McGowen, Clevenger, & Ament, 2008; Ramp, Caldwell, Edwards, Warton, & Croft, 2005). The identification of such 'hotspots' or koala road-kill blackspots has been achieved by this study. Mitigation efforts designed to reduce motor AVCs often focus on discouraging animals from road sides and decreasing speed of vehicles (Magnus, Kriwoken, Mooney, & Jones, 2004). However, others argue that mitigation can only be effective if habitat use by the target species is considered (Roger & Ramp, 2009; Santos, Lourenço, Mira, & Beja, 2013; Simmons, Sunnucks, Taylor, & van der Ree, 2010). The findings of this research strongly support this proposition.

Mitigation

Mitigation measures such as wildlife over-passes have been trialled and found to work better for certain species than others even within the same family e.g. possums (Goosem, Wilson, Weston, & Cohen, 2008). Koala underpasses have been implemented successfully at several sites (Dexter, Appleby, Edgar, Scott, & Jones, 2016) in Queensland (Taylor & Goldingay, 2010) and New South Wales (Bax, 2006; Taylor & Goldingay, 2004). However, the success of other projects have been questioned (Litvaitis & Tash, 2008; Pieters, 1999) or found to be of varying success only (Van der Ree, Clarkson, Holland, Gulle, & Budden, 2008). Such measures include koala exclusion fences, sometimes combined with koala and wildlife, under or over-passes (Forman, 2003; Goosem & Weston, 2002; Hayes, 2006). These measures are rarely installed retrospectively (Pyper, 2004), instead, they are usually combined with the building of a new road, road widening or duplication (Bond & Jones, 2008). In Victoria such constructions are rare, although one was implemented on another highway leading into Ballarat where koala roadkill had been recorded. The Ballarat Bypass koala exclusion fencing and underpass project must be considered a failure. While the exclusion fences (Figure 5.6) were not maintained well and koalas were able to enter the highway through open sections or underneath the wire where it was not tied up properly, it has most likely cut a koala population in half by reducing the ability of many animals to overcome the obstacle of the highway, as the underpasses supplied were found only to be used by foxes, not by koalas (Prevett, Hives, & Cerini, 1992). Fences guiding koalas to underpasses also need to be wide and non-threatening and cannot be labyrinth-like and overgrown with vegetation (Figure 5.7). Underpasses must be target species-specific and those used by koalas are usually wide, open, tall and short, not like the design used at the Ballarat Bypass (Figure 5.8). Fencing and underpasses were installed when the four lane, Ballarat Bypass was originally constructed. Installing such mitigation devices along the Midland Highway study site is a more difficult undertaking. The Midland Highway is mostly a dual-lane road with much of the fragmented koala habitat, often consisting of individual or clumps of remnant habitat trees, being found largely on the verge of the road (Figure 3.1 in Chapter 3). It is difficult to fence off this type of habitat without affecting the vegetation itself or compromising on road safety measure e.g. width of shoulder of road. In any case, any mitigation should always, as the priority, include and focus on retention and revegetation of, Primary and Secondary A, koala habitat.

Temporary signage incorporating flashing lights (dynamic signage) have been effective in reducing deer collisions with vehicles (Hardy, Lee, & Al-Kaisy, 2006; Hedlund, Curtis, Curtis, & Williams, 2004; Sullivan, Williams, Messmer, Hellinga, & Kyrychenko, 2004), and activated warning signs have been tested on koala as well with varying effect (Bond & Jones, 2013; Litvaitis & Tash, 2008; Stanley, Hardy, & Lassacher, 2006). Such devices are difficult to implement and maintain especially in black-spot locations such as found in this study where it is difficult to tag all animals and where koalas often live in trees very close to the road; this could have the effect that warning signs would be operating continuously or there might be limited time for the signal to be activated. In any case, such measures would need to be run out in conjunction with an elaborate education and monitoring campaign.

Mitigation measures implemented at the Ballarat Bypass

Figure 5-4 The fence on the right guiding koalas to the small koala underpass was left unfinished.

Figure 5-5 Labyrinth-like koala guide fence—overgrown with vegetation.

Figure 5-6 Second underpass—very narrow diameter, dark, continues for 60 m under the road.

5.4.5 Education. Experiences from the process of promoting and implementing the Koala Plan of Management for Ballarat (Schlagloth et al., 2006) have shown that education plays a vital part in informing the public about the need for targeted conservation actions for local koala populations. While koala habitat atlases exist for the other two councils that encompass the highway, it is suggested for those councils to also develop koala management plans and join forces with the City of Ballarat in promoting koala conservation measures, especially awareness of koala road-kill blackspots and preventative measures that can be easily taken by residents and drivers of vehicles. Such campaigns must target driving behaviour and should be timed to have maximal effect before the spring/summer breeding season, highlight collision hotspots/blackspots, recommend daytime travel (Rowden et al., 2008) and reduced speed in areas of concern (Ellis et al., 2016). Any adopted road-kill reduction measures such as under/over-passes, speed reduction, fencing etc. (see section 5.2.3 for more detailed suggestions) would also require repeated public promotion. The retention of remnant koala habitat needs to be promoted with landholders and enshrined in regulation and policies and strategic revegetation with primary koala habitat species needs to be encouraged; Kavanagh and Stanton (2012) also suggest that revegetation to restore habitat for the koala should be focused in areas where remnant vegetation is already present. Whatever koala road-kill mitigation measures will be implemented, regular education awareness campaigns need to be maintained as the public easily forgets and the issue is effectively ignored in public policy (Lunney, 2013). Any new urban development planning must consider habitat preservation and revegetation, and koala fencing and under/over-passes for new roads.

5.5 Future Research

Validation of model

Polak, Rhodes, Jones, and Possingham (2014) promote the use of a decision science framework to determine the most cost-effective combination of actions to mitigate the effects of roads on wildlife under budget constraints. Such decision framework requires the collection of a wide array of data to be effective; when it comes to the management of koalas and their habitat near roads, one always needs to first collect baseline habitat and population information to allow comparisons to be made before and after management and over time. These data will assist in comparing the site subject to the development proposal to other sites and situations, and establish management prescriptions that will minimise the effect any work will have on the local koala population. A detailed understanding of population processes needs to be established to enable both the predictive assessment of outcomes given certain management options, and also to quantify the impact of external threats and the potential amelioration of these threats.

Goosem (2012) calls for a holistic approach to mitigation of road impacts that include adequate long term funding, before and after construction monitoring also of genetic connectivity, and should comprise replication at the landscape scale.

While the collection of baseline data is not the norm when it comes to road design and modifications, a number of studies involving radio tracking of koalas pre-, during and post-construction to investigate the effectiveness of various measures need undertaking. Some of the inferences developed in this paper should be independently testable; the koala road-kill conceptual model should be applied and executed to test its potential to be applied to similar situations. For example the conceptual model for the Nebo koala population should be tested on-site including koala habitat surveys, road-kill monitoring and ranging behaviour of koalas.

A broader, longer-term study

Taylor and Goldingay (2012) called for a national strategy to mitigate the impacts of roads on wildlife populations in Australia in light of a lack of research and funding. While the science and study of road ecology has developed since then, there still remains the need to develop a national strategy before building new roads in all of the koala's range.

In the case of the Ballarat-Midland Highway study, it is essential to conduct a longer-term study encompassing several seasons to ensure observation of changes during breeding & non-breeding times and to widen the area and numbers of source animals. This would strengthen the findings in relation to koala ranging behaviour and movements in relation to roads and shed some more light on the question of the road-side habitat functioning as a habitat sink.

While speed zones did not show a strong impact for the occurrence of koala road-kill blackspots in this study, research into actual travel speeds along this road is required to establish whether adherence to existing speed limits may influence the frequency or severity of AVCs.

5.6 Overall Significance

This research clearly showed that collisions between vehicles and koalas pose a risk to koala populations in the Ballarat region. Especially male, and probably younger koalas were affected and also had lower chances of rehabilitation. Young koalas disperse from, or can be displaced from, optimal habitat to sub-optimal habitat by older individuals (Gordon, McGreevy, & Lawrie, 1990; Mitchell & Martin, 1990). Hindell and Lee (1987) working in the Brisbane ranges, linked koala habitat utilisation to the floristic and structural aspects of *Eucalyptus* communities. They found that koala density was higher where the most preferred fodder species was most abundant, had greater height and large canopies. They concluded that the large, most preferred fodder trees provide more foliage, thus requiring less frequent moves by the koala. Moore and Foley (2005) showed that tree visitation rate was most strongly influenced by tree size with koalas biasing their visits towards larger-than-average trees. Additionally, Santamaria, Keatley, and Schlagloth (2005) found that koalas in the Ballarat area preferred larger trees of their preferred fodder species; these findings were fully reflected by this research. Koala habitat in the study area was, to a large extent, made up of remnant vegetation containing mostly large trees. Koalas occupying these areas of remnant vegetation containing the best habitat, in general, had smaller home ranges, changed trees less frequently and had fewer road crossings—giving a clear indication of the importance of remnant native vegetation of preferred koala habitat species, for the long term survival of koalas in this area. In contrast, koala road-kill blackspots did occur, but away from these areas of remnant habitat, in most parts with larger proportions of the lower koala quality habitat with a greater degree of fragmentation. Koala roadkill are a serious threat to local koala populations.

Mitigation efforts aimed at reducing AVCs in general focus on preventing animals from crossing roads or minimising the chances of vehicles colliding with animals by implementing speed restrictions or installing warning signs (Magnus et al., 2004); but to be effective, they must consider habitat use of the target species (Roger & Ramp, 2009). This concept is fully supported by the findings of this research, with the amount, and the degree of fragmentation, of koala habitat being the decisive parameters in determining where koala road-kill blackspots occur. While koala visibility was not proven to be an important variable in the process of determining the likely occurrence of 'blackspots', the availability of koala habitat categorically was.

The approach taken in the design of the koala road-kill model in this research, by incorporating detailed habitat and fragmentation parameters, must be seen as a valuable application of similar uses of such parameters when investigating threats to koalas at a landscape scale (Januchowski et al., 2008; McAlpine & Eyre, 2002; McAlpine, Rhodes, et al., 2006; Rhodes et al., 2014). The development of the model aids in better understanding the dynamics of koala populations living near roads and determine their conservation requirements.

Habitat loss and fragmentation are considered to be the major drivers of population decline (Department of the Environment, 2009; McAlpine et al., 2015), however, the structure of the landscape and roads play an important part in this process and need to be incorporated into koala conservation—with an effective KRB model, as described in this research, being an essential tool.

So why did the koala cross the road?

Given that it is impractical to reverse 200 years of accumulated habitat loss, the overall goal of this thesis was to identify factors that cause koalas to be killed on certain sections of roads as this was deemed to be a more achievable task with a realistic hope of attaining some reduction in the threats to the long term survival of the koala. This research has achieved this goal and therefore the answer to the above question is: to get to the preferred fodder tree of *E. viminalis*, that is now on the other side of a road, since anthropogenic changes have severely fragmented the koala’s habitat.

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Appendix A: PCA Principal Component Analysis @ 400 m radius

Data worksheet

Name: Data2

Data type: Other

Sample selection: All

Variable selection: 1-5, 8, 11, 12, 14, 16, 17, 23, 26, 27, 29, 31, 32, 38, 41, 42, 44, 46, 47, 53, 56, 57, 59, 61, 62

Eigenvalues			
PC	**Eigenvalues**	**%Variation**	**Cum.% Variation**
1	2.49E+03	32.4	32.4
2	2.01E+03	26.2	58.6
3	1.26E+03	16.4	75.0
4	607	7.9	82.9
5	392	5.1	88.1

Eigenvectors					
Coefficients in the linear combinations of variables making up PCs					
Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Vis_NW	-0.264	0.039	-0.052	0.143	-0.404
Vis_SE	-0.143	0.030	0.081	-0.045	-0.824
Wid_NW	0.016	-0.009	0.064	-0.088	0.046
Wid_SE	0.016	-0.009	0.064	-0.088	0.046
Sp_Lim_NW	-0.128	-0.042	0.185	-0.127	-0.246
LProp_C1P	-0.004	0.337	0.242	0.058	0.022
NumP_C1P	0.093	0.309	0.245	0.037	0.011
PDen_C1P	0.016	.320	0.260	0.020	0.060
SPArea_C1P	0.057	0.318	0.226	0.106	0.001
MdPAr_C1P	0.077	0.319	0.226	0.074	-0.029
MPSRat_C1P	.067	0.310	0.240	0.039	0.048
LProp_C2P	0.265	0.061	-0.102	-0.278	-0.075
NumP_C2P	0.275	0.074	-0.085	-0.218	-0.106

Eigenvectors					
Coefficients in the linear combinations of variables making up PCs					
Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
PDen_C2P	0.258	0.062	-0.081	-0.313	-0.058
SPArea_C2P	0.264	0.062	-0.073	-0.269	-0.112
MdPAr_C2P	0.273	0.067	-0.091	-0.227	-0.106
MPSRat_C2P	0.265	0.067	-0.077	-0.260	-0.048
LProp_C3P	0.191	0.057	-0.174	0.293	-0.065
NumP_C3P	0.199	0.056	-0.163	0.280	-0.078
PDen_C3P	0.190	0.058	-0.178	0.286	-0.060
SPArea_C3P	0.194	0.060	-0.175	0.271	-0.073
MdPAr_C3P	0.193	0.060	-0.171	0.281	-0.071
MPSRat_C3P	0.199	0.063	-0.165	0.263	-0.066
LProp_C4P	0.148	-0.280	0.256	0.106	-0.012
NumP_C4P	0.216	-0.221	0.226	0.100	-0.065
PDen_C4P	0.150	-0.274	0.264	0.064	-0.030
SPArea_C4P	0.196	-0.214	0.263	0.060	-0.048
MdPAr_C4P	0.222	-0.191	0.257	0.082	-0.028
MPSRat_C4P	0.194	-0.234	0.246	0.072	-0.047

Principal Component Scores					
Sample	**SCORE1**	**SCORE2**	**SCORE3**	**SCORE4**	**SCORE5**
0-400	28.7	14.6	39.1	6.96	-54.8
800-400	-27.7	0.0564	57.8	64.3	-30.7
1600-400	-64.6	-10.4	89.8	10.8	-26.5
2400-400	2.61	0.252	76.5	-59.2	-13
3200-400	-19.9	-0.935	54.5	64.6	-0.601
4000-400	-95.1	-25.2	-1.03	-25.9	29.9
4800-400	-46.3	-5.99	-15.6	-80.1	-4.19
5600-400	-85.4	33.4	36.6	-21.6	16.6
6400-400	-106	-17.3	-1.76	-18.6	9.94
7200-400	-74.2	-68.9	47.1	-5.46	-9.8
8000-400	-91	29.4	40.4	0.343	23.4

Principal Component Scores					
Sample	**SCORE1**	**SCORE2**	**SCORE3**	**SCORE4**	**SCORE5**
8800-400	-102	-30.7	-3.59	-24.7	-14.9
9600-400	-105	-31.5	-7.22	-23.3	-6.02
10400-400	37	-54.1	-8.87	-12.2	-33.1
11200-400	9.02	-0.632	75.1	-60.1	7.93
12000-400	-0.59	-14.7	-65.9	-12.3	3.44
12800-400	-51	-17.8	-58	38.7	14.5
13600-400	-59.5	-73.8	25.3	8.39	12.1
14400-400	-58.1	-18.9	-54.6	39.9	-21.5
15200-400	-8.19	-5.27	-65.7	-12.8	-21
16000-400	30.8	-52.2	-18.6	-3.37	-31.1
16800-400	39.7	-54.8	-20.9	-3.77	-7.79
17600-400	33.8	-52.2	-21.6	0.222	-8
18400-400	36	-55.9	-20.2	-6.28	-19.2
19200-400	37.6	-55.6	-21.4	-3.36	-15.1
20000-400	53.9	13.2	31.4	5.9	6.68
20800-400	14	62.7	-21.7	-9.12	12.1
21600-400	-46.9	47.6	-1.56	46.9	15.5
22400-400	0.839	65.5	-22.9	-8.47	-15.6
23200-400	-92.1	38.8	31	-14	8.59
24000-400	-53.1	-77.8	28.5	-6.45	20.6
24800-400	-55.8	-10.8	-40.6	42.6	-4.18
25600-400	43.2	15.4	27.5	14.4	-24
26400-400	16.8	63.2	-24.5	-8.6	33.9
27200-400	15.1	62.4	-21.5	-7.72	16.5
28000-400	-1.25	68.5	-26.5	-1.92	-30.5
28800-400	6.66	65.4	-27.3	0.0455	0.641
29600-400	0.625	67.7	-25.2	-5.45	-11.2
30400-400	48.9	13.8	28.2	11.1	11
31200-400	2.18	62.5	-17.3	-8.76	-11.6
32000-400	8.74	63.8	-19.6	-10.2	-8.35
32800-400	4.4	66.3	-21.3	-9.11	-21.2
33600-400	52.5	13.7	34.1	3.31	-12.1

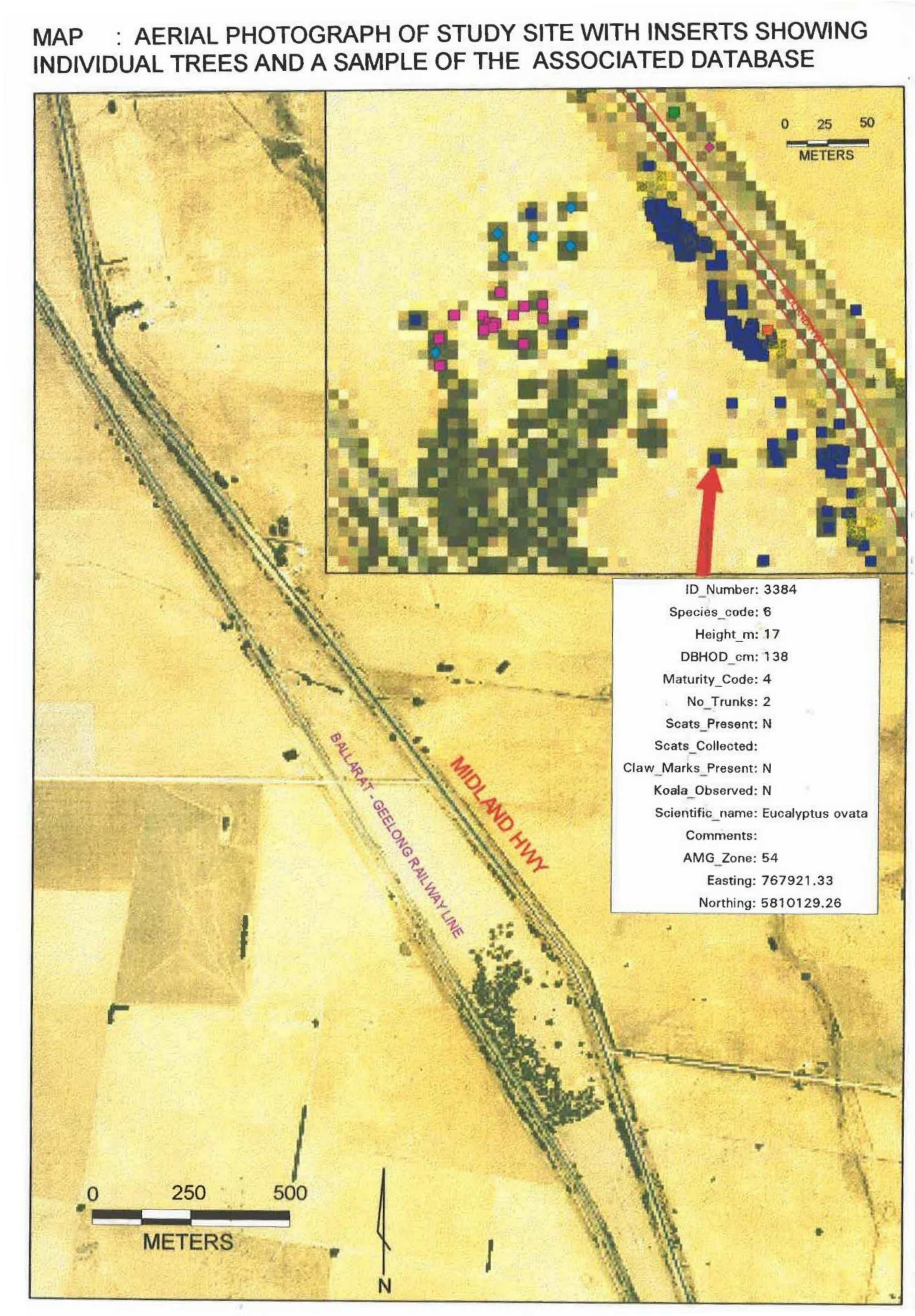
Principal Component Scores					
Sample	**SCORE1**	**SCORE2**	**SCORE3**	**SCORE4**	**SCORE5**
34400-400	49.6	14.2	24.9	15.3	7.28
35200-400	43.9	-53.2	-20.5	-2.63	6.31
36000-400	-56	-11.9	-48.6	38.5	33
36800-400	9.4	67	-27	-9.87	16
37600-400	0.698	68.3	-26.3	-6.26	-6.21
38400-400	-49.9	53.7	-7.24	43.6	3.61
39200-400	-18.9	-64.9	3.81	42.3	-5.8
40000-400	40.2	13.3	40.5	1.51	-38.3
40800-400	41	-54.2	-12.6	-8.5	2.98
41600-400	12.9	61.5	-14.9	-13.1	4.74
42400-400	-12.1	13	-63.3	-15.1	-30.9
43200-400	58.4	12.3	29.6	6.4	28.1
44000-400	58.4	12.3	29.6	6.4	28.1
44800-400	58.4	12.3	29.6	6.4	28.1
45600-400	53.1	13.5	32.6	4.75	-2.42
46400-400	46.7	-53.9	-20.8	-4.3	20.8
47200-400	48.1	-53	-18.7	-6.77	26
48000-400	48.1	-54.3	-20.8	-4.43	23.6
48800-400	48.2	-56.7	-22.2	-5.94	23.8
49600-400	37.3	-56.1	-24.2	-1.22	2.16
50400-400	38.6	-55	-21.2	-3.66	-9.05
51200-400	54.9	12.9	30	7.12	17
52000-400	54.9	12.9	30	7.12	17
52800-400	54.9	12.9	30	7.12	17

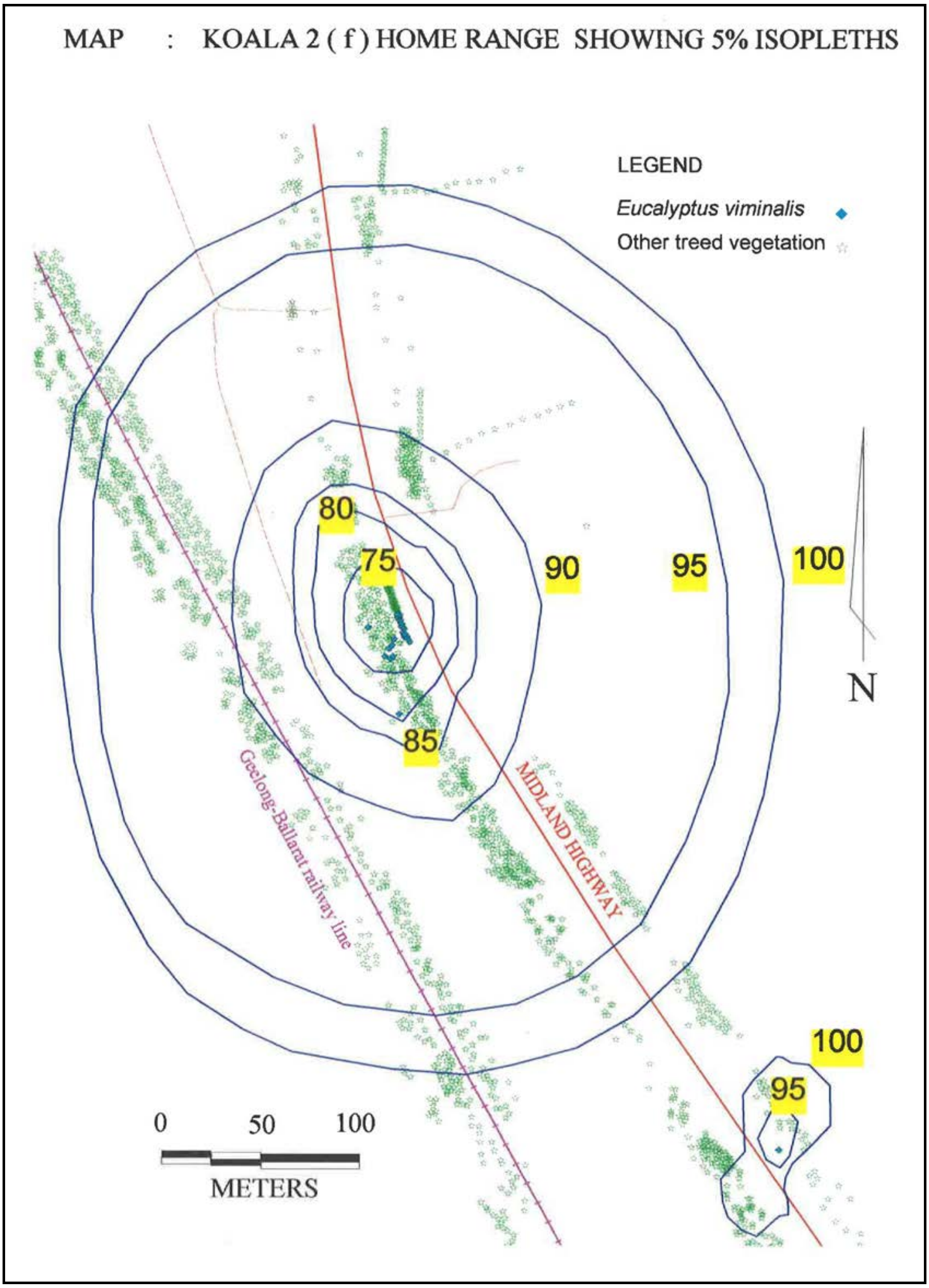
Outputs

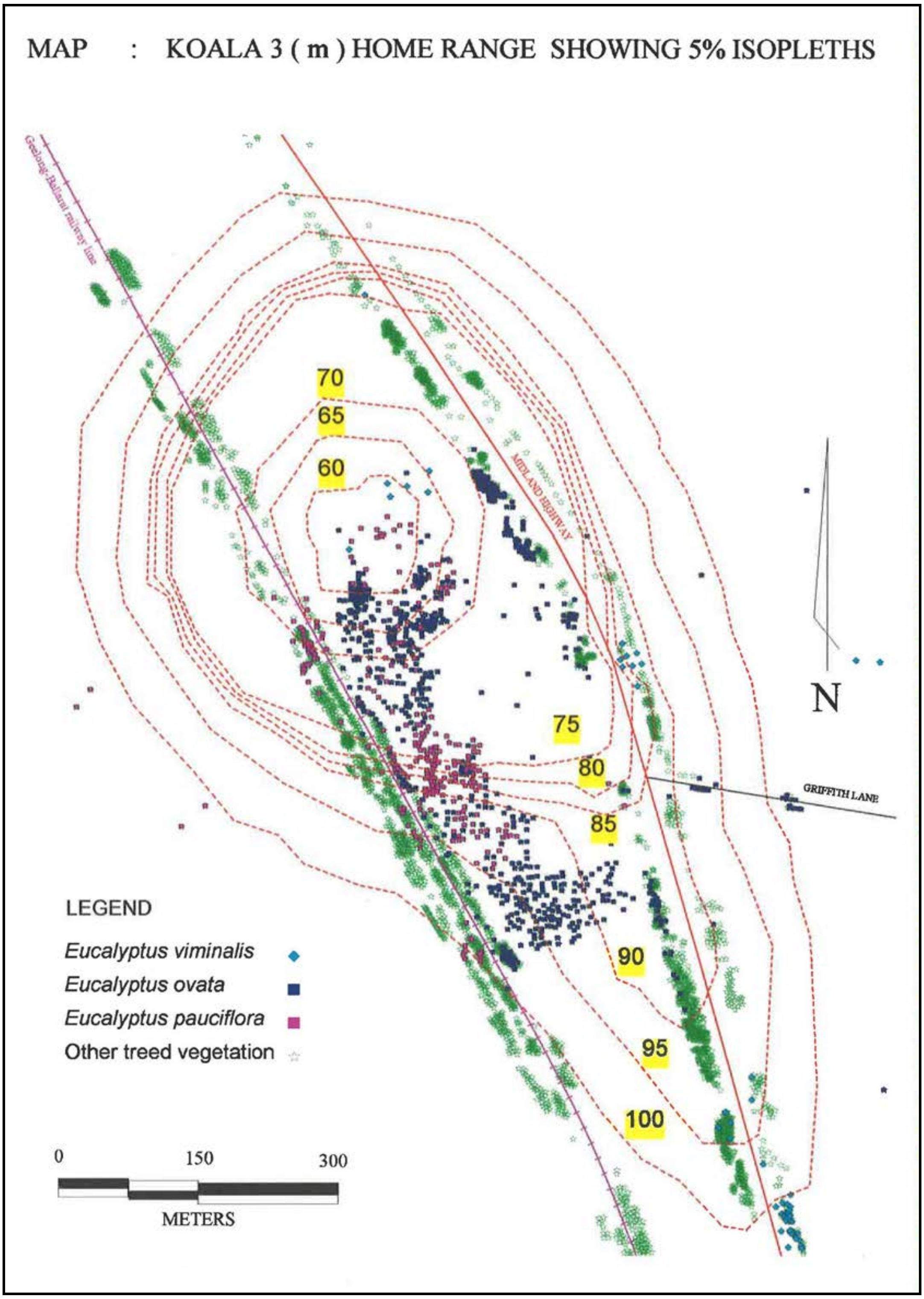
Plot: Graph31

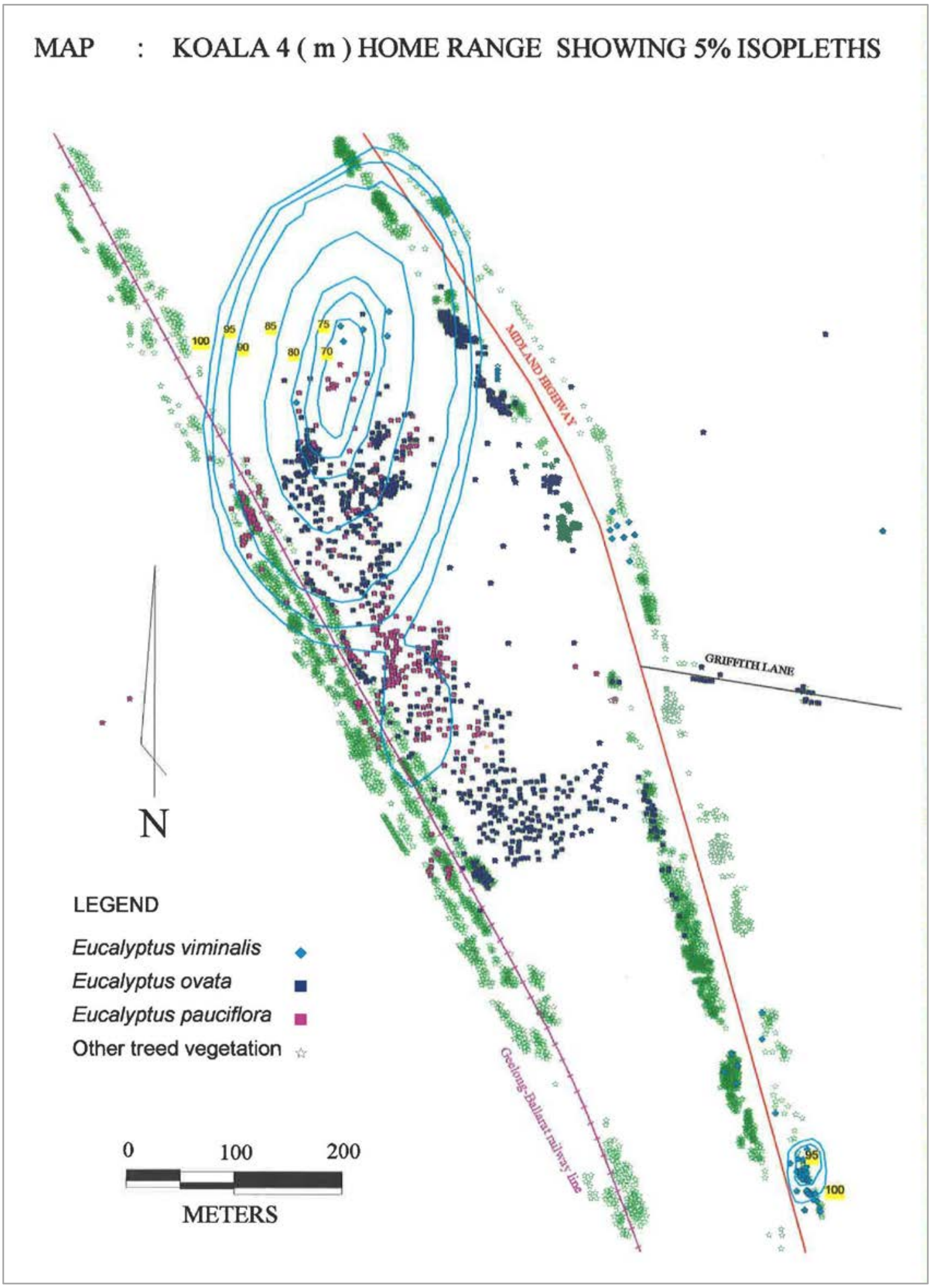
Appendix B: Scree Test for Principal Component Analysis @ 400 m radius

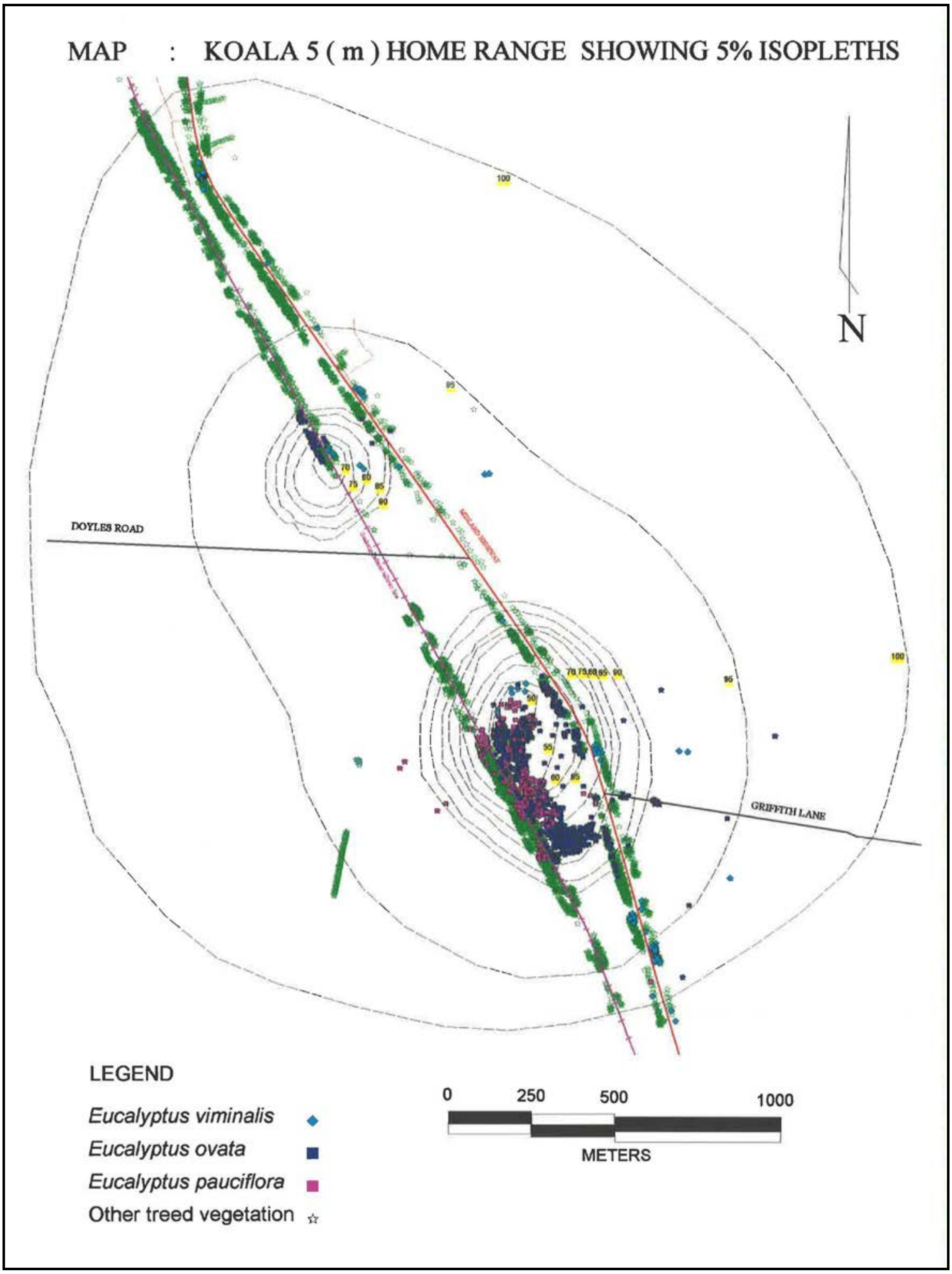
Appendix C: Map—Arial photograph and home ranges

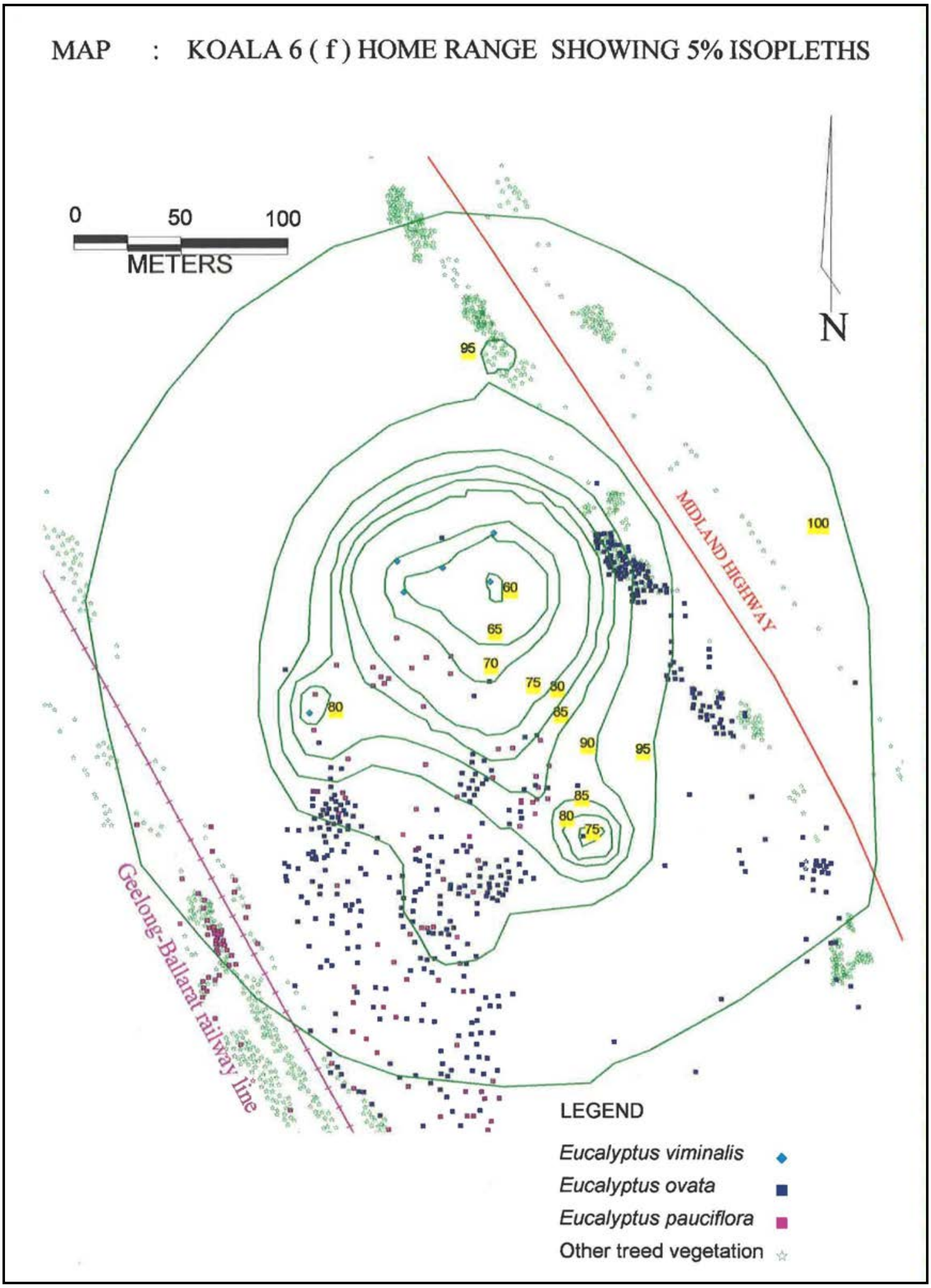


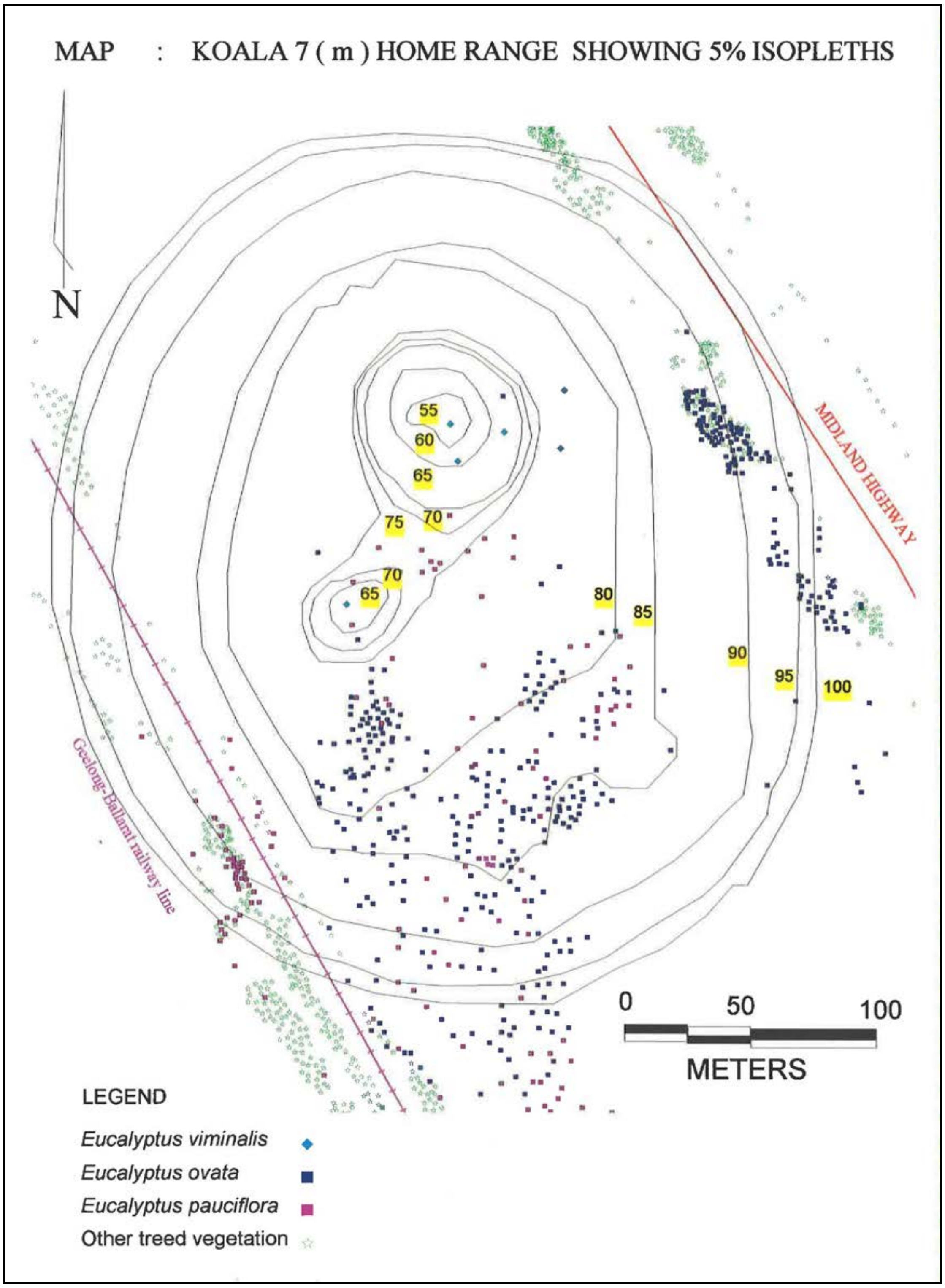

MAP : KOALA 2 (f) HOME RANGE SHOWING 5% ISOPLETHS
LEGEND
Eucalyptus viminalis
Other treed vegetation
80
75
85
90
95
100
100
95
N
Geelong-Ballarat railway line
MIDLAND HIGHWAY
0
50
100
METERS


MAP : KOALA 3 (m) HOME RANGE SHOWING 5% ISOPLETHS
Geelong-Ballarat railway line
MIDLAND HIGHWAY
GRIFFITH LANE
N
70
65
60
75
80
85
90
95
100
LEGEND
Eucalyptus viminalis
Eucalyptus ovata
Eucalyptus pauciflora
Other treed vegetation
0
150
300
METERS

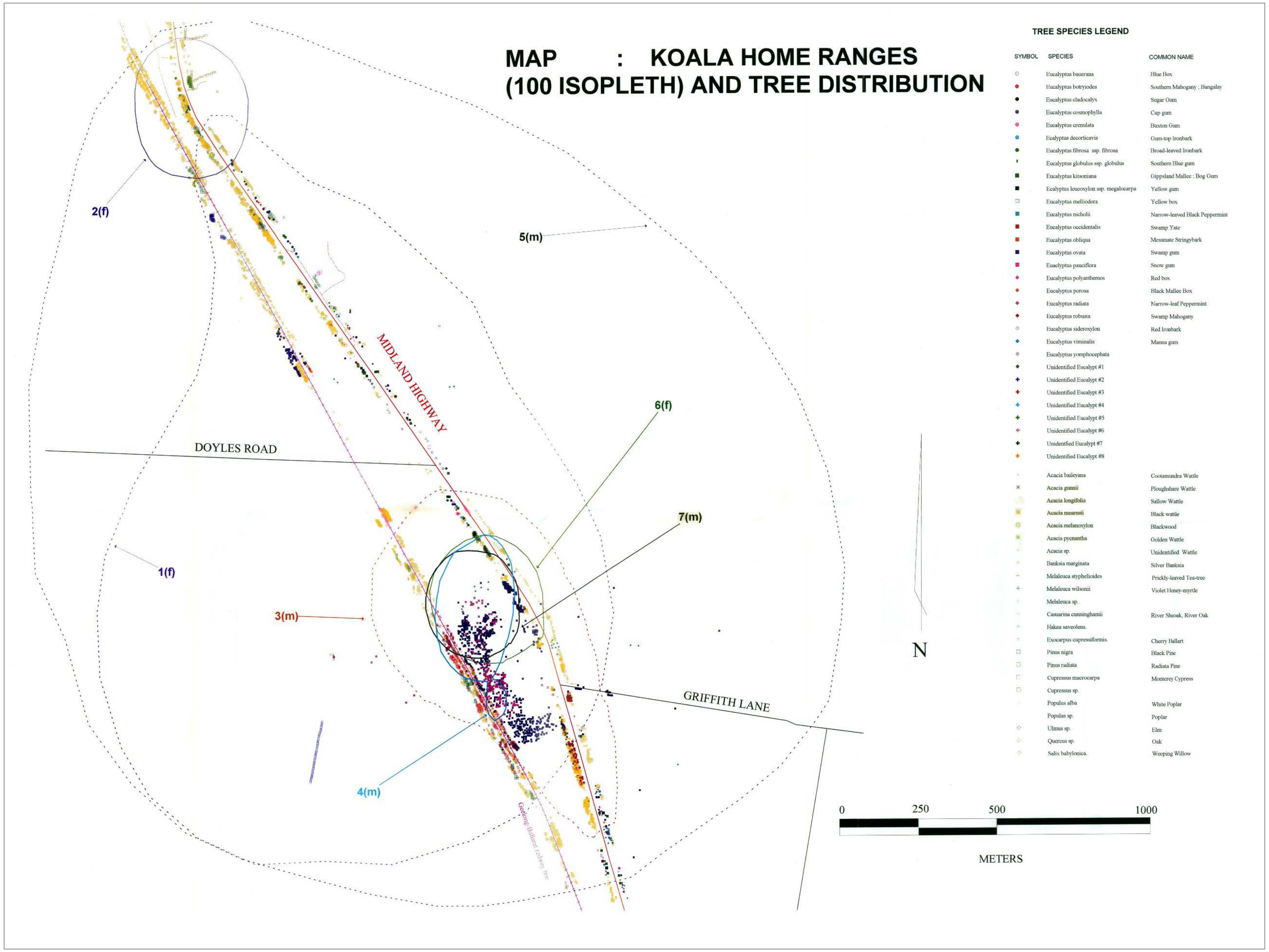

MAP : KOALA 4 (m) HOME RANGE SHOWING 5% ISOPLETHS
100
95
90
85
80
75
70
MIDLAND HIGHWAY
GRIFFITH LANE
N
LEGEND
Eucalyptus viminalis
Eucalyptus ovata
Eucalyptus pauciflora
Other treed vegetation
0
100
200
METERS
Geelong-Ballarat railway line
95
100


MAP : KOALA 5 (m) HOME RANGE SHOWING 5% ISOPLETHS
N
DOYLES ROAD
GRIFFITH LANE
100
95
90
LEGEND
Eucalyptus viminalis
Eucalyptus ovata
Eucalyptus pauciflora
Other treed vegetation
0
250
500
1000
METERS


MAP : KOALA 6 (f) HOME RANGE SHOWING 5% ISOPLETHS
0
50
100
METERS
N
MIDLAND HIGHWAY
Geelong-Ballarat railway line
95
100
60
65
70
75
80
80
85
90
95
85
80
75
LEGEND
Eucalyptus viminalis
Eucalyptus ovata
Eucalyptus pauciflora
Other treed vegetation


MAP : KOALA 7 (m) HOME RANGE SHOWING 5% ISOPLETHS
N
55
60
65
70
75
70
65
80
85
90
95
100
MIDLAND HIGHWAY
Geelong-Ballarat railway line
0
50
100
METERS
LEGEND
Eucalyptus viminalis
Eucalyptus ovata
Eucalyptus pauciflora
Other treed vegetation

Appendix D: Koala home ranges and tree distribution



Appendix E: Introduction to the Nebo-Eton Road Concept

The Queensland Department of Main Roads, in conjunction with various contractors, is undertaking a residual impact assessment as part of offset works required for the construction of two dual-lane carriageways, split carriageways, and general road construction for 3.756 km of the ‘Eton Range crossing’ on the Peak Downs Highway between Mackay and Nebo in Central Queensland, the Nebo-Eton Road. The residual impact assessment is based on the impact to the local koala population after the implementation of mitigation measures undertaken as part of the development. The proposal aims to provide conservation benefit and environmental value for the koala, and herewith establishes an opportunity for the koala roadkill model to be tested in a new location and situation within the Eton Range, but is also applicable to the wider Clarke-Connors Ranges region (Department of Transport and Main Roads, 2015).

Koala roadkill have been recorded along this highway for many years without having been analysed in any great detail. The actual area of road works is composed of four mapped Regional Ecosystems (REs), and some non-remnant vegetation. All vegetation in the area provides suitable habitat for koalas, except for the vine thicket community represented by RE 8.12.3. However, koala roadkills have been reported for many other sections of this road (Figure 5.3), where also other REs are found. The Nebo – Eton Road traverses 26 different REs, 20 of which, to various degrees, are likely to contain koala habitat tree species.
The main koala fodder tree species likely to be found in the area are *Eucalyptus tereticornis, E. camaldulensis*, *E. coolabah, E. melanophloia*, *E. crebra*, *E. populnea, E. drepanophylla* and *E. platyphylla* (Melzer, Cristescu, Ellis, FitzGibbon, & Manno, 2014).

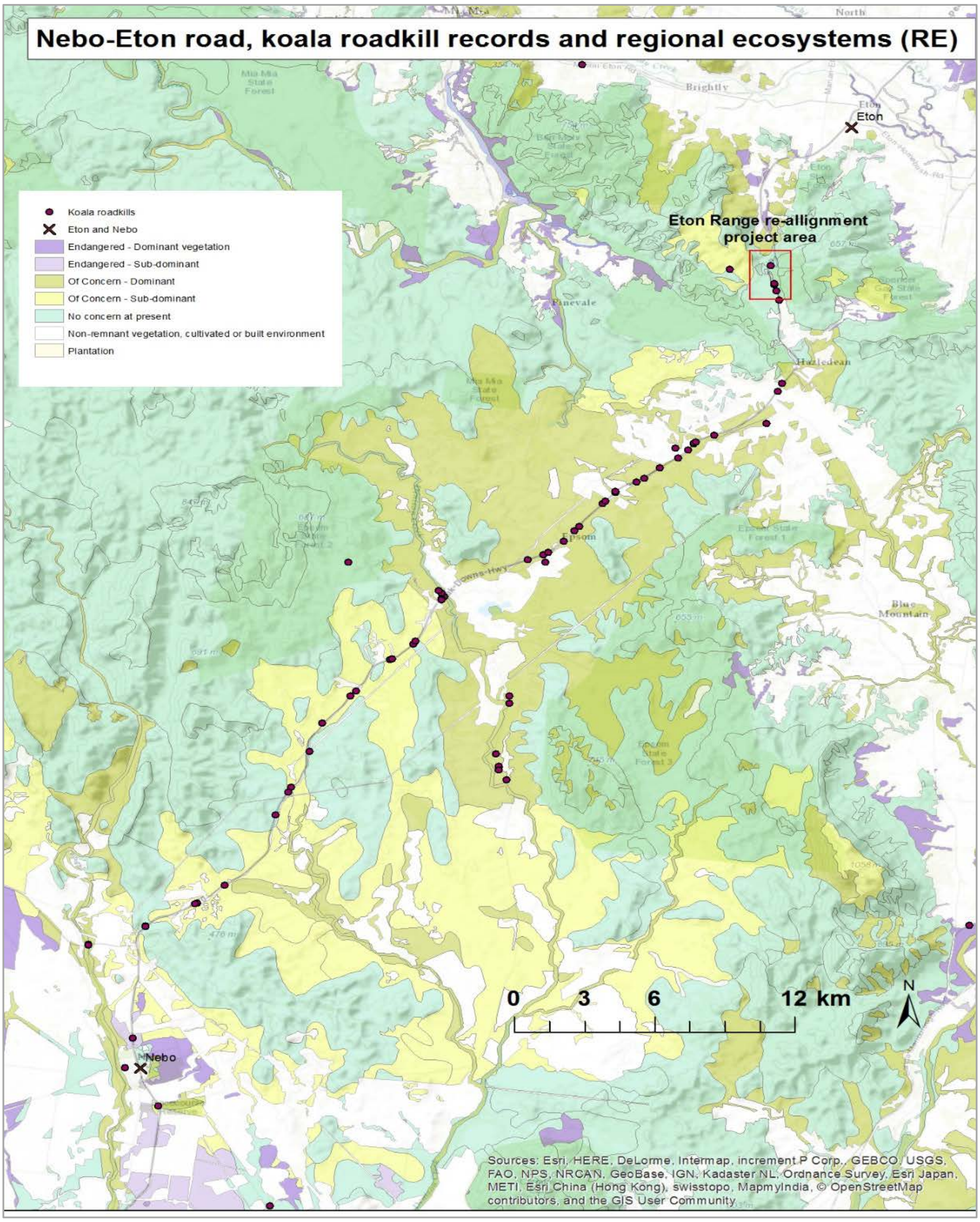


Figure A 1 Location of study site with koala road-kill locations and Regional Ecosystem classes.

A direct impact on the local koala population is possible due to the planned removal of some 30.9 ha of suitable koala habitat near the site of the development. Additional pressure may result from the fragmentation of koala habitat at the site. Habitat removal has been identified as an impact; some mitigation measures including koala fencing, a fauna crossing and sequential clearing, have been implemented with the aim of ensuring that no long term decrease in the size of the existing population occurs (Department of Transport and Main Roads, 2015).

The report by the Department of Transport and Main Roads (2015) used historical koala records to identify a potential north-south koala corridor and a potential koala road-kill black-spot approximately 10 km south-west of the project on the Peak Downs Highway.
The authors of the report question the reasons for this location being used as a crossing point by the local koalas as it was expected for koalas to cross the road near areas with high levels of koala activity, located in flatter sections of the highway, at the top of the range.

The conceptual model sets in place a plan for the identification of probable blackspots along the Nebo-Eton Road and for these to be compared to locations of historical koala roadkill.

The conceptual model follows the methods applied to the Midland Highway (Victoria) koala road-kill black-spot analysis outlined in Chapter three of this thesis and summarised in the flowchart Figure 5.4.

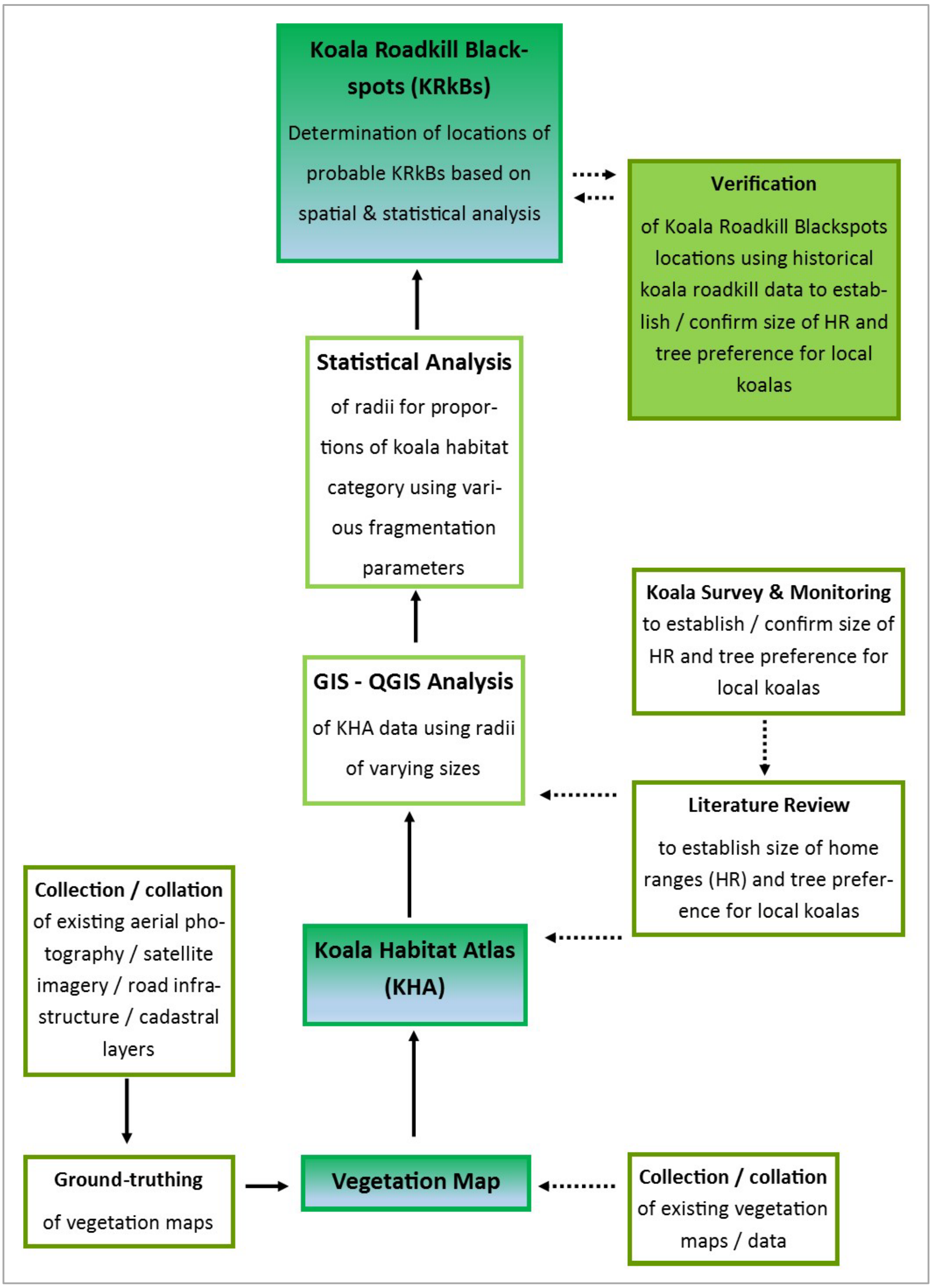


Figure A 2 Koala Road-kill Blackspot Assessment Flow Chart—Nebo-Eton Road.

The main stages of the approach are:

Vegetation Map: Good quality and accurate vegetation maps are the essential starting tool in the process of determining Koala Road-kill Blackspots (KRBs). Existing vegetation maps for the study site (5 km both sides of the Nebo-Eton Road) need to be obtained and collated including Regional Ecosystem Maps (RE). These need to be ground-truthed with an emphasis on the *Eucalyptus* communities that form the basis of the KH. To facilitate the mapping and ground-truthing processes, existing aerial photography, satellite imagery, road infrastructure and cadastral layers need to be obtained and overlayed with the vegetation map.

Koala Habitat Atlas (KHA): The KHA is based on the spatial arrangement of the *Eucalyptus* communities in the study site and the proportions of preferred koala habitat trees. It is therefore essential to conduct a literature review to obtain the tree species preference for koalas in the study site. If such information is not available or only patchy records exist, a koala survey is required. Such surveys can be conducted by searching for koala scats under trees and determining tree usage, by koala scat analysis using electron microscopy or similar or by radio tracking animals and observing their use of trees.

GIS—QGIS Analysis: A review of the literature and/or koala monitoring is required to obtain home range (HR) sizes for koalas in the study site, especially for animals occupying the lowest KH areas. The average HR size determines the size of radii used in the analysis. As a rough guide, an average HR of 95 ha equates to a radius of around 550 m, a HR of 50 ha equates to a radius of around 400 m, and an average HR size of 25 ha equates to a radius of around 280 m. These measurements should only be seen as a guide as it is difficult to accurately determine koala HR; it is likely that radii of several different sizes need to be used to obtain statistically valid samples. Application of LecoS plugin for patch and landscape statistics.

Statistical Analysis: Analysis of the various radii for proportions of the various koala habitat quality category using fragmentation parameters as outlined in Chapter 3.2, will show locations of probable blackspots. This analysis can be done using any statistical software such as PRIMER, SPSS, R.

KRBs: It should be possible to locate KRBs or areas of concern using the statistical analysis outlined above. However, where data on the distribution of koala roadkill are available, as is the case for the Nebo-Eton Road, verification of the model must be conducted by statistically testing if their location is random or not. This will assist in separating areas that are of concern for koalas from actual KRBs and should guide the allocation of funds for preventative or risk reduction measures such exclusion fencing and under/over-passes.