Managing Central Queensland's Clarke-Connors Range koala population.

Predicting future koala road-kill hotspots.

Dr. Rolf Schlagloth

Koala Research – CQ, CQUniversity.

2018

Recommended citation: Schlagloth, R. (2018) Managing Central Queensland's Clarke-Connors Range koala population Predicting future koala road-kill hotspots. A report to the Department of Transport and Main Roads, Qld. Koala Research-CQ, School of Medical and Applied Sciences, CQUniversity, Rockhampton.

Acknowledgements

The author would like to thank:

Dr. Flavia Santamaria (Koala Research-CQ, School of Medical and Applied Sciences, CQUniversity) for assistance with editing and production of maps;

Wayne Houston (School of Medical and Applied Sciences, CQUniversity) for his support with the PRIMER analyses;

Michael Harte for his work on the QGIS analyses; and

TMR, especially Stephen Clague, for enabling access to the mobile laser scanning (MLS) (HawkEye) data and Digital Video Road (DVR) program.

This report was prepared as part of a larger study 'Managing the Clarke-Connors Range koala population' funded by the Queensland Department of Transport and Main Roads (TMR).

Queensland Government

Contents

Figures

Tables

Summary

Koala road-kill data were analysed on a section of the Peak Downs Highway between Nebo and Eton from September 2014 to April 2018. The analysis was carried out on 81 records and ten koala road-kill blackspots (KRBs) were identified.

The KRBs were associated with plant communites associated with high value koala habitat. *E. tereticornis* and *E. crebra/drepanophylla* were the most relevant species within this type of habitat. Moreover, these occur in relatively large areas of that habitat and where the habitat edge length per/ ha tends to increase.

Plant communities that contain low quality koala habitat were not associated with high numbers of road-kills.

There was no significant association found between parameters related to the road, driver visibility, speed limits and road width and KRBs. However, this needs to be investigated further.

Overall, the modelling indicates that where a road traverses a landscape with large areas of high value koala habitat distributed in mosaics or reticulated networks, KRBs are likely to occur. However, the model can be improved by more detailed local floristic descriptions.

Introduction

As part of the realignment of the Peak Downs Highway at Eton Range, the Department of Transport and Main Roads (TMR) undertook to fund a study of the koalas inhabiting Central Queensland's Clark Connors Range with the goal of better understanding future management options around the highway, and in the greater region. Koala Research – CQ at CQUniversity was commissioned to undertake the study. The objectives of the study were to:

1.0 Defining koala population management units across the Clarke-Connors Range;

2.0 Understanding koala habitat use, diet, and ranging behaviour in the vicinity of the Eton to Nebo stretch of the Peak Downs Highway;

3.0 Analyse habitat and undertake modelling in an attempt to predict future koala-road kill hotspots on the Eton to Nebo stretch of the Peak Downs Highway; and

4.0 Undertake investment planning for installation of wildlife barriers, and underpasses on the Peak Downs Highway between Eton and Nebo beyond the current area of works of the Eton Range realignment.

This report deals with point 3.0 'Analyse habitat and undertake modelling in an attempt to predict future koala-road kill hotspots on the Eton to Nebo stretch of the Peak Downs Highway' (Figure 1).

The project commenced in mid-2016 and was completed in December 2018, with peer reviewed publications drafted during 2019.

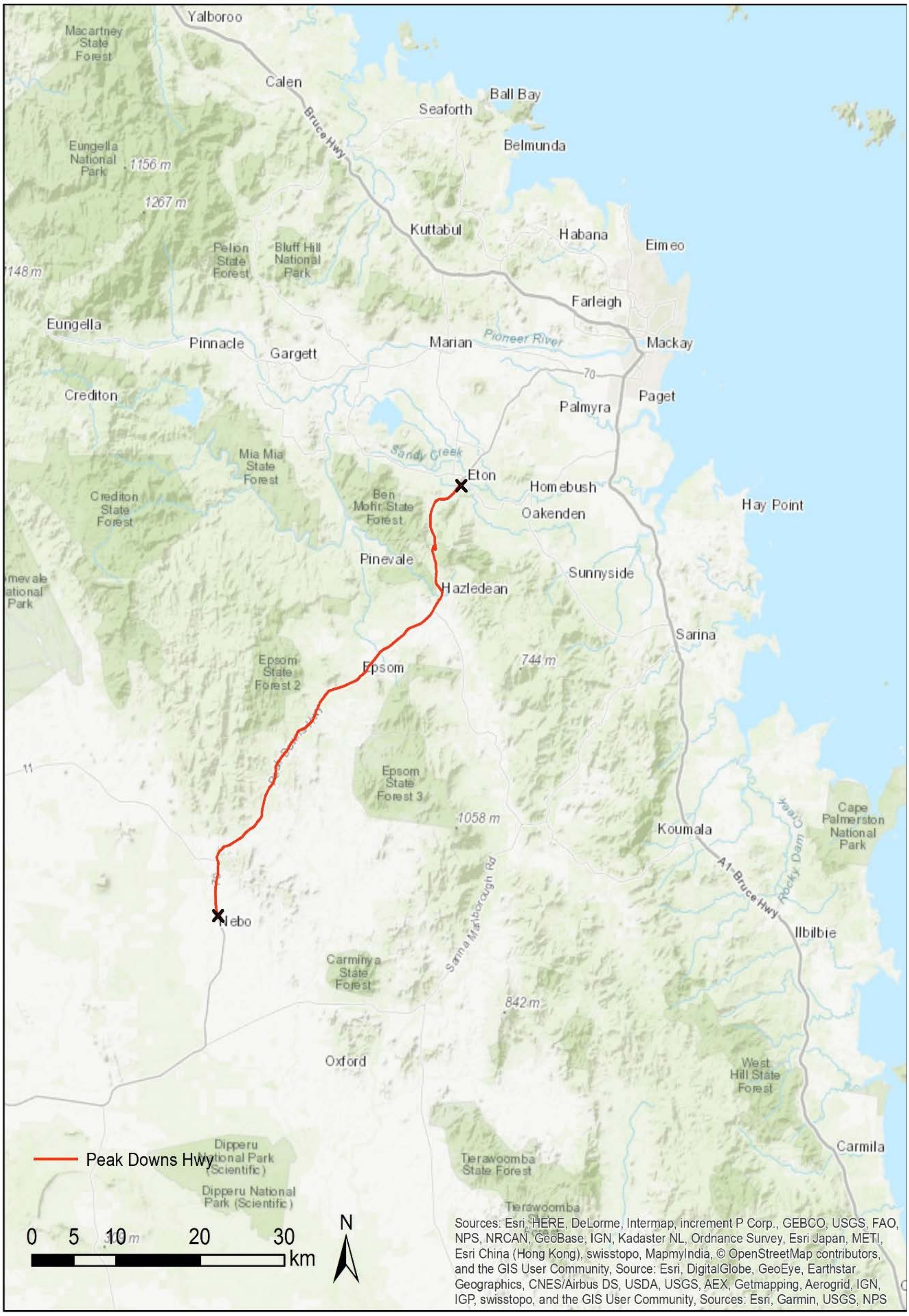

Figure 1 Eton to Nebo stretch of the Peak Downs Highway.

Literature

The impact of collisions with animals has many facets: the direct effect on the animals' lives (e.g. injury, death), the ecological impact, especially, but not only, in the case of protected species (Fahrig & Rytwinski, 2009), the financial cost of the accident to the insurance company and/or the owner of the car. In Australia, collisions with kangaroos, emus, koalas and other wildlife can also be very dangerous to drivers, by resulting in injuries, and also damaging to the vehicles (Lee, Klöcker, Croft, & Ramp, 2004). Furthermore, Animal Vehicle Collisions (AVCs) can have a negative psychological impact on people (Seiler et al., 2004). Various papers (Canfield, 1991; Dique et al., 2003; Port Stephens Comprehensive Koala Plan of Management Steering Committee, 2010; Semeniuk, Close, Smith, Muir, & James, 2012) have highlighted the occurrence of AVCs involving koalas in Queensland, New South Wales and Victoria respectively. 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 millions 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); these studies also looked at the best methodology to apply to determine the existence of a blackspot.

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.

Causes of Collisions.

Dique et al. (2003) argued that habitat destruction, koala density and traffic volume are the main contributors to koala road deaths 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). Bird road-kills 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 that crossed the road when traffic intensity was lower. They also found that slow moving animals were more likely to be hit than faster moving species. 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 the 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. Animals may need to increase or change home range sizes which can expose 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 road-kill among macropods has been attributed to the presence of curves on sections of roads (Klöcker, Croft, & Ramp, 2006). Brockie (2007), in his study of hedgehog and possum road-kill 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 were built with steep banks. High speed road zones are more susceptible to AVCs (Rowden et al., 2008), in fact, in that study 77.8% of animal collisions occurred at 100km/h or more.

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

- habits of the species (e.g., 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
- roads (e.g., width, design-curves, embankments, density of).

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 five 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 either not survive, or die later elsewhere, making detailed analysis difficult.

Blackspots for AVCs 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), identifies roads and the associated AVCs as 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. 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).

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 blackspot and compare various parameters to blackspot and non-blackspot areas, or to the presence or absence of road-kill. This project aims to establish whether koala road-kill blackspots occur along a section of highway before analysing the factors that contribute to the occurrence of any such blackspots.

Modelling.

In common with most areas of the world, Australia has undergone substantial land clearing and landscape modification due to agricultural 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 as well as a contraction in the koala's range (Australian Government, 2009; Melzer, Carrick, Menkhorst, Lunney, & St. John, 2000). Modelling approaches provide a tool to improving informed decision making 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. Lins, Gardon, Meyer, & Santos (2017) utilised landscape and forest parameters to predict suitable protected areas for keystone species. 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 blackspot identification. They promoted the use of predictive models as they enable the identification of explanatory factors that allows for species-specific management strategies to be developed and implemented at blackspot locations.

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 that provide connectivity and enhance opportunities for safe koala movement between habitat patches intersected by main roads.

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 (Guisan & Thuiller, 2005). Sanderson, Redford, Vedder, Coppolillo, & 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.

This study applies a modelling approach originally applied to a koala population living near a highway in Western Victoria (Schlagloth, 2018). The project produced a framework for predicting koala hotspots along that highway, and made suggestions regarding investment in wildlife protection measures.

Aim

The project aims to identify potential koala road-kill black spots (KRBs) by applying existing CQUni modelling of koala black-spots to koala problem areas around the Peak Downs Highway between Eton and Nebo.

General approach

In broad terms, the relationship between koala habitat attributes, topography and the pattern of road kills is analysed to identify associations with frequency of koala road deaths. Results will be tested: (a) against current mapped records of koala road kills; and (b) against areas of known koala habitat.

Method

Display of koala road-kills

All records of koala road-kills (81 records ranging from September 2014 to April 2018) were obtained from the wider community and the TMR, and displayed using ArcGIS-ArcMap (10.3.1). In an attempt to finding the areas of concern and blackspots for koala road-kill, all road-kill data were analysed in QGIS (QGIS Development Team, 2015) using the 'heatmap' extension (QGIS Plugin Repository, 2014) and applying 500 metre radii. The 'heatmap' plugin uses Kernel Density Estimation (Silverman, 1986) to create a density (heatmap) raster of an input point vector layer. This involves 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.

Application of model

The application of the model (Schlagloth, 2018) sees koala road-kills, koala habitat, drivers' visibility and the speed limit along the highway analysed to determine KRBs.

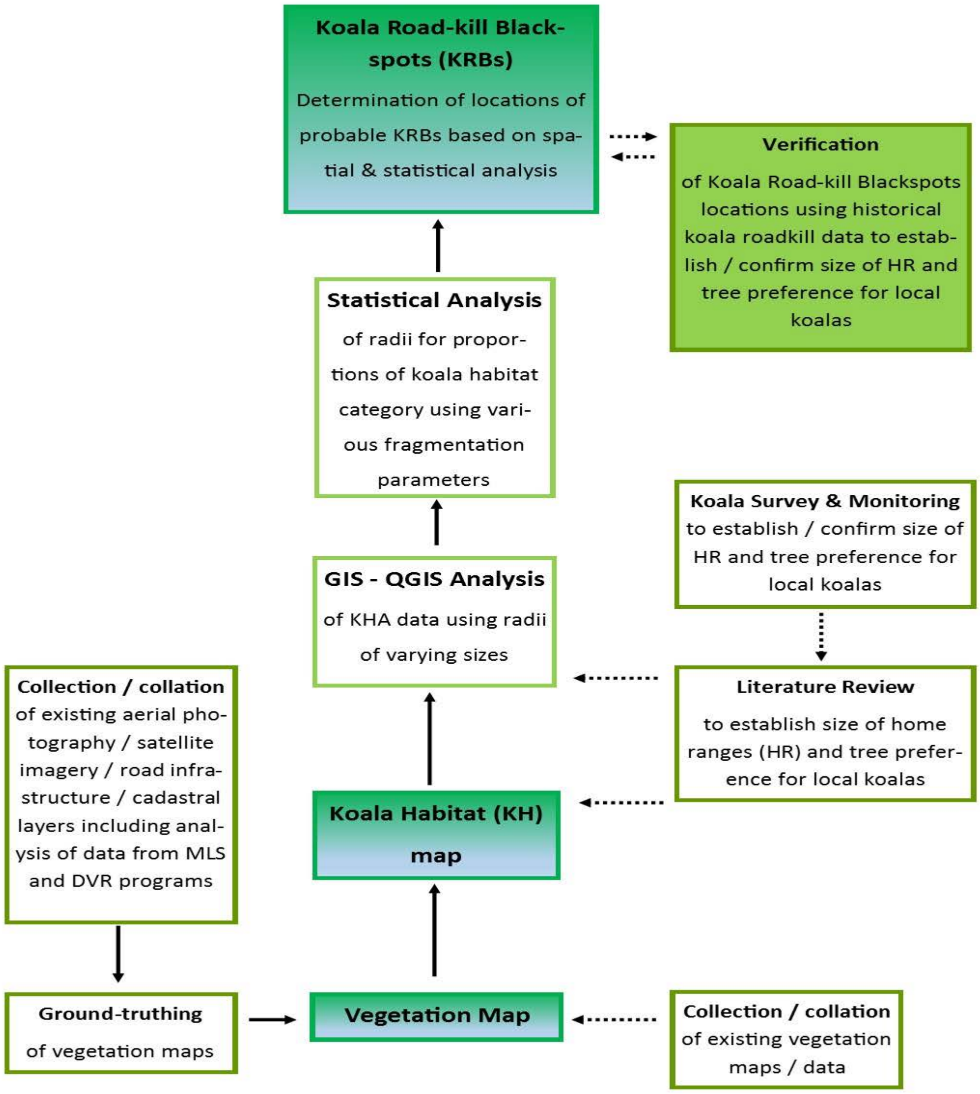

Figure 2 Koala Road-kill Blackspot Assessment Flow Chart—Nebo-Eton Highway.

The model was developed to gain an understanding of the degree to which each variable affects sites of road-kills along the highway. In this work, 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.

Koala habitat mapping

Koala Habitat (KH) ranking, based on Regional Ecosystems (REs) and some ground-truthing of sections of the highway, was provided by Dr Alistair Melzer. Appendix A displays the RE codes, the percentage of each RE and the KH ranking for each RE and RE combinations; Appendix B provides a short description for each RE listed in Appendix A as well as the Biodiversity status. Five ranks were defined for KH (Table 1) with five classes from poor to very high koala habitat quality.

Table 1 Koala habitat classes ranking Nebo-Eton Road.

Rank Ranges	Rank Bin	Frequency	Hectares	Quality	Class
0.00-0.60	0.6	96	12,441.90	poor	1
0.60-2.60	2.6	55	4,460.81	low	2
2.60-3.65	3.65	107	12,812.32	medium	3
3.65-4.65	4.65	101	16,749.32	high	4
4.65-5	5	8	465.59	very high	5
	>5	0			

Variable groups

Koala habitat quality— was defined using the habitat classes shown above which are based on an expert-driven qualitative classification (Melzer, 2015).

Vehicular speed— was defined as the legal speed limit (km/h) at a chainage point (in this study every 50m). 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. The information on speed limits and width of the Nebo to Eton section of the Peak Downs Highway was provided by the TMR (Mackay / Whitsunday District). The speed limit along most of the highway is 100km/h except for a 400m section at 80km/h, followed by a 2.3km section at 60km/h and a 330m section at 80km, 8.5km south of Eton.

Driver visibility— is defined as the greatest distance a driver can possibly see at a chainage point. These measurements (expressed in metres), were transcribed from HawkEye (ARRB Group, 2016) footage supplied by TMR. HawkEye is similar to Google's street view; footage was taken 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, is 124.8m, and 237.3m on high-beam, but differences are known to exist for drivers of different age groups (Debaillon, Carlson, He, Schnell, & Aktan, 2007; Zwahlen & Schnell, 1999). Trucks were not considered separately here; their headlight beam would be greater and the driver's view be better; however, their braking distance will also be different. Night vision on low-beam and high-beam is generally considered not to be much different from cars though, 76m and 152m respectively (Trucking Truth Training Company, 2015). However, data are not easily obtainable and comparable with site-specific differences to be expected. Anecdotal evidence for the study site suggests that trucks are one of the major contributors to koala road-kills as they breaking distance is greater than that of cars, they are operated at all hours of the night with many drivers having become de-sensitised to the issue (T. Dalton, personal communication, November 2018). Further research into this particular aspect is warranted, but due to a lack of available data, only the daylight visibility was used in the analysis even though the daylight visibility, at many chainage points, would likely be greater than visbility at night.

Width of road— is defined by the number of lanes (two–four) 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). The width of the highway varies, with overtaking lanes in alternate directions along multiple sections.

Landscape/degree of fragmentation and 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 shows the metrics from the LecoS plugin which considered to be of potential importance and were applied to each of the five koala habitat qualities:

The following full list of variables was measured and recorded; their sources and ownership are recorded in detail in Table 2. The locations of koala road-kill and blackspots, identified as part of Figures 3 & 4, were incorporated into the model.

Table 2 Variables, their specifics, acronyms and source.

Variable group	Variable specific	Acronym/ name of specific variables	Source	Source ownership/ access
Koala habitat quality	Poor quality koala habitat; Low quality koala habitat ; Medium quality koala habitat; High quality koala habitat; Very high quality koala habitat. Cover of area for each class within various radii (50, 100, 200, 400, 800, 1600, 3200 and 5000 m)	LCover_C1 LCover_C2 LCover_C3 LCover_C4 LCover_C5	A. Melzer koala habitat map	A. Melzer (CQU)
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	TMR
Driver—visibility	Visibility (distance in m in driving direction)	Vis_SorE/ Vis_NorW	Hawkeye MLS-DVR	TMR
Width of road	Width of road (number of lanes (2–4)	Wid_SorE/ Wid_NorW	Data base	TMR
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 Proportion of habitat	LProp_CxP EdLen_CxP EdDen_CxP NumP_CxP PDen_CxP GPArea_CxP SPArea_CxP MnPAr_CxP MdPAr_CxP MPSRat_CxP OCArea_CxP Prop_Cx_Pi	Koala habitat map	A. Melzer (CQU)
Road-kill	Number of koala road-kill recorded at each chainage point within various radii	No_kills	Road-kill data base	TMR / A. Melzer
	Number of koala road-kill recorded at chainage point not considering increasing radii	Kills_50m		

Table 3 Fragmentation Metric Definitions.

Adapted from Elkie, Rempel, and Carr (1999) & Wang (2014). ‘x’ will be substituted by 1,2,3,4,5 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.
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 area’ has 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). Core area represents the area in the patch greater than the specified depth-of-edge distance from the perimeter. 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. The Lecos ‘Overall Core Area’ analysis tool used the default value for edge depth which is one pixel (10m) from the edge of a patch.
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 patches as an index, except that it expresses number of patches on a per unit area basis.

Mapping and analysis of the vegetation:

Table 4 Process of analysing the vegetation map.

Step	Materials	Software	Methods
1	Regional Ecosystem (RE) maps for entire study site	GIS	Digital RE maps extended to entire study site and vegetation classes converted to koala habitat categories.
2	Vector layers of vegetation classes	QGIS ver. 2.8; Grass R.-> vector	Vector vegetation / koala habitat classes converted into raster vegetation / koala habitat 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

A Principal Component Analysis (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). All variables were standardised prior to analysis to ensure all variables were on the same scale. Component loadings are shown in brackets after each variable (e.g. LCover_C4P (0.227) and represent the correlations between the variable and the component.

PCA was conducted for all parameters (see Table 2 for detailed description of each) 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 two-dimensional plot was rotated by 90^0 in PRIMER (Clarke & Warwick, 2001).

Eigenvectors with a value of above 0.32 can be considered having a very 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 (2013) add that the value is most suitable for studies using habitat or abiotic variables. This study considered 0.20 as the cut-off value as a mixture of variables are used.

Results

Between 2014 and April 2018, 81 koalas were recorded on the highway between Eton and Nebo, of these 74 were road-killed and seven were alive including a female with joey seen in in 2016. All validated reports were imported into ArcMap. A map of the distribution of koala road-kill along the section of the Peak Downs Highway between Eton to Nebo (62km) is shown in Figures 3 & 4.

Clustering was identified in the distribution of fatalities for the koala road-kill, meaning that the fatalities occurred in clusters, rather than being randomly distributed along the road (Figure 4). Koala road-kill blackspots (KRBs) occurred in stretches along the 62km section of the highway. Several main KRBs (> 2 kills), some stretching for several kilometres, can clearly be seen along the length of the road as well as other areas of concern.

Further analysis was conducted aiming at identifying parameters that may contribute to the occurrence of these KRBs. The locations of koala road-kill and blackspots, identified in the previous analyses, were incorporated into the model.

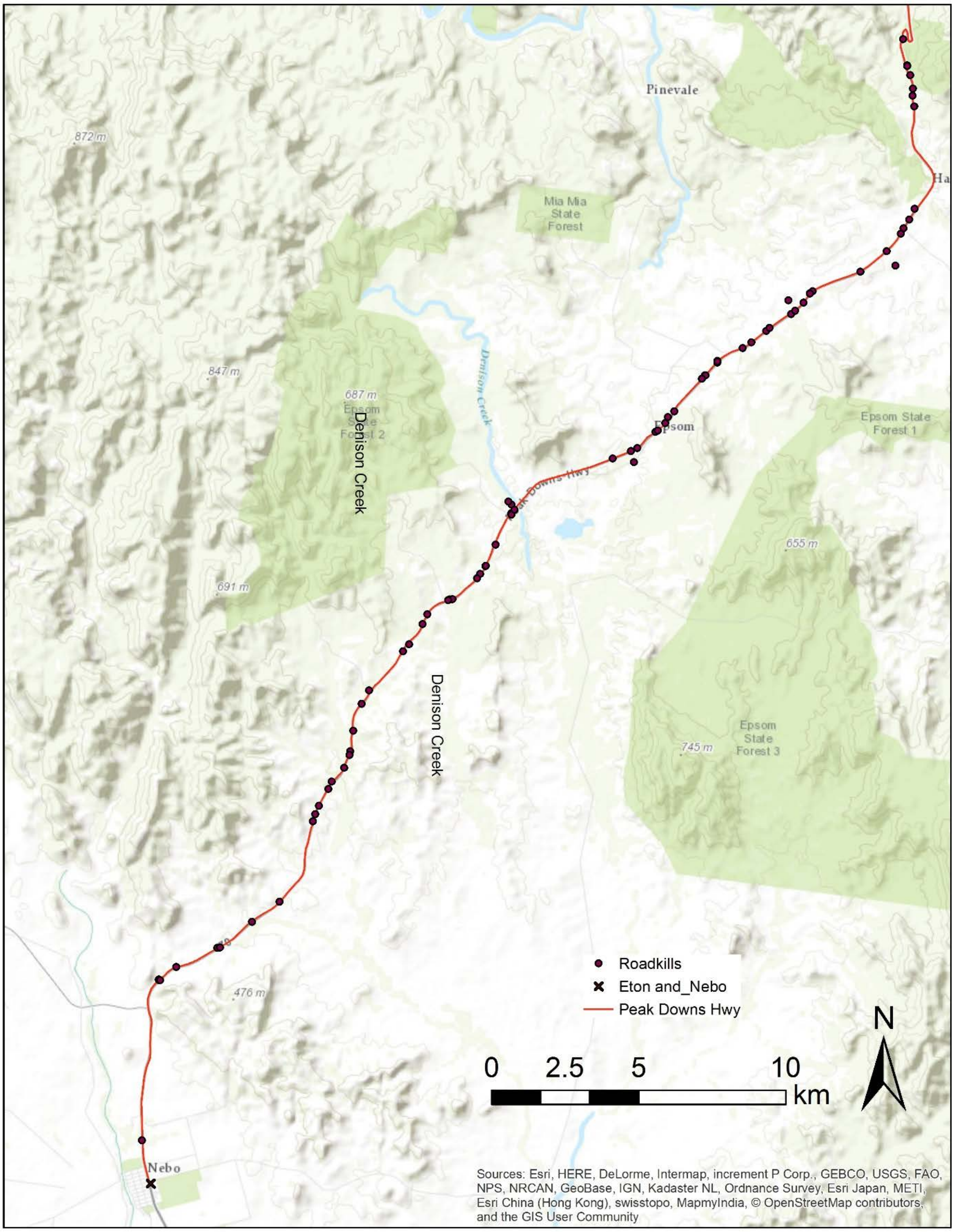

Figure 3 Distribution of koala road-kill along the Eton-Nebo section of the Peak Downs Highway.

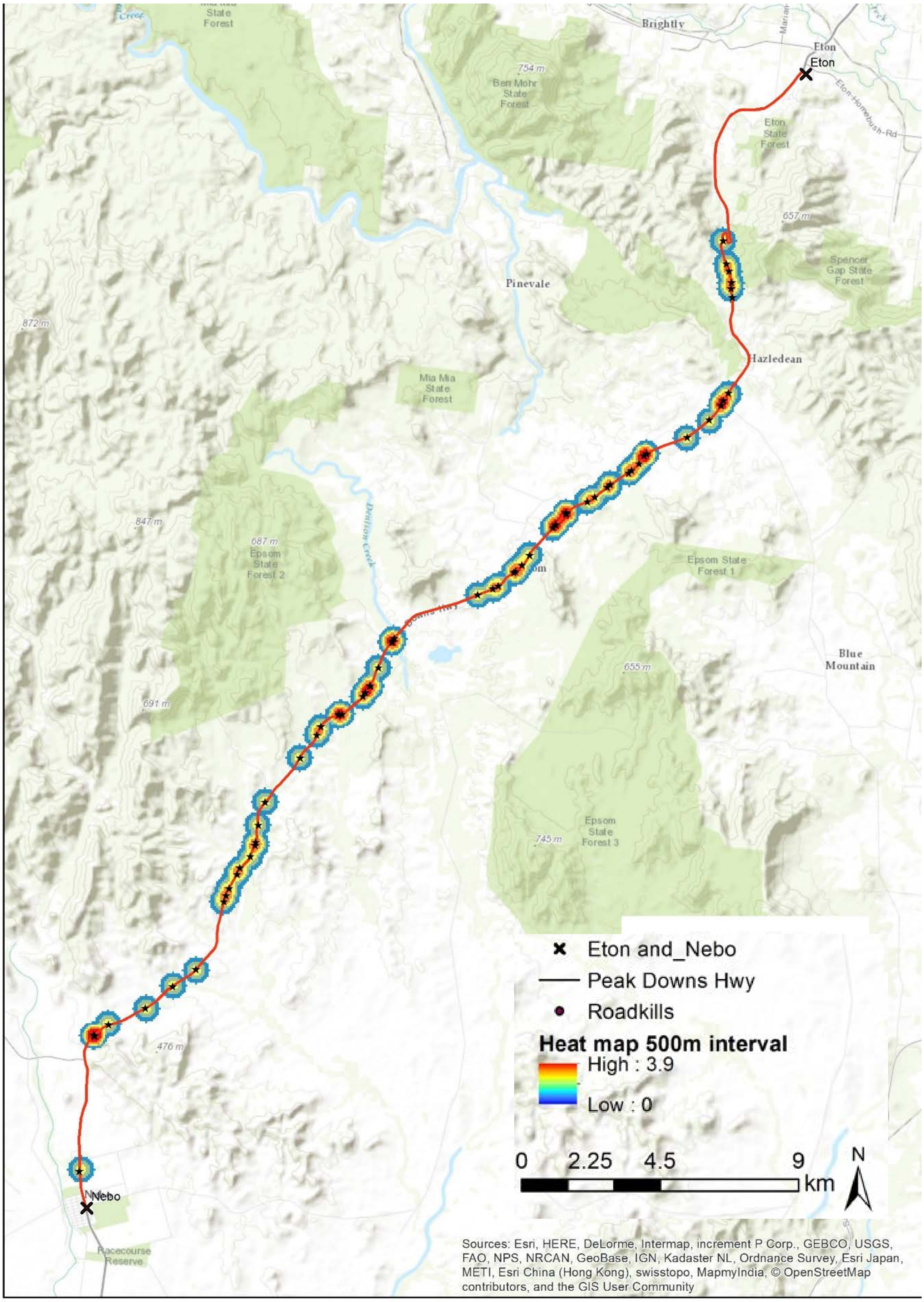

Figure 4 Heat map of koala road-kill along the Nebo-Eton section of the Peak Downs Highway. Indicated are several areas with concentrations of koala road-kill to be labelled blackspots.

The analysis in PRIMER, at 800 m radii, showed the greatest separation of ranked data for the categories of koala road-kill (categories for numbers of road-kill was generated by PRIMER using intervals of five).

It was therefore decided to analyse the correlations for variables within the 800 m radii investigation and progressively exclude variables with multiple correlations of values of above 0.9 (Manly, 2016), as multicollinearity impacts on results (Alin, 2010; Ranjit, 2010). Efficiency of multivariable analysis highly depends on correlation structure among predictive variables. Inference for multivariable analysis assumes that all predictive variables are uncorrelated (Yoo, Mayberry, Bae, Singh, He, & Lillard, 2014). Each cover class (EDLen, GPArea and OCArea) was highly correlated with LCover. Consequently EDLen, GPArea and OCArea were excluded. Speed limit variables were all highly correlated (>0.9) so SL_mean was retained, and med, min, max and Spee_Limi were excluded. TDIST_start and TDIST end were also highly inversely correlated. TDIST start was excluded.

The final multivariate PCA analysis with the greatest clustering is shown in (Figure 5).

The first twoaxes explain 39% of variation by the ordination overall. The strongest **positive** eigenvectors were in the Class 4 & 5 vegetation (full descriptions: Appendices A & B).

Class 4 generally contains key koala food tree species *Eucalyptus crebra/E. drepanophylla* and *E. tereticornis* in *woodlands to open forests* but may also contain other food tree species such as *E. coolabah, E. populnea, or E. platyphylla* (8.3.1a, 8.3.6a, 8.11.1, 8.12.7c, 11.3.2, 11.3.3, 11.3.4, 11.3.25, 11.3.25b, 11.4.2, 11.5.8, 11.12.1a, 11.12.3, 11.12.6a); and

Class 5 generally contains key koala food tree species *Eucalyptus camaldulensis, E. tereticornis or E. coolabah* but may also contain *E. platyphylla* in open forests to woodlands, wetlands or fringing riverine wetlands or woodland fringing swamps (8.3.6a, 8.3.13c, 8.11.5a, 11.3.4, 11.3.25, 11.3.25b, 11.3.27b, 11.3.27f).

The strongest **negative** eigenvectors are in the Class 2 vegetation.

Class 2 generally contains few important koala food tree species, usually sparsely distributed in open forests to woodlands (8.3.2, 8.3.5, 8.3.6a, 8.11.4, 8.12.5a, 8.12.7a, 8.12.7c, 8.12.9, 8.12.12a, 8.12.16, 8.12.32, 11.3.4, 11.4.2, 11.4.9, 11.4.13, 11.5.3, 11.7.2, 11.8.3, 11.8.4, 11.8.5, 11.9.9, 11.11.1, 11.12.1a, 11.12.4).

This indicates that more road-kills tend to occur where more Class 4 & 5 vegetation is present and fewer road-kills where Class 2 vegetation occurs. In particular, landcover of koala habitat quality 4 (LCover_C4P, 0.227), and the proportion of this habitat (Prop_C4_Pi, 0.227) feature a strongly positive influence on PC1, together with edge density of that habitat (EdDen_C4P, 0.224). While landcover and proportion for the lower koala habitat quality (LCover_C2P, -0.203; Prop_C2_Pi, -0.203) featured strongly negatively on PC1. Parameters associated with the best koala habitat quality (class 5) featured strongly on PC2 (LCover_C5P, 0.225; EdDen_C5P, 0.242; NumP_C5P, 0.237; PDen_C5P, 0.237; SPArea_C5P, 0.225; MnPAr_C5P, 0.225; MdPAr_C5P, 0.225; Prop_C5_Pi, 0.225). The full list of PCA Ordination results is shown in Appendix C.

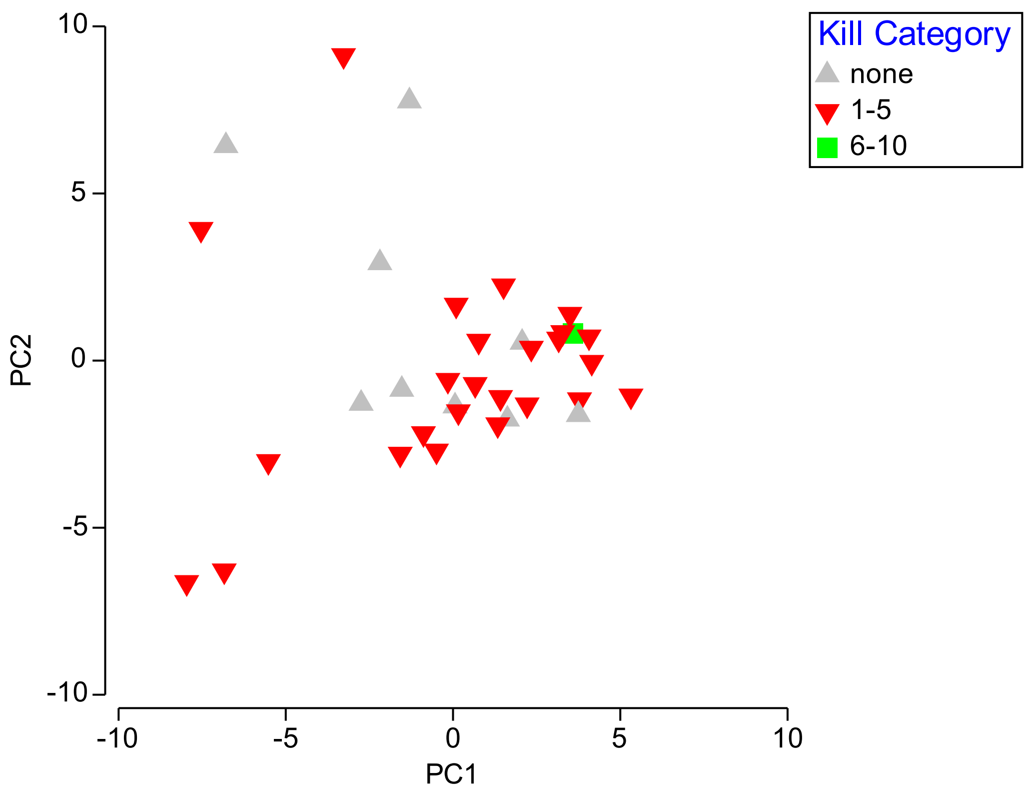

Figure 5 PCA in PRIMER @ 800m radius where samples show 'most clustering'.
Kill categories are the number of koala road-kill in increments of 5.

Road parameters such as width, traffic speed or driver visibility did not feature strong negative or positive eigenvectors and were therefore considered to be of low contributio to this koala road-kill model.

A number of clusters of koala road-kills were identified which were restricted into 10 KRBs (Figure 6).

Clusters are labelled as C1-10 (Nebo Junction, Fiery Creek, Boundary Creek, Black Soil Gully, Cut Creek Bridge, Denison Creek Bridge, Mount Spencer, Stockyard Creek, Hannaville and Hamdenvale) and are described in detail in the infrastructure report associated with this study (Melzer, 2018).

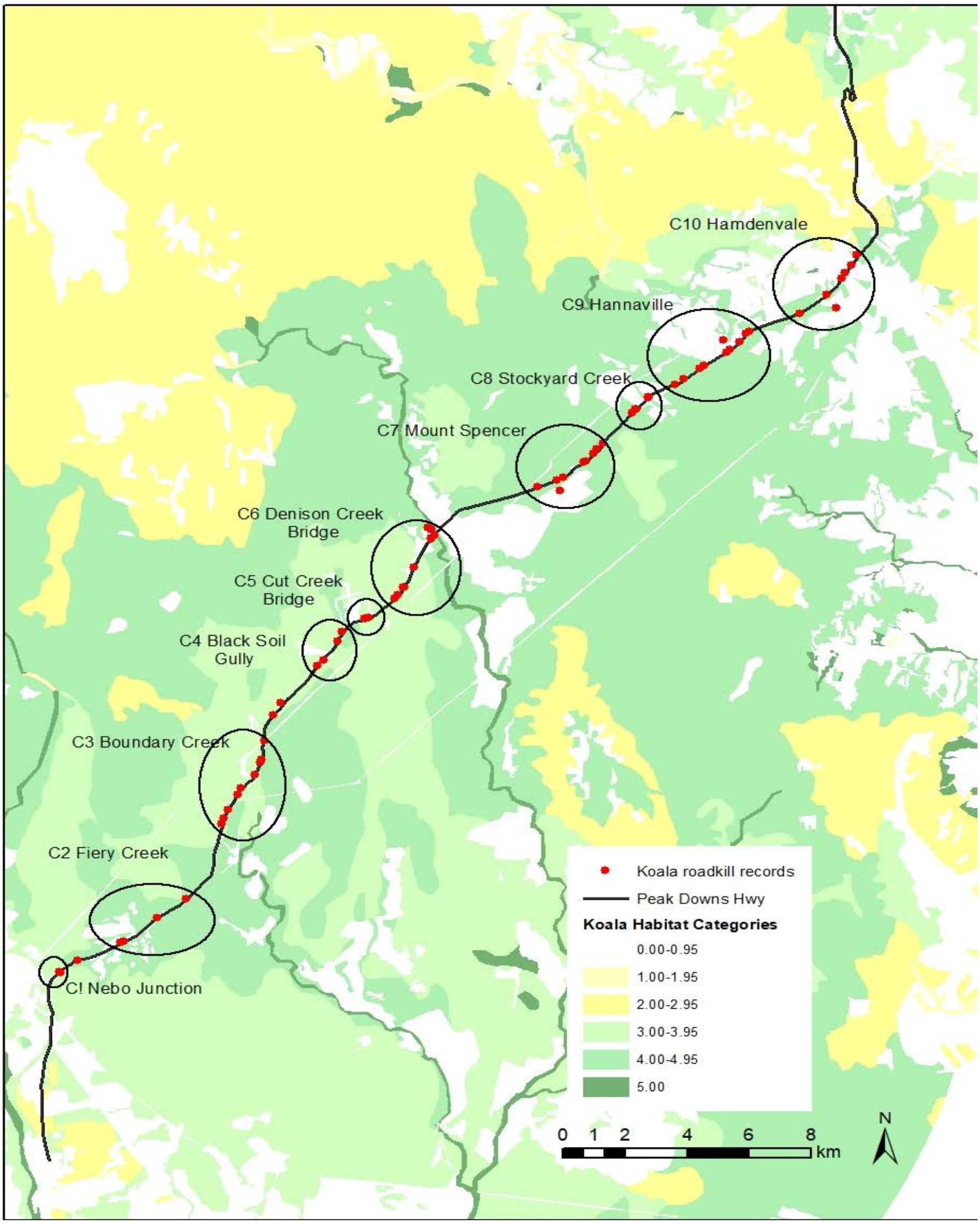

Figure 6 Koala road-kills and clusters along the Eton-Nebo section of the Peak Downs Highway over mosaic of koala habitat classes.

Discussion

Depending on the selection of cut-off values for the heatmap analyses of KRBs, there are 19 clusters of koala road-kills. These resolve into ten zones (KRBs) with between two and four koala road kills. Most notably, in this study, factors contributing to the likelihood of koalas being involved in an AVC are those related to the area and architecture of the koala habitat as well as the relative quality of that habitat. The most important influences are the parameters associated with the better koala habitat (classes 4 & 5) within the surrounding landscape. That is, the blackspots were associated with (1) plant communites where *E. tereticornis* and *E. crebra/drepanophylla* are prominent features, and (2) where there are relatively large areas of that habitat, and where the habitat edge length per/ ha tends to increase (Figure 6).

Larger amounts of good quality habitat would likely result in greater numbers of koalas and therefore a greater likelihood of collisions with vehicles where roads intersect these areas. Similarly, the relatively strong featuring of parameters reflecting the availability and degree of fragmentation of the very good quality koala habitat, is likely to be because these areas can be expected to harbour more koalas than less favourable habitat and this would increase the likelihood of collisions on roads dividing that habitat when koalas move between vegetation fragments (Rhodes et al., 2006). Koala habitat of Class 5 is the least represented in the study site.

Of note is that the value for the parameters associated with landcover of the lower quality koala habitat (Class 2) indicates a negative influence of this habitat type on the likelihood of koala road-kills occurring. One possible explanation could be that these areas reduce the likelihood of vehicle collisions with koalas because of the probability of there being few or no individuals present in such areas.

More detailed data for habitat usage by individual koalas is needed, on a ‘smaller’ scale (individual patches and trees).

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 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 animal 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 the proportion of koala habitat that was of high quality was greater, although these could occur in many patches; a finding that reflects results from the Victorian study where the same methodology was applied (Schlagloth, 2018). This investigation also confirms 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 highly fragmented good quality koala habitat 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). In contrast to the Ballarat study site which was highly fragmented due to anthropogenic influences, the native vegetation, and especially the good quality koala habitat, near the Peak Downs Highway occurred naturally in fragments, mosaics or reticulations (Figure 6). These would have the same architecture as a partly cleared landscape.

Ramp et al. (2005) promote the use of habitat parameters, as it allows the identification of explanatory factors, that in turn permit the development of species-specific management strategies for implemented at blackspot locations. Habitat parameters were of great importance in the modelling applied in this study. However, a model is only as good as the data that are entered. The blackspot modelling applied here could be improved by the input of more detailed, field collected floristic data. The RE classification used here provides descriptions based on state-wide assessments, so local application is improved through ground-truthing. Conversely, RE's are available in a state-wide coverage and provide a readily available data set for broader application.

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 in this study site 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 800 m radius (compared to the 400m in Schlagloth (2018) appears to be a reasonable analytical unit based on PCA showing most spread at this measurement and considering that homerange sizes for koalas in Central Queensland are generally larger than those in Victoria. Evidence exists that koalas, in the study site, show a tendency to move long distances. Their behaviour may reflect an adaptation to a naturally patchy mosaic of good quality habitat that is reminiscent of that predicted for artificialy cleared lands.

Given the limitations of this study, road parameters such as width, traffic speed and driver visibility cannot be totally excluded from contributing to koala road-kill. Greater visibility may result in greater speed and possibly difficulties for drivers to avoid koalas on the road; as for 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).

This study focused mainly on habitat features in the broader landscape surrounding the highway and some road features on which data were readily available. However, there is scope to extend the modelling to include fine-scale factor such as driver visibility at night or localised landscape features immediately adjacent to the road that may impact on animals ability to cross the road such as steep cuts or drop offs that are likely to be difficult to traverse for koalas.

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 road-kill in a number of different species found no correlation between the volume of traffic and the occurrence of blackspots. While parameters relating to habitat appear to be the greater contributors to the occurrence of KRBs in this location, road factors cannot be categorically excluded and the role they may play warrants further investigation.

Conclusion

Ten koala road-kill blackspots (KRBs) were identified between Nebo and Eton on the Peak Downs Highway.

The KRBs were associated with (1) plant communites where *E. tereticornis* and *E. crebra/drepanophylla* are prominent features, and (2) where there are relatively large areas of that habitat, and where the habitat edge length per/ ha tends to increase

Conversely, areas where road kills were less likely to occur or did not occur were associated with plant communities that contain few important koala food tree species and where these are sparsely distributed in open forests to woodlands.

Parameters associated with the road, driver visibility, 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 road-side habitat but would need to be investigated further.

In general, the modelling suggests that likely road-kill blackspots could be predicted where a carriageway cuts through landscape elements with relatively large areas of high value koala habitat, and where that habitat occurs in mosaics or reticulated networks. However, more detailed local floristic descriptions would improved the local resolution of the model.

References

Alin, A. (2010). Multicollinearity. Wiley Interdisciplinary Reviews: *Computational Statistics*, *2*(3), 370–374.

ARRB Group (2016). *Hawkeye 2000 Series*. Retrieved from https://www.arrb.com.au/equipment-services/hawkeye-2000-series.aspx

Australian Government (2009). *National koala conservation and management strategy 2009–2014.* Canberra: National Koala Conservation and Management Strategy Steering Committee Natural Resource Management Ministerial Council Retrieved from http://www.environment.gov.au/biodiversity/publications/koala-strategy/index.html.

Barson, M. M., Bordas, V. M., & Randall, L. (2000). *Land cover change in Australia: Results of the Collaborative Bureau of Rural Sciences-State Agencies' Project on remote sensing of agricultural land cover change*. Bureau of Rural Sciences Canberra.

Benesch, A. R., Munro, U., Krop, T., & Fleissner, G. (2010). Seasonal changes in the behaviour and circadian rhythms in activity and behaviour of captive koalas *Phascolarctos cinereus*. *Biological Rhythm Research, 41*(4), 289–304.

Brockie, R. E. (2007). Notes on New Zealand mammals 4. Animal road-kill "blackspots". *New Zealand Journal of Zoology, 34*, 311–316.

Canfield, P. J. (1991). A survey of koala road kills in New South Wales. *Wildlife Diseases, 27*(4), 657–660.

Chatfied, C., & Collins, A. J. (2013). *Introduction to multivariate analysis*: Springer.

Clarke, K. R., & Gorley, R. N. (2015). *PRIMER v7: user manual/tutorial. PRIMER-E,* (Version 7). Plymouth.

Clarke, K. R., & Warwick, R. M. (2001). Change in marine communities: An approach to statistical analysis and interpretation using PRIMER-E (2nd ed.). Plymouth, United Kingdom: PRIMER-E Ltd.

Coffin, A. W. (2007). From road-kill to road ecology: a review of the ecological effects of roads. *Transport Geography, 15*(5), 396–406.

Costello, A. B., & Osborne, J. W. (2011). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research and Evaluation*, *10*(7).

Debaillon, C., Carlson, P. J., He, Y., Schnell, T., & Aktan, F. (2007). *Updates to research on recommended minimum levels for pavement marking retroreflectivity to meet driver night visibility needs*. Retrieved from https://www.fhwa.dot.gov/publications/research/safety/07059/index.cfm

Department for Transport Energy and Infrastructure (2010). *Road trauma in South Australia*. Retrieved from http://www.unley.sa.gov.au/webdata/resources/ files/Item_85_-_Attachment_-_URSC_April_2010.pdf

Department of Environment and Climate Change (2008). *Recovery plan for the koala (Phascolarctos cinereus)*. Retrieved from http://www.environment.nsw.gov.au/ resources/threatenedspecies/08450krp.pdf

Department of Environment and Heritage Protection (2012). *Koalas and cars*. Retrieved from http://www.ehp.qld.gov.au/wildlife/koalas/pdf/koalas-and-cars.pdf

Department of Infrastructure and Regional Development (2016). *Black spot sites eligibility*. Retrieved from http://investment.infrastructure.gov.au/funding/blackspots/ eligibility_of_sites.aspx

Department of the Environment (2009). *National Koala Conservation and Management Strategy 2009–2014*. Retrieved from http://www.environment.gov.au/biodiversity/ threatened/publications/national-koala-conservation-mgt-strategy-2009-2014

Dique, D. S., Thompson, J., Preece, H. J., Penfold, G. C., de Villiers, D. L., & Leslie, R. S. (2003). Koala mortality on roads in south-east Queensland: The koala speed zone trial. *Wildlife Research, 30*(4), 419–426.

Drew, C. A., Wiersma, Y., & Huettmann, F. (2010). *Predictive species and habitat modelling in landscape ecology: Concepts and applications*. Springer Science & Business Media.

Elkie, P., Rempel, R., & Carr, A. (1999). *Patch analyst user's manual*. Ontario Ministry of Natural Resources, Northwest Science & Technology, TM–002, 16.

Ellis, W. A. H., FitzGibbon, S. I., Barth, B. J., Niehaus, A. C., David, G. K., Taylor, B. D., . . . Carrick, F. (2016). Daylight saving time can decrease the frequency of wildlife–vehicle collisions. *Biology Letters, 12*(11), 20160632.

Elvik, R. (2008). Comparative analysis of techniques for identifying locations of hazardous roads. Transportation Research Record. *Journal of the Transportation Research Board* (2083), 72–75.

Elvik, R. (2010). Why some road safety problems are more difficult to solve than others. *Accident Analysis & Prevention, 42*(4), 1089–1096.

Elvik, R., Vaa, T., Erke, A., & Sorensen, M. (2009). *The handbook of road safety measures*. Bingley, United Kingdom: Emerald Group Publishing.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, 487–515.

Fahrig, L., & Rytwinski, T. (2009). Effects of roads on animal abundance: An empirical review and synthesis. *Ecology and Society, 14*(1), 21.

Geurts, K., Wets, G., Brijs, T., & Vanhoof, K. (2004). Identification and ranking of black spots: Sensitivity analysis. *Transportation Research Record: Journal of the Transportation Research Board.* (1897), 34–42.

Goldenbeld, C., & van Schagen, I. (2007). The credibility of speed limits on 80km/h rural roads: The effects of road and personality characteristics. *Accident Analysis & Prevention, 39*(6), 1121–1130.

Grimm, V. (1999). Ten years of individual-based modelling in ecology: What have we learned and what could we learn in the future? *Ecological Modelling, 115*(2), 129–148. doi:10.1016/S0304-3800(98)00188-4.

Guisan, A., & Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. *Ecology letters*, *8*(9), 993–1009.

Hels, T., & Buchwald, E. (2001). The effect of road-kill on amphibian populations. *Biological Conservation, 99*(3), 331–340.

Hilborn, R., & Mangel, M. (1997). *The ecological detective: Confronting models with data*. *28*. Princeton University Press.

Jaeger, J. A., Bowman, J., Brennan, J., Fahrig, L., Bert, D., Bouchard, J., . . . von Toschanowitz, K. T. (2005). Predicting when animal populations are at risk from roads: an interactive model of road avoidance behaviour. *Ecological Modelling, 185*(2), 329–348. doi:10.1016/j.ecolmodel.2004.12.015

Januchowski, S. R., McAlpine, C., Callaghan, J. G., Griffin, C. B., Bowen, M., Mitchell, D., & Lunney, D. (2008). Identifying multiscale habitat factors influencing koala (*Phascolarctos cinereus*) occurrence and management in Ballarat, Victoria, Australia. *Ecological Management & Restoration, 9*(2), 134–142. doi:10.1111/j.1442-8903.2008.00405.x

Jung, M. (2016). *LecoS - A python plugin for automated landscape ecology analysis* (Version 2.0.5). Retrieved from https://github.com/Martin-Jung/LecoS.

Klöcker, U., Croft, D. B., & Ramp, D. (2006). Frequency and causes of kangaroo-vehicle collisions on an Australian Outback Highway. *Wildlife Research, 33*(1), 5–15.

Lassau, S. A., Ryan, B., Close, R., Moon, C., Geraghty, P., Coyle, A., & Pile, J. (2008). Home ranges and mortality of a road-side koala *Phascolarctos cinereus* population at Bonville, New South Wales. *Australian Zoologist, 34(34)*, 127–136.

Lee, E., Klöcker, U., Croft, D. B., & Ramp, D. (2004). Kangaroo-vehicle collisions in Australia's sheep rangelands, during and following drought periods. *Australian Mammalogy, 26*(2), 215–226.

Lins, D., Gardon, B., Meyer, F., & Santos, R. (2017). Keystone Species, Forest and Landscape: A Model to Select Protected Areas. *Environmental Management*, *59*(6), 1017–1033.

Lunney, D. (2013). Wildlife road-kill: Illuminating and overcoming a blind spot in public perception. *Pacific Conservation Biology, 19*(4), 233–249.

Malo, J. E., Suárez, F., & Diez, A. (2004). Can we mitigate animal-vehicle accidents using predictive models? *Applied Ecology, 41*(4), 701–710.

Mannering, F. (2009). An empirical analysis of driver perceptions of the relationship between speed limits and safety. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*(2), 99–106.

McAlpine, C. A., Callaghan, J. G., Lunney, D., Bowen, M. E., Rhodes, J. R., Mitchell, D. L., & Possingham, H. P. (2005). *Conserving south-east Queensland koalas: How much habitat is enough?* Paper presented at the SEQ Biodiversity Conference 2004, Gatton, Queensland.

McAlpine, C. A., Rhodes, J. R., Callaghan, J. G., Bowen, M. E., Lunney, D., Mitchell, D. L., . . . Possingham, H. P. (2006). The importance of forest area and configuration relative to local habitat factors for conserving forest mammals: A case study of koalas in Queensland, Australia. *Biological Conservation, 132*(2), 153–165. doi:10.1016/j.biocon.2006.03.021

McGarigal, K., Cushman, S. A., Neel, M. C., & Ene, E. (2002). *FRAGSTATS: Spatial pattern analysis program for categorical maps* (Version 3). Amherst: University of Massachusetts. Retrieved from http://www.umass.edu/landeco/research/fragstats/fragstats.html

Melzer, A. (2018). *Infrastructure investment opportunities on the Nebo to Eton stretch of the Peak Downs Highway, Central Queensland.* Koala Research –CQ, School of Health, Medical and Applied Sciences, CQuniversity, Rockhampton.

Melzer, A. (2015). *Ranking koala habitat using Queensland's mapped regional ecosystems*. Unpublished. Koala Research –CQ, School of Medical and Applied Sciences, CQuniversity, Rockhampton.

Melzer, A., Carrick, F., Menkhorst, P., Lunney, D., & St. John, B. (2000). Overview, critical assessment, and conservation implications of koala distribution and abundance. *Conservation Biology, 14*(3), 619–628.

Moon, K., Adams, V. M., Januchowski Hartley, S. R., Polyakov, M., Mills, M., Biggs, D., . . . Raymond, C. M. (2014). A multidisciplinary conceptualization of conservation opportunity. *Conservation Biology, 28*(6), 1484–1496. doi:10.1111/cobi.12408

Osborne, J. W., & Costello, A. B. (2009). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Pan-Pacific Management Review, 12*(2), 131–146.

Polak, T., Rhodes, J. R., Jones, D., & Possingham, H. P. (2014). Optimal planning for mitigating the impacts of roads on wildlife. *Applied Ecology, 51*(3), 726–734. doi:10.1111/1365-2664.12243

Port Stephens Comprehensive Koala Plan of Management Steering Committee (2010). *Submission: Inquiry into the status, health and sustainability of the koala*. Retrieved from https://senate.aph.gov.au/submissions/.../viewdocument.aspx?id.

Preece, H. J. (2007). *Monitoring and modelling threats to koala populations in rapidly urbanising landscapes: koala coast, South-East Queensland, Australia*. (PhD), University of Queensland, Brisbane.

QGIS Development Team (2015). *QGIS Geographic Information System* (Version 2.8.4—Wien): Open Source Geospatial Foundation Project. Retrieved from http://www.qgis.org/

QGIS Plugin Repository (2014). *Heatmap Plugin*: Creativecommons.com. Retrieved from https://docs.qgis.org/1.8/en/docs/user_manual/plugins/plugins_heatmap.html

Queensland Government (2006). *Nature conservation (koala) conservation plan 2006*. Brisbane: Queensland Government. Retrieved from https://www.legislation.qld.gov.au/LEGISLTN/CURRENT/N/NatureConKP06.pdf.

Ramp, D., Caldwell, J., Edwards, K. A., Warton, D., & Croft, D. B. (2005). Modelling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. *Biological Conservation, 126*(4), 474–490.

Ramp, D., Wilson, V. K., & Croft, D. B. (2006). Assessing the impacts of roads in peri-urban reserves: Road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. *Biological Conservation, 129*(3), 348–359.

Ranjit, K. P. (2010). *Multicollinearity: Causes, Effects and Remedies*. IASRI, New Delhi.

Rhodes, J., Lunney, D., Callaghan, J., & McAlpine, C. (2014). A few large roads or many small ones? How to accommodate growth in vehicle numbers to minimise impacts on wildlife. *PLOS ONE, 9*(3), 1–10. doi:http://dx.doi.org/10.1371/journal.pone.0091093

Rhodes, J., Wiegand, T., Mcalpine, C., Callaghan, J., Lunney, D., Bowen, M., & Possingham, H. P. (2006). Modelling species' distributions to improve conservation in semi-urban landscapes: koala case study. *Conservation Biology, 20*(2), 449–459. doi:10.1111/j.1523-1739.2006.00330.x

Richman, M. B. (1988). A cautionary note concerning a commonly applied eigenanalysis procedure. *Tellus B, 40*(1), 50–58.

Roger, E., & Ramp, D. (2009). Incorporating habitat use in models of fauna fatalities on roads. *Diversity and Distributions, 15*(2), 222–231.

Rowden, P., Steinhardt, D., & Sheehan, M. (2008). Road crashes involving animals in Australia. *Accident Analysis & Prevention, 40*(6), 1865–1871.

Sanderson, E. W., Redford, K. H., Vedder, A., Coppolillo, P. B., & Ward, S. E. (2002). A conceptual model for conservation planning based on landscape species requirements. *Landscape and Urban Planning, 58*(1), 41–56.

Schlagloth, R. (2018). *Modelling koala road-kill blackspots.*PhD thesis; Central Queensland University.

Seiler, A., Helldin, J., & Seiler, C. (2004). Road mortality in Swedish mammals: results of a drivers' questionnaire. *Wildlife Biology, 10*(3), 225–233.

Semeniuk, M., Close, R., Smith, A., Muir, G., & James, D. (2012). *Investigation of the impact of roads on koalas*. Australian Museum Business Services College Street, Sydney NSW.

Shlens, J. (2014). A tutorial on principal component analysis. *arXiv preprint arXiv:1404.1100*.

Silverman, B. W. (1986). *Density estimation for statistics and data analysis* (Vol. 26). Boca Raton, Florida: Chapman and Hall/CRC Press.

Simpkins, C. (2009*). Principle components analysis—a short primer*. Retrieved from http://www.cc.gatech.edu/~simpkins/teaching/gatech/cs4641/slides/pca-primer.pdf

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate analysis*. California State University Northridge: Harper Collins College.

Taylor, B. D., & Goldingay, R. L. (2004). Wildlife road-kill on three major roads in north-eastern New South Wales. *Wildlife Research, 31*(1), 83–91.

Trucking Truth Training Company (2015). *Driving at Night*. Retrieved from http://www.truckingtruth.com/cdl-training-program/page23.

Wall, M. E., Rechtsteiner, A., & Rocha, L. M. (2003). Singular value decomposition and principal component analysis, *A practical approach to microarray data analysis* (pp. 91–109): Springer.

Wang, X., Blanchet, F. G., & Koper, N. (2014). Measuring habitat fragmentation: an evaluation of landscape pattern metrics. *Methods in Ecology and Evolution, 5*(7), 634–646.

Warner, H. W., & Åberg, L. (2008). Drivers' beliefs about exceeding the speed limits. Transportation Research Part F. *Traffic Psychology and Behaviour, 11*(5), 376–389.

World Health Organisation (2016). *Global Health Observatory dat*a. Retrieved from http://www.who.int/gho/mortality_burden_disease/en/

Yoo, W., Mayberry, R., Bae, S., Singh, K., He, Q. P., & Lillard Jr, J. W. (2014). A study of effects of multicollinearity in the multivariable analysis. *Applied science and technology*, *4*(5), 9.

Zwahlen, H., & Schnell, T. (1999). Visibility of road markings as a function of age, retroreflectivity under low-beam and high-beam illumination at night. *Transportation Research Record* (1692), 152–163. doi:http://dx.doi.org/10.3141/1692-16

Appendices

Appendix A: RE – Koala Habitat rank

Regional Ecosystem (RE)	Percentage RE	Koala Habitat rank
11.12.4	100	0
11.3.1	100	0

11.3.11	100	0
11.3.21	100	0
11.4.1	100	0
11.4.4	100	0
11.4.9	100	0
11.8.11	100	0
11.8.13	100	0
11.8.3	100	0
11.9.1	100	0
11.9.1/11.3.1	80/20	0
11.9.1/11.9.5	60/40	0
11.9.4a	100	0
11.9.5	100	0
8.1.1	100	0
8.1.1/8.1.2	90/10	0
8.1.1/8.1.2/8.1.5	80/10/10	0
8.1.1/8.1.3/8.1.2	65/20/15	0
8.1.1/8.1.4/8.1.5	90/5/5	0
8.1.1/8.1.5	70/30	0
8.1.2	100	0
8.1.2/8.1.1	80/20	0
8.1.2/8.1.3	70/30	0
8.1.2/8.1.3/8.1.5	90/5/5	0
8.1.3	100	0
8.1.3/8.1.1	70/30	0
8.1.3/8.1.2	60/40	0
8.1.3/8.1.2/8.1.5/8.1.1	50/30/10/10	0
8.1.3/8.1.4	90/10	0
8.1.3/8.1.5/8.1.1	80/10/10	0
8.1.4	100	0
8.1.4/8.1.5	90/10	0
8.1.5	100	0
8.1.5/8.1.1	60/40	0
8.1.5/8.1.1/8.1.3	50/40/10	0
8.1.5/8.1.1/8.1.4	60/30/10	0
8.11.2	100	0
8.12.10a	100	0
8.12.16	100	0
8.12.1a/8.12.31b/8.12.3a	60/30/10	0
8.12.2	100	0
8.12.2/8.12.17a	70/30	0
8.12.2/8.12.3a	60/40	0
8.12.2/8.12.3a/8.12.19	60/20/20	0
8.12.27a	100	0
8.12.27b	100	0
8.12.31a	100	0
8.12.31b	100	0
8.12.3a	100	0
8.12.3a/8.12.19	80/20	0
8.12.3a/8.12.2	60/40	0

8.12.3a/8.12.2/8.12.19	70/20/10	0
8.12.3b	100	0
8.12.8	100	0
8.2.6a	100	0
8.2.6a/8.2.1	95/5	0
8.2.6a/8.2.11/8.2.1	90/5/5	0
8.3.10/8.3.1a	70/30	0
8.3.11	100	0
8.3.12	100	0
8.3.15	100	0
8.3.1a	100	0
8.3.1a/8.3.10	90/10	0
8.8.1b	100	0
8.1.3/8.1.2/8.3.13a/8.1.1	70/20/5/5	0.05
8.1.3/8.1.2/8.3.13a	60/30/10	0.1
8.1.3/8.1.4/8.3.13a	70/20/10	0.1
8.12.31a/8.12.31b/8.12.5a	70/25/5	0.1
8.3.15/8.3.1a/8.3.3a	50/40/10	0.1
8.3.1a/8.3.3a	90/10	0.1
8.1.3/8.3.13a/8.1.4	70/20/10	0.2
8.12.31a/8.12.5a	90/10	0.2
8.1.3/8.3.13a/8.1.5/8.1.1	60/25/10/5	0.25
11.4.9/11.12.1	90/10	0.3
11.4.9/11.4.2	90/10	0.3
11.12.4/11.12.1a	90/10	0.4
8.3.12/8.1.4/8.3.13c	60/30/10	0.5
11.4.9/11.3.2	80/20	0.6
8.12.10a/8.12.5a/8.12.31a	60/30/10	0.6
8.12.31b/8.12.5a	70/30	0.6
8.3.3a/8.3.1a	60/40	0.6
8.3.13a/8.1.1/8.1.4	70/20/10	0.7
8.3.13a/8.1.4	70/30	0.7
8.3.5/8.3.1a	80/20	0.8
8.3.5/8.3.12/8.3.2	70/15/15	0.85
8.3.5/8.3.3a/8.3.1a	70/15/15	0.85
8.3.5/8.3.2/8.3.11/8.3.3a	75/15/5/5	0.95
11.10.1	100	1
11.8.14	100	1
8.11.3a	100	1
8.3.13a	100	1
8.3.2	100	1
8.3.2/8.3.3a	95/5	1
8.3.3a	100	1
8.3.3a/8.3.5	90/10	1
8.3.5	100	1
8.3.5/8.3.2	80/20	1
8.3.5/8.3.2/8.3.3a	90/5/5	1
8.3.5/8.3.3a	95/5	1
11.3.1/11.3.3/11.3.11	60/30/10	1.2
8.12.5a/8.12.31b	60/40	1.2

8.3.12/8.3.13a/8.3.13c	50/30/20	1.3
11.8.5/11.8.11	70/30	1.4
8.12.23/8.12.7a	60/40	1.4
8.3.3a/8.3.6a	90/10	1.4
8.3.3a/8.3.6a/8.3.5	80/10/10	1.4
11.3.2/11.3.1	50/50	1.5
11.4.9/11.3.4	70/30	1.5
11.8.3/11.8.4	50/50	1.5
11.9.5/11.9.7a/11.9.2	50/30/20	1.5
8.12.12a/8.12.3a	50/50	1.5
8.12.7a/8.12.10a	80/20	1.6
8.3.5/8.3.6a/8.3.3a	80/15/5	1.6
11.9.7/11.9.5	60/40	1.8
8.3.5/8.3.6a	80/20	1.8
11.4.13	100	2
11.8.5	100	2
8.11.4	100	2
8.12.32	100	2
8.12.5a	100	2
8.12.7a	100	2
8.12.7a/8.12.32	60/40	2
11.12.1a/11.12.4	70/30	2.1
11.8.4/11.8.3	70/30	2.1
8.12.7a/8.12.12a	80/20	2.2
8.3.5/8.3.6a/8.3.2	60/30/10	2.2
8.12.5a/8.12.12a	70/30	2.3
8.12.7a/8.12.9	70/30	2.3
11.4.13/11.4.2	60/40	2.4
11.4.2/11.4.9	80/20	2.4
11.5.3/11.7.2	80/20	2.4
8.12.7c/8.12.16	60/40	2.4
11.4.13/11.3.4	80/20	2.6
11.5.3/11.4.13	60/40	2.6
11.9.9/11.11.1	60/40	2.6
8.12.12a/8.12.5a	60/40	2.6
8.12.12a/8.12.7a	60/40	2.6
8.12.12a/8.3.3a	80/20	2.6
11.4.2/11.4.13	70/30	2.7
11.5.3/11.4.9	90/10	2.7
11.4.2/11.4.2/11.4.13	50/30/20	2.8
11.12.1	100	3
11.12.1/11.3.2	90/10	3
11.12.1/11.4.2	70/30	3
11.12.1a	100	3
11.3.10	100	3
11.3.2	100	3
11.4.2	100	3
11.4.2/11.5.2	80/20	3
11.5.2	100	3
11.5.3	100	3

11.5.3/11.3.2	60/40	3
11.5.3/11.4.2	80/20	3
11.5.9c	100	3
11.8.4	100	3
11.9.10	100	3
11.9.2	100	3
11.9.2/11.9.7	60/40	3
11.9.2/11.9.7a	60/40	3
11.9.2/11.9.9	60/40	3
11.9.7	100	3
11.9.7a	100	3
11.9.7a/11.9.9	80/20	3
11.9.7a/11.9.9/11.9.2	50/30/20	3
11.9.9	100	3
11.9.9/11.9.2	80/20	3
8.12.12a	100	3
8.12.4	100	3
8.12.9	100	3
11.12.1a/11.3.25b	95/5	3.05
11.12.1/11.3.25	90/10	3.2
11.12.1/11.3.4	90/10	3.2
11.12.1a/11.3.4	90/10	3.2
11.9.2/11.3.4	80/20	3.4
11.9.9/11.3.2/11.3.25	40/40/20	3.4
8.3.6a/8.3.3a	60/40	3.4
8.3.6a/8.3.5/8.3.3a	60/35/5	3.4
11.12.6a/11.12.4	90/10	3.6
11.5.3/11.3.4	70/30	3.6
8.12.14a/8.12.12a	60/40	3.6
8.3.6a/8.3.1a/8.3.3a	70/15/15	3.65
11.12.3	100	4
11.12.3/11.12.1a	90/10	4
11.12.6a	100	4
11.3.4/11.5.8/11.3.25b	60/30/10	4
11.3.4/11.5.8/11.4.2	60/20/20	4
8.11.1	100	4
8.12.7c	100	4
8.3.6a/8.3.1a	80/20	4
11.3.3/11.3.4/11.3.25	60/30/10	4.4
11.3.4/11.3.2	70/30	4.4
11.3.4/11.12.1a/11.3.25b	65/30/5	4.65
11.3.25	100	5
11.3.25b	100	5
11.3.27b	100	5
11.3.27f	100	5
11.3.4	100	5
11.3.4/11.3.25	90/10	5
11.3.4/11.3.27b	70/30	5
8.11.5a	100	5
8.3.13c	100	5

8.3.6a	100	5

Appendix B: RE descriptions

(modified from State of Queensland, 2018 https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about)

Regional Ecosystem code	Regional Ecosystem descriptions	Status
8.1.1	Closed forest to open shrubland of mangrove species forming a variety of associations, depending on their position in relation to tidal channels and the amount of freshwater input they receive.	No concern at present
8.1.2	Samphire open forbland to isolated clumps of forbs.	Of concern
8.1.3	*Sporobolus virginicus* open tussock grassland to closed tussock grassland. Occasional emergents may include mangrove spp., *Melaleuca* spp., *Acacia* spp. and *Clerodendrum inerme*.	Of concern
8.1.4	*Schoenoplectus subulatus* and/or *Eleocharis dulcis* sparse sedgeland to closed sedgeland or *Paspalum vaginatum* sparse tussock grassland to closed tussock grassland.	Endangered
8.1.5	*Melaleuca* spp. and/or *Eucalyptus tereticornis* and/or *Corymbia tessellaris* low open woodland to open forest (to open shrubland) (2-20m tall).	Endangered
8.2.1	*Casuarina equisetifolia* subsp. *incana* open forest to low woodland (to isolated clumps of trees) and/or dwarf open shrubland to open scrub and/or sparse herbland to herbland, on foredunes.	Of concern
8.2.6a	*Corymbia tessellaris* open forest to low woodland. *Acacia leptocarpa* and/or *Allocasuarina littoralis* are occasionally present as a co-dominant or subdominant canopy tree. *Corymbia clarksoniana* may be a minor component of the canopy.	Of concern
8.2.11	*Melaleuca* spp. closed forest to woodland (4-18m tall). Dominants may include one or several of *M. leucadendra, M. quinquenervia, M. viridiflora* var. *attenuata* and *M. dealbata*.	Of concern
8.2.13a	*Themeda triandra* and/or *Imperata cylindrica* and/or *Chionachne cyathopoda* tussock grassland to closed tussock grassland (0.3-0.7m tall), or *Xanthorrhoea latifolia* subsp. *latifolia* dwarf open shrubland to open heath (0.3 - 2m tall).	Endangered
8.2.13c	*Eucalyptus tereticornis* and/or *Corymbia tessellaris* low woodland to open forest (9-22m tall). *Melaleuca quinquenervia* and/or *M. dealbata* are sometimes codominant or associated species in the canopy. Other occasional associated canopy species may include *Melaleuca viridiflora* var. *viridiflora* (or *M. viridiflora* var. *attenuata*), *Eucalyptus platyphylla Lophostemon suaveolens* and *Albizia procera*. There are sometimes very sparse to sparse lower tree layers which may be dominated by species such as *Melaleuca viridiflora* var. *viridiflora*, *Eucalyptus tereticornis, E. platyphylla and Livistona decora*.	Endangered
8.3.1a	Riverine wetland or fringing riverine wetland. Semi-deciduous notophyll to mesophyll vine forest.	Endangered
8.3.2	*Melaleuca viridiflora* var. *viridiflora* open forest to woodland (to low open forest to low open woodland) (5-14m tall). Occasional associated canopy species or emergents include *Corymbia clarksoniana, Eucalyptus platyphylla, Lophostemon suaveolens, C. dallachiana, C. intermedia, E. exserta, Pandanus cookii* and *E. drepanophylla*.	Endangered
8.3.3a	*Melaleuca leucadendra* or *M. fluviatilis* and/or Casuarina cunninghamiana open forest to woodland (to low open forest to low-	Of concern

	woodland) (8-30m tall). Occasional associated species include *Lophostemon suaveolens, Corymbia intermedia, Nauclea orientalis, Terminalia sericocarpa, Ficus racemosa, Eucalyptus tereticornis, Corymbia trachyphloia* and *Pandanus cookii*.	
8.3.5	*Eucalyptus platyphylla* and/or *Lophostemon suaveolens* and/or *Corymbia clarksoniana* open forest to low woodland (7-24m tall). Includes areas with almost pure stands of *E. platyphylla*, and a few areas which are pure stands of *L. suaveolens*. More commonly these three species occur together. Occasional associated canopy species are *Eucalyptus drepanophylla* (or *E. crebra*), *Corymbia dallachiana*, *C. intermedia* and *C. tessellaris*.	Endangered
8.3.6a	*Eucalyptus tereticornis, Corymbia intermedia* (or *C. clarksoniana*) and *Lophostemon suaveolens* open forest to woodland, or *C. tessellaris* open forest to woodland. *Eucalyptus tereticornis* may sometimes codominate where *C. tessellaris* is prominent.	Of concern
8.3.10	Semi-evergreen to evergreen notophyll vine forest. This ecosystem is primarily defined by its landform, occurring on fans at the base of ranges, and excluding riparian rainforest. Dominants are very variable. Emergents may include *Eucalyptus tereticornis, Acacia fasciculifera* and *Cryptocarya hypospodia*.	No concern at present
8.3.11	*Melaleuca viridiflora* var. *attenuata* closed forest to woodland (8-14m tall). Other occasional to rare associated canopy species include *Pandanus cookii, Nauclea orientalis, Melaleuca dealbata, M. leucadendra and Lophostemon suaveolens*, and more rarely, *Corymbia tessellaris* and *Eucalyptus tereticornis*.	Endangered
8.3.12	I*mperata cylindrica* and/or *Sorghum nitidum forma aristatum* and/or *Ischaemum australe* closed tussock grassland to open tussock grassland.	Endangered
8.3.13	*Melaleuca quinquenervia* and/or *M. leucadendra* and/or *M. dealbata* and/or *Eucalyptus tereticornis* and/or *Corymbia tessellaris* closed forest to low open woodland (to tall open forest) (5-35m tall). Associated canopy species may include *Melaleuca viridiflora* var. *viridiflora, Melaleuca viridiflora* var. *attenuata, Lophostemon suaveolens, Corymbia intermedia, Eucalyptus platyphylla* and *Albizia procera*.	Endangered
8.3.13a	*Melaleuca quinquenervia* and/or *M. leucadendra* closed forest to low open woodland (to tall open forest) (10-35m tall). Occasional associated species may include *Melaleuca viridiflora* var. *viridiflora, Melaleuca viridiflora* var. *attenuata, Lophostemon suaveolens, Corymbia intermedia* and *Eucalyptus tereticornis*.	Of concern
8.3.13c	*Eucalyptus tereticornis* and/or *Corymbia tessellaris* low woodland to open forest (9-22m tall). *Melaleuca quinquenervia* and/or *M. dealbata* are sometimes codominant or associated species in the canopy. Other occasional associated canopy species may include *Melaleuca viridiflora* var. *viridiflora* (or *M. viridiflora* var. *attenuata*), *Eucalyptus platyphylla*, *Lophostemon suaveolens* and *Albizia procera*. There are sometimes very sparse to sparse lower tree layers which may be dominated by species such as *Melaleuca viridiflora* var. *viridiflora, Eucalyptus tereticornis, E. platyphylla* and *Livistona decora*, and there is sometimes a well-developed rainforest element.	Of concern
8.3.15	Open water in river channels, waterholes and lagoons, and exposed stream bed and bars. Usually devoid of emergent vegetation although scattered trees and shrubs such as *Melaleuca viminalis* or *Melaleuca* spp. may be present.	Of concern
8.8.1b	Evergreen notophyll vine forest. Emergents may include *Argyrodendron actinophyllum* subsp. *diversifolium*, *A. polyandrum* and *Cryptocarya hypospodia*.	Of concern

8.11.1	*Eucalyptus drepanophylla* woodland to open forest (15-28m tall). *Eucalyptus platyphylla* is sometimes an associated to codominant species in the canopy, though *E. drepanophylla* may sometimes be the only species present, especially along ridgelines. *Corymbia clarksoniana* is a frequent associated species in the canopy, and *Lophostemon suaveolens* is occasionally present.	Of concern
8.11.2	Semi-evergreen notophyll to microphyll vine forest. Emergents such as *Argyrodendron polyandrum* and *Dysoxylum mollissimum* subsp. *molle* may be present. Typical canopy dominants are *Argyrodendron polyandrum, Terminalia porphyrocarpa, Myristica globosa* subsp. *muelleri, Archontophoenix cunninghamiana, Falcataria toona* and *Dendrocnide photinophylla*.	Of concern
8.11.3a	*Corymbia intermedia* and/or *Eucalyptus portuensis* and/or *C. clarksoniana* and/or *E. platyphylla* and/or *E. drepanophylla* open forest to woodland (15-32m tall). There is usually a mixture of three or more species in the canopy, and there are several other species which may sometimes be dominant, co-dominant or associated in the canopy, including *E. exserta, C. tessellaris* and *E. tereticornis*. There is usually a very sparse to mid-dense secondary tree layer, often consisting of juvenile *Eucalyptus* spp. and *Corymbia* spp., as well as sometimes *Lophostemon suaveolens, L. confertus, Acacia leptocarpa, Melaleuca viridiflora* var. *viridiflora* and rainforest pioneering species.	Least concern
8.11.4	*Eucalyptus platyphylla* and/or *Corymbia clarksoniana* and/or *C. intermedia* and/or *C. tessellaris* open woodland to open forest (9-25m tall). Associated canopy species may include *E. drepanophylla, E. crebra, E. tereticornis* and *C. tessellaris*.	Endangered
8.11.5a	*Corymbia tessellaris* and *Eucalyptus tereticornis* open forest to woodland. Occasionally *C. clarksoniana* is a co-dominant or associated species, and *Lophostemon suaveolens* is sometimes present.	Of concern
8.12.1a	Evergreen notophyll feather palm vine forest.	No concern at present
8.12.2	Evergreen notophyll to complex notophyll vine forest.	No concern at present
8.12.3a	Evergreen notophyll to microphyll vine forest.	No concern at present
8.12.3b	Semi-evergreen microphyll vine thicket.	No concern at present
8.12.4	*Eucalyptus grandis* open forest (25-40m tall). *Corymbia intermedia* is a common associated species in the canopy, and *Eucalyptus portuensis* is also occasionally present. Other species sometimes present may include *E. resinifera, C. trachyphloia* and *E. tereticornis*.	Of concern
8.12.5a	*Lophostemon confertus* and/or *Eucalyptus portuensis* (or *E. exserta*) open forest to closed scrub (5-38m tall). Other occasional co-dominant or associated species include *Corymbia trachyphloia, Acacia spirorbis* subsp. *solandri, E. drepanophylla* and *Acacia falcata*.	Least concern
8.12.7a	*Corymbia citriodora* and *Eucalyptus portuensis* open forest to woodland (12-27m tall). *Corymbia trachyphloia* and *C. intermedia* are occasional subdominants, whilst *E. drepanophylla, E. tereticornis* and *E. exserta* may be associated canopy species. There is often a very sparse to mid-dense secondary tree layer, with typical species often including *C. trachyphloia, E. portuensis, C. citriodora, E. drepanophylla* and *Lophostemon confertus*.	No concern at present
8.12.7c	*Eucalyptus drepanophylla* low woodland to open forest (6-20m tall). *Corymbia citriodora* may sometimes be codominant in the canopy.	No concern at present

	Other occasional associated species in the canopy may include *E. melanophloia, C. trachyphloia, E. exserta, C. erythrophloia, E. portuensis* and *E. platyphylla*.	
8.12.8	*Eucalyptus montivaga* open forest (25-40m tall). Co-dominant to associated species in the canopy may include *Corymbia intermedia, Eucalyptus resinifera* and *E. acmenoides*. There is often a sparse to very sparse secondary tree layer dominated by *Allocasuarina littoralis* (or *A. torulosa*), with other associated species often including *Banksia integrifolia* subsp. *compar* and juvenile *Eucalyptus* spp. and *Corymbia* spp. from the canopy.	Of concern
8.12.9	*Eucalyptus tereticornis* woodland to open forest (18-30m tall). *Corymbia intermedia* and/or *Lophostemon suaveolens* can sometimes be codominant in the canopy. Other occasional associated canopy species may include *E. drepanophylla*.	Of concern
8.12.10a	*Leptospermum neglectum* and/or *L. polygalifolium* and/or *Acacia aulacocarpa* and/or *A. julifera* subsp. *curvinervia* and/or *Lophostemon confertus* dwarf open shrubland to closed scrub (to low woodland) (0.8-3m tall). Associated species in the canopy or as emergents may include *Dodonaea viscosa, Corymbia trachyphloia, Melaleuca hemisticta, Eucalyptus exserta, Grevillea banksii* and *Banksia spinulosa* var. *spinulosa*.	Of concern
8.12.11a	Semi-evergreen microphyll vine thicket.	Of concern
8.12.12a	*Corymbia intermedia* and/or *Eucalyptus platyphylla* open forest to woodland (occasionally closed forest) (12-25m tall) with several other canopy co-dominants or subdominants always present, which may include *E. drepanophylla, E. tereticornis, C. tessellaris* and *E. portuensis*.	No concern at present
8.12.14a	*Eucalyptus drepanophylla* and/or *E. exserta* open forest to shrubland (3-18m tall). Associated canopy species may include *Lophostemon confertus, Acacia spirorbis* subsp. *solandri, A. leptostachya, Corymbia intermedia* and *C. clarksoniana*.	No concern at present
8.12.19	Semi-deciduous complex notophyll feather palm vine forest.	No concern at present
8.12.16	Deciduous to semi-evergreen microphyll vine thicket.	Of concern
8.12.17a	Evergreen microphyll mossy forest to thicket.	Of concern
8.12.27a	*Corymbia intermedia* or *C. clarksoniana* open forest. Common associated canopy species may include *C. tessellaris* and *Eucalyptus tereticornis*. Sometimes *C. intermedia* (or *C. clarksoniana*) are subdominants with dominant *C. tessellaris* and/or *E. tereticornis*. Other occasional associated species in the canopy may include *E. drepanophylla, Livistona decora, Lophostemon suaveolens, Albizia procera, E. platyphylla, C. intermedia* x *C. clarksoniana* and *E. exserta*.	Endangered
8.12.27b	*Corymbia intermedia* or *C. clarksoniana* open forest. Common associated canopy species may include *C. tessellaris* and *Eucalyptus tereticornis*. Sometimes *C. intermedia* (or *C. clarksoniana*) are subdominants with dominant *C. tessellaris* and/or *E. tereticornis*. Other occasional associated species in the canopy may include *E. drepanophylla, Livistona decora, Lophostemon suaveolens, Albizia procera, E. platyphylla, C. intermedia x C. clarksoniana* and *E. exserta*.	Endangered
8.12.31a	*Eucalyptus resinifera* and/or *E. portuensis* and/or *E. acmenoides* closed forest to low open forest (to closed scrub) (4-40m tall). Associated canopy species may include *Corymbia intermedia,*	No concern at present

	Syncarpia glomulifera subsp. *glomulifera, Banksia integrifolia* subsp. *compar, C. trachyphloia* and occasionally *E. exserta, E. suffulgens* and *Lophostemon confertus*.	
8.12.31b	*Allocasuarina littoralis* and/or *A. torulosa* closed forest to closed scrub (to open forest).	No concern at present
8.12.32	*Corymbia intermedia* woodland to open forest (15-34m tall). Includes small areas dominated by *Allocasuarina littoralis* and/or *Eucalyptus exserta* and/or *Lophostemon confertus* woodland to closed forest (3-15m tall). Associated canopy species may include *E. portuensis, Lophostemon suaveolens, E. tereticornis, Banksia integrifolia* subsp. *compar, Allocasuarina littoralis, A. torulosa, E. drepanophylla* and *E. crebra*.	No concern at present
11.3.1	Open forest dominated by *Acacia harpophylla* and/or *Casuarina cristata* (particularly in southern parts), with or without scattered emergent *Eucalyptus* spp. such as *E. coolabah, E. largiflorens, E. populnea, E. orgadophila* and *E. woollsiana*.	Endangered
11.3.2	*Eucalyptus populnea* woodland to open woodland. *E. melanophloia* may be present and locally dominant.	Of concern
11.3.3	*Eucalyptus coolabah* open woodland to woodland with a grassy understorey.	Of concern
11.3.4	*Eucalyptus tereticornis* woodland to open forest. Other tree species that may be present and locally dominant include *E. camaldulensis, Corymbia tessellaris, E. coolabah, C. clarksoniana, E. populnea* or *E. brownii, E. melanophloia, E. platyphylla* or *Angophora floribunda. E. crebra* and *Lophostemon suaveolens* may be locally dominant (subregion 14).	Of concern
11.3.10	*Eucalyptus brownii* grassy woodland. This unit usually occurs as a woodland of *Eucalyptus brownii*.	Least concern
11.3.11	Semi-evergreen vine thicket or semi-deciduous notophyll rainforest, frequently with emergent *Eucalyptus tereticornis* or *E. raveretiana*.	Endangered
11.3.21	Grassland dominated by *Dichanthium sericeum* and/or *Astrebla* spp. (*A. lappacea, A. elymoides* and *A. squarrosa*). Scattered trees and shrubs may occur including *Eucalyptus coolabah, E. populnea, E. tereticornis* or *Acacia* spp.	Endangered
11.3.25	*Eucalyptus camaldulensis* or *E. tereticornis* open forest to woodland. Other tree species such as *Casuarina cunninghamiana, E. coolabah, Melaleuca bracteata, Melaleuca viminalis, Livistona* spp. (in north), *Melaleuca* spp. and *Angophora floribunda* are commonly present and may be locally dominant.	Of concern threatening processes other than clearing
11.3.25b	*Melaleuca leucadendra* and/or *M. fluviatilis, Nauclea orientalis* open forest. A range of other canopy or sub-canopy tree species also occur including *Pandanus tectorius, Livistona* spp., *Eucalyptus tereticornis, Corymbia tessellaris, Millettia pinnata, Casuarina cunninghamiana, Livistona decora, Lophostemon suaveolens* or *L. grandiflorus*, rainforest species and, along drainage lines, *Eucalyptus camaldulensis* or *E. tereticornis*.	Of concern
11.3.27b	Vegetation ranges from open water +/- aquatics and emergents such as *Potamogeton crispus, Myriophyllum verrucosum, Chara* spp., *Nitella* spp. *Nymphaea violacea, Ottelia ovalifolia, Nymphoides indica, N. crenata, Potamogeton tricarinatus, Cyperus difformis, Vallisneria caulescens* and *Hydrilla verticillata*. Often with fringing woodland, commonly *Eucalyptus camaldulensis* or *E. coolabah* but also a wide range of other species including *Eucalyptus platyphylla, E. tereticornis.*	Of concern
11.3.27f	*Eucalyptus coolabah* and/or *E. tereticornis* open woodland to woodland fringing swamps.	Of concern

11.4.1	Semi-evergreen vine thicket +/- *Casuarina cristata*.	Endangered
11.4.2	*Eucalyptus populnea/brownii* or *E. melanophloia* +/- *Corymbia dallachiana* +/- *C. tessellaris* +/- *E. crebra* +/- *E. platyphylla* woodland.	Of concern
11.4.4	Tussock grassland.	Of concern
11.4.8	Woodland to open forest dominated by *Eucalyptus cambageana* and *Acacia harpophylla* or, sometimes in the north, *A. argyrodendron*. *E. thozetiana* is sometimes present on shallower soils.	Endangered
11.4.9	Open forest, occasionally woodland, dominated by *Acacia harpophylla* usually with a low tree mid-storey of *Terminalia oblongata* and *Eremophila mitchellii*.	Endangered
11.4.13	*Eucalyptus orgadophila* open woodland. Associated species include *Corymbia dallachiana* and *C. erythrophloia*.	Least concern
11.5.2	*Eucalyptus crebra* +/- *Corymbia clarksoniana* +/- *C. citriodora* +/- *E. moluccana woodland*. Other canopy or sub-canopy trees that may be present include *Lysicarpus angustifolius, Acacia rhodoxylon, Eucalyptus exserta, E. tenuipes* and *Corymbia tessellaris*.	Least concern
11.5.3	*Eucalyptus populnea* +/- *E. melanophloia* +/- *Corymbia clarksoniana* +/- *C. dallachiana* and occasionally *E. cambageana* or *E. brownii* dominate the tree layer (14m median height and 11-15m range) woodland. Localised areas may be dominated by *E. melanophloia*, occasionally *E. crebra* and other canopy species.	No concern at present
11.5.8	Mosaic of *Melaleuca viridiflora* and/or *M. nervosa* woodland and *Eucalyptus crebra, Corymbia intermedia, E. latisinensis* and *Lophostemon suaveolens* woodland.	No concern at present
11.5.9c	*Eucalyptus crebra* +/- *Corymbia intermedia* +/- *E. moluccana* +/- *C. dallachiana* woodland.	Least concern
11.7.2	Monospecific stands of *Acacia* spp. forest/woodland on Cainozoic lateritic duricrusts. *Acacia shirleyi* and/or *Acacia catenulata* usually predominate the woodland to low woodland to low open forest tree canopy (7-12m high). Other *Acacia* spp. That commonly occur and occasionally dominate the tree layer include *A. rhodoxylon, A. burrowii, A. sparsiflora, A. crassa* and *A. blakei*. Emergent eucalypt species such as *Eucalyptus thozetiana, E. crebra, E. decorticans* and *E. exserta* may be present.	Least concern
11.8.3	Semi-evergreen vine thicket which may have emergent *Acacia harpophylla, Casuarina cristata* and *Eucalyptus* spp.	Of concern
11.8.4	*Eucalyptus melanophloia* and/or *E. crebra* +/- *E. orgadophila* +/- *Corymbia erythrophloia* grassy open woodland.	No concern at present
11.8.5	*Eucalyptus orgadophila* grassy open woodland. *E. orgadophila* predominates and forms a distinct but discontinuous canopy sometimes with other sub-dominant species such as *Corymbia erythrophloia, E. melanophloia* and occasionally *E. crebra*. Shrubs are usually scarce and scattered although a well-defined shrubby layer does develop in some areas. On the lower slopes at better sites, softwood scrub species may form tall and low shrub layers under the canopy of *Eucalyptus orgadophila*.	Least concern
11.8.11	Grassland dominated by *Dichanthium sericeum, Aristida* spp., *Astrebla* spp. and *Panicum decompositum* with or without trees such as *Eucalyptus orgadophila, E. melanophloia, Corymbia erythrophloia* and *Acacia salicina*.	Of concern
11.8.13	Semi-evergreen vine thicket and microphyll/notophyll rainforest.	Endangered
11.8.14	*Eucalyptus crebra* and *Corymbia dallachiana* grassy woodland.	Of concern

11.9.1	Open forest to woodland of *Eucalyptus cambageana* or *E. thozetiana* and *Acacia harpophylla*. *E. cambageana* is commonly codominant with *Acacia harpophylla* in the open forest, or the open forest may be dominated by *A. harpophylla* and have scattered emergent *Eucalyptus cambageana* or *E. thozetiana* trees.	Endangered
11.9.2	*Eucalyptus melanophloia* and/or *E. orgadophila* grassy woodland to open woodland. Other tree species occasionally present as subdominants include *Corymbia erythrophloia*, *E. populnea* or *Corymbia dallachiana*.	No concern at present
11.9.4a	Semi-evergreen vine thicket, generally dominated by a low tree layer (5-10m high) which is floristically diverse and variable.	Endeangered
11.9.5	Open forest dominated by *Acacia harpophylla* and/or *Casuarina cristata* (10-20m) or *A. harpophylla* with a semi-evergreen vine thicket understorey.	Endangered
11.9.7	*Eucalyptus populnea* predominates forming a distinct but discontinuous canopy (10-20 m tall). Occasionally *E. melanophloia* is present in the canopy. Lower trees are absent or infrequent.	Of concern
11.9.7a	*Eucalyptus populnea* predominates forming a distinct but discontinuous canopy (10-15 m high). Other trees may be scattered throughout the canopy.	Of concern
11.9.9	*Eucalyptus crebra* grassy woodland. *E. moluccana* sometimes conspicuous on lower slopes.	No concern at present
11.9.10	*Eucalyptus populnea* predominates forming a distinct but discontinuous canopy (15-18 m tall). *Acacia harpophylla* and sometimes *Casuarina cristata* usually forms a lower tree layer (8-14 m tall) which occasionally becomes the dominant layer.	Of concern
11.10.1	*Corymbia citriodora* predominates and forms a distinct but discontinuous woodland (to open forest) canopy (20-30m high). On rocky slopes, *Eucalyptus crebra* and *C. hendersonii* may be scattered throughout the canopy or locally abundant. On flats and footslopes, scattered *E. crebra, C. clarksoniana* and *C. tessellaris* may occur. *Corymbia trachyphloia* and *E. cloeziana* often occur on crests and plateaus while *E. apothalassica* and *E. longirostrata* sometimes occur in moister microhabitats.	No concern at present
11.12.1	*Eucalyptus crebra* +/- *Corymbia erythrophloia* shrubby woodland. *E. melanophloia* is often present and may be locally dominant. Also includes localised areas dominated by *E. persistens*.	No concern at present
11.12.1a	*Eucalyptus crebra* +/- *E. exserta* woodland.	No concern at present
11.12.3	*Eucalyptus crebra*, *E. tereticornis* +/- *Angophora leiocarpa* and *E. melanophloia* woodland. Other tree species that may be present include *Corymbia clarksoniana, C. tessellaris, C. erythrophloia, C. citriodora* and *E. exserta*.	Of concern
11.12.4	*Araucaria cunninghamii* is a common emergent from the general canopy layer with is 15-28 metres high. Canopy species include *Falcataria toona, Ficus virens, Canarium australianum, Alstonia scholaris, Planchonella pohlmaniana, Cleistanthus dallachyanus* and *Backhousia citriodora*.	No concern at present
11.12.6a	*Eucalyptus crebra* +/- *Corymbia citriodora* and/or *E. acmenoides* +/- *Lophostemon suaveolens* woodland to open forest.	No concern at present
11.12.13	*Eucalyptus crebra, Corymbia erythrophloia, C. dallachiana* and *C. tessellaris* +/- *C. intermedia* +/- *E. acmenoides* +/- *Canarium australianum* mixed open forest or woodland.	No concern at present

Appendix C- PCA ordination results

800 m radius excluding highly correlated variables (those >0.9).

PCA Ordination results using non-highly correlated variables
Variable selection: 1,3-5,7-10,12,14-16,18-21,23,25-27,29-32,34,36-38,40-43,45,47-49,51-54,56-71,75-79,81,83

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	12.8	21.3	21.3
2	10.5	17.5	38.8
3	8.68	14.5	53.3
4	5.52	9.2	62.5
5	4.72	7.9	70.3

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5

LCover_C1P	-0.056	0.188	-0.133	0.163	-0.185
EdDen_C1P	0.083	0.078	-0.044	0.200	-0.268
NumP_C1P	0.112	-0.024	-0.129	0.063	-0.046
PDen_C1P	0.112	-0.024	-0.129	0.063	-0.046
SPArea_C1P	-0.070	0.064	0.042	0.071	-0.117
MnPAr_C1P	-0.107	0.183	-0.034	0.119	-0.146
MdPAr_C1P	-0.107	0.178	-0.016	0.104	-0.137
MPSRat_C1P	0.079	-0.016	-0.006	-0.002	-0.064
LCover_C2P	-0.203	-0.130	-0.164	-0.011	0.028
EdDen_C2P	-0.198	-0.106	-0.174	0.018	0.026
NumP_C2P	-0.186	-0.012	-0.146	0.084	0.083
PDen_C2P	-0.186	-0.012	-0.146	0.084	0.083
SPArea_C2P	-0.145	-0.134	-0.124	-0.041	-0.051
MnPAr_C2P	-0.198	-0.145	-0.146	-0.039	0.001
MdPAr_C2P	-0.178	-0.158	-0.141	-0.071	-0.043
MPSRat_C2P	-0.111	0.068	-0.005	0.131	0.267
LCover_C3P	-0.041	-0.060	0.314	0.012	-0.058
EdDen_C3P	-0.062	-0.040	0.304	0.079	-0.049
NumP_C3P	-0.083	0.034	0.247	0.171	-0.010
PDen_C3P	-0.083	0.034	0.247	0.171	-0.010
SPArea_C3P	-0.045	-0.112	0.150	-0.176	0.009
MnPAr_C3P	-0.048	-0.095	0.280	-0.104	-0.030
MdPAr_C3P	-0.052	-0.091	0.254	-0.109	-0.024
MPSRat_C3P	-0.130	0.075	0.056	0.183	0.223
LCover_C4P	0.227	-0.003	-0.074	-0.112	0.170
EdDen_C4P	0.224	0.042	-0.078	-0.112	-0.009
NumP_C4P	0.133	0.122	-0.037	-0.161	-0.200
PDen_C4P	0.133	0.122	-0.037	-0.161	-0.200
SPArea_C4P	0.122	-0.039	-0.041	-0.083	0.272
MnPAr_C4P	0.180	-0.038	-0.049	-0.096	0.269
MdPAr_C4P	0.171	-0.045	-0.043	-0.093	0.272
MPSRat_C4P	0.016	0.011	-0.078	-0.047	-0.123
LCover_C5P	-0.081	0.225	0.026	-0.244	-0.005
EdDen_C5P	-0.110	0.242	0.015	-0.185	0.052
NumP_C5P	-0.135	0.237	0.000	-0.088	0.135
PDen_C5P	-0.135	0.237	0.000	-0.088	0.135
SPArea_C5P	-0.081	0.225	0.026	-0.244	-0.005
MnPAr_C5P	-0.081	0.225	0.026	-0.244	-0.005
MdPAr_C5P	-0.081	0.225	0.026	-0.244	-0.005
MPSRat_C5P	-0.146	0.188	-0.006	0.033	0.224
SUM_cover	0.104	-0.098	0.100	-0.010	0.134
SUM_propor	0.000	0.000	0.000	0.000	0.000
Area_PiRSq	0.000	0.000	0.000	0.000	0.000
Area_2RSq	0.000	0.000	0.000	0.000	0.000
Prop_C1_Pi	-0.056	0.188	-0.133	0.163	-0.185
Prop_C2_Pi	-0.203	-0.130	-0.164	-0.011	0.028
Prop_C3_Pi	-0.041	-0.060	0.314	0.012	-0.058
Prop_C4_Pi	0.227	-0.003	-0.074	-0.112	0.170
Prop_C5_Pi	-0.081	0.225	0.026	-0.244	-0.005
SUM_PropPi	0.093	-0.085	0.087	0.023	0.059
FWid_mean	-0.160	-0.112	0.116	-0.134	0.001
FWid_med	-0.152	-0.098	0.149	-0.113	0.026
FWid_min	-0.086	-0.113	0.076	-0.048	-0.036
FWid_max	-0.143	-0.099	0.044	-0.149	-0.025
FWid_count	-0.127	-0.107	0.035	-0.103	0.013
SL_mean	0.181	0.129	0.113	0.093	0.011
SL_count	-0.182	-0.103	-0.095	-0.086	-0.010
Vis_E	-0.074	0.106	-0.005	0.196	0.285
Vis_W	-0.087	0.106	0.011	0.190	0.238
TDIST_STAR	-0.103	-0.144	-0.053	-0.102	0.013
TDIST_END	0.083	-0.121	0.009	-0.063	-0.059
TDIST_ST_1	0.001	-0.103	-0.190	-0.139	-0.113
Total_Form	-0.103	-0.168	-0.057	-0.140	-0.064

Principal Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
800-0	1.62	-1.76	1.16	-0.0212	1.27
800-1600	-6.84	-6.29	-1.3	-3.48	-0.474
800-3200	-7.96	-6.64	-4.48	-2.02	-0.219
800-4800	-5.52	-3.02	-4.47	0.23	-1.44
800-6400	-2.75	-1.28	-4.35	2.31	-0.505
800-8000	0.0586	-1.36	-4.43	-0.58	-1.24
800-9600	0.093	1.66	-2.04	-0.315	-4.15
800-11200	3.16	0.646	-2.76	0.752	-1.62
800-12800	1.51	2.24	-1.72	1.96	-1.77
800-14400	3.59	0.816	-2.37	1.02	-0.0465
800-16000	5.32	-1.06	-2.08	-1.32	5.43
800-17600	3.49	1.39	-2.69	0.679	-2.16
800-19200	3.78	-1.17	0.547	-1.18	1.58
800-20800	4.15	-0.0485	-2.24	-0.532	1.83
800-22400	3.28	0.842	-2.02	0.31	0.128
800-24000	2.06	0.543	-0.381	0.115	-0.167
800-25600	-1.31	7.76	-2.21	-2.7	-1.21
800-27200	-3.27	9.13	2.74	-8.39	-0.881
800-28800	-1.58	-2.8	5.89	-0.384	-0.671
800-30400	0.766	0.581	2.4	2.1	-1.54
800-32000	-0.886	-2.18	4.71	-0.173	-0.879
800-33600	-0.497	-2.7	4.61	-1.85	-0.342
800-35200	1.34	-1.92	2.98	-0.793	-0.684
800-36800	0.661	-0.714	2.3	0.106	-0.243
800-38400	0.159	-1.53	4.38	0.655	0.36
800-40000	1.42	-1.1	2.17	0.0348	0.0736
800-41600	3.75	-1.62	-0.97	-1.97	3.63
800-43200	2.21	-1.32	1.18	-1.53	2.98
800-44800	4.06	0.711	-2.74	0.986	-1.01
800-46400	2.34	0.374	0.382	0.452	-0.886
800-48000	-0.155	-0.588	4.06	1.62	-1.37
800-49600	-2.19	2.92	3.06	5.96	-1.67
800-51200	-1.53	-0.865	1.18	2.16	-1.18
800-52800	-7.54	3.93	0.0386	4.01	7.18
800-54400	-6.79	6.42	-0.548	1.77	1.9