CSIRO PUBLISHING

RESEARCH PAPER
https://doi.org/10.1071/AM21018

Australian MAMMALOGY
The Australian Mammal Society

Koala road kills are linked to landscape attributes on Central Queensland's Peak Downs Highway

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Handling Editor:
Ross Goldingay

Received: 25 May 2021
Accepted: 6 November 2021
Published: 31 January 2022

Cite this:
Melzer A and Black L (2022)
Australian Mammalogy
44(3), 319–327. doi:10.1071/AM21018

ABSTRACT

Koala (*Phascolarctos cinereus*) road kills occur frequently along the Peak Downs highway through the Clarke-Connors ranges. Highway upgrades allowed mitigation of koala-vehicle collision frequency while maintaining koala population connectivity. This project aimed to understand road kill distribution to inform protective infrastructure investment. Koala road kills were associated with: (1) streams and associated alluvia where the dominant vegetation included *Eucalyptus tereticornis* and *E. platyphylla*; (2) ridges supporting *E. drepanophylla* open forest/woodland abutting streams or alluvia; and (3) mid-lower slopes, dominated by *E. drepanophylla* that were dissected by minor streams fringed by *E. tereticornis* ± *E. platyphylla*. Road kills did not occur in *E. drepanophylla* open forest/woodland on ridge upper slopes, crests or on hills, although koalas occur in this landscape. Explaining why koala road kills are linked to landscape features requires investigation. It is likely that: (1) landscape elements associated with drainage lines, alluvia and *E. tereticornis* support a relatively high koala abundance, and hence the road kill risk is correspondingly higher; and (2) the engineered road architecture and road verge characteristics in these landscape elements are conducive to koalas crossing the road.

Keywords: hotspots, *Phascolarctos cinereus*, road kill cluster, highway protective infrastructure, koala-vehicle collision, mitigation measures, Peak Downs Highway, landscape analysis.

Introduction

The negative impacts of roads on wildlife are well recognised (Taylor and Goldingay 2010; van der Ree *et al.* 2011), and include direct death through vehicle impacts, barriers to dispersal and population fragmentation (Goosem and Marsh 1997; Laurance *et al.* 2009; de Oliveira *et al.* 2013). Local population extinctions may occur (e.g. Jones 2000). Community and scientific concern has led to attempts to better define and mitigate these impacts. These research aims have included understanding the spatial and temporal characteristics of the impacts and devising systems to prioritise targeted investment in protective infrastructure (Spanowicz *et al.* 2020).

Road-associated impacts affect Australia's iconic koala (*Phascolarctos cinereus*) wherever such linear infrastructure intersects habitat of resident koala populations (Lassau *et al.* 2008; NRMMC 2009; de Oliveira *et al.* 2013). The koala's distribution extends across four Australian states (Queensland – Qld, New South Wales – NSW, Victoria – Vic, South Australia – SA) and the Australian Capital Territory (ACT) with road impacts occurring in all five jurisdictions. These impacts include injury and death from vehicle collisions (Dique *et al.* 2003; QLD DERM 2011; NSW DPIE 2020), contributions to local population declines (de Oliveira *et al.* 2013; Gonzalez-Astudillo *et al.* 2017), as well as being a factor in population fragmentation and, potentially, genetic isolation (Lee *et al.* 2010; Dudaniec *et al.* 2013). In particular, vehicle collisions are recognised as a nationally significant threatening process acting on the species (NRMMC 2009; McAlpine *et al.* 2015).

The koala is classified as *vulnerable* in NSW, the ACT and Qld (Australian *Environment Protection and Biodiversity Act* 1999, NSW *Biodiversity Conservation Act* 2016, Qld *Nature Conservation Act* 1992). In NSW, the ACT and Qld road-impact mitigation measures were developed in response to the koala's vulnerable classification as well as to public concerns for and empathy (Jackson 2007) with the koala. Whilst the threats can be avoided by directing road routes away from known koala populations, in most cases routes are long established and redirection is not feasible. Consequently, there has been considerable investment in developing mitigating measures. Generally, this includes constructed barrier and funnelling fences, underpasses and overpasses (e.g. Qld DTMR 2000, 2010; VicRoads 2012; NSW RMS 2015, 2019*a*, 2019*b*), although with varying degrees of effectiveness (e.g. Bond and Jones 2008; Dexter *et al.* 2016; Goldingay *et al.* 2018; Goldingay *et al.* 2019) and, where the opportunity arises, retrofitting existing structures such as bridges.

The Peak Downs Highway runs west from Mackay on the Central Queensland coast. Between the village of Eton and the township of Nebo the highway crosses the Clarke-Connors ranges. These ranges support large stands of remnant eucalypt open forest. An extensive koala population is associated with these open forests (Melzer *et al.* 2018*b*) and koala road kills are common along the highway. However, the distribution of road kills is not uniform, and clusters or hotspots are evident (Schlagloth 2018*b*). The upgrading of part of this highway provided the Queensland Department of Transport and Main Roads (DTMR) with an opportunity to install mitigation measures to reduce koala-vehicle collisions and maintain population connectivity across the road corridor (https://www.tmr.qld.gov.au/projects/eton-range-realignment-project). However, the koala population was poorly understood, and prior to infrastructure investment DTMR commissioned a suite of studies of the koalas, and of the pattern of koala road kills along the highway (Ellis *et al.* 2018; Melzer *et al.* 2018*a*, 2018*b*; Schlagloth 2018*b*). This paper reports on one of those studies. The aims of this study were to provide some basis for the classification of road kill risk on the highway and to focus potential investment in protective infrastructure.

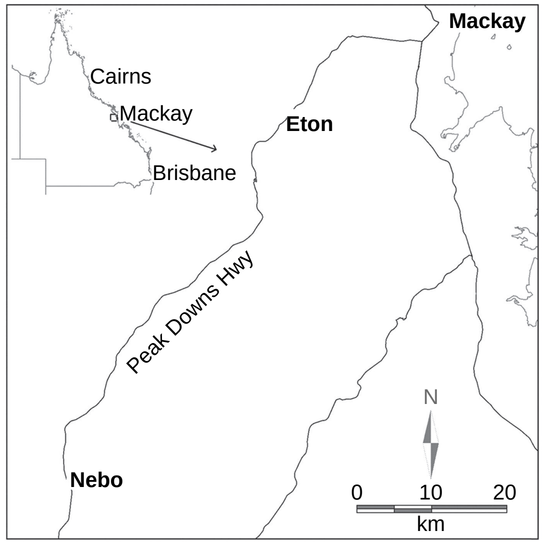

Fig. 1. Study area location between Nebo and Eton in relation to Mackay on the Central Queensland coast.

Methods

Study area

The study occurred on the Peak Downs highway west of Mackay (Fig. 1). It investigated koala road kill clustering and landscape associations that occurred along the 40.7 km stretch of Peak Downs Highway from Nebo Junction to Hazledean. The signed speed limit through this stretch of highway is 100 km/h. The measured traffic speed data has a median of 102.2 km/h (n = 470 874, range 55–135 km/h) (DTMR data Fiery Creek monitoring site January 2016–June 2017). At the time of the study there was no wildlife protection infrastructure in place on this part of the highway. The highway traverses the Clarke-Connors ranges, through a series of ridges and valleys and includes short traverses of undulating alluvial flats. The vegetation is predominantly remnant eucalypt open forest with some small areas of cleared or partially cleared lands, predominantly on the alluvial flats. *Eucalyptus drepanophylla* dominate the open forests associated with the ridges. *Eucalyptus tereticornis* and *E. platyphylla* dominate the minor alluvia associated with the first and second order streams that dissect the ranges as well as the few third and fourth order streams and their associated alluvial flats. The eucalypt open forest is not confined to the road reserve but is part of an extensive forested landscape extending over approximately 400 km of coastal ranges.

Interpreting the pattern of koala road kill records

Community volunteers and members of Fauna Rescue Whitsunday monitored the Nebo to Eton stretch of the Peak Downs highway on a daily basis throughout the study period (September 2014–August 2017). The coordinates of koala road kills were recorded with a hand-held GPS (Garmin GPSMAP 64ST) or later derived from the measured road distance from Nebo. The distribution of 69 koala road kills was mapped from Nebo Junction to Hazledean. Each record was given a unique number. These are listed in Table 1. The records were unevenly distributed along the study portion of the highway. This allowed the highway to be divided into road stretches based on whether koala road kills were present or were absent. This visual classification resulted in the highway to be divided into 18 highway stretches. Eleven of these stretches encompassed from 2 to 10 koala road kills. No kills were recorded in the remaining seven stretches. The road kill stretches extended over about 29.4 km (72%) of the 40.7 km study area. The start and

Table 1. Description of highway stretches ± koala road kill records (September 2014–August 2017) between Eton and Nebo on the Peak Downs highway.

Stretch number	Koala records code	Chainage (km) Start	Chainage (km) End	Vegetation and land form element description
1	30, 89, 106, 107	6.56	7.46	*Eucalyptus tereticornis*, *E. platyphylla* alluvial flat, rising to *E. drepanophylla* woodland on adjacent ridge.
2	0			*Eucalyptus drepanophylla* open forest on ridge crests.
3	83, 145, 88, 102	9.16	12.43	*Eucalyptus platyphylla* woodland with occasional *E. tereticornis* on alluvial flat. *E. drepanophylla* open forest to woodland on adjacent ridges and hills, with *E. tereticornis* and *Melaleuca* sp. open woodland in minor drainage lines and gullies.
4	0			*Eucalyptus drepanophylla, Corymbia dallachyana*, *C. erythrophloia* on ridge crests and hills adjacent to stream fringing forest including isolated to very isolated *E. tereticornis*.
5	77, 104, 248, 78, 27, 96, 244, 103, 60	14.95	18.79	*Eucalyptus tereticornis*, *E. platyphylla* tall open woodland on alluvia. *E. drepanophylla*, *E. platyphylla* ± *E. tereticornis*, *Corymbia tessellaris* open forest to woodland on adjacent lower ridge slopes. Tall *Melaleuca* fluviatilis and *C. tessellaris* emergent from a forest of rainforest elements fringing the creek.
6	239, 76			*Eucalyptus drepanophylla* open forest or woodland on ridges and hill tops; including one broad alluvial flat supporting *E. tereticornis*, *E. platyphylla* woodland.
7	58, 129, 242, 243	21.63	23.70	*Eucalyptus tereticornis*, *Corymbia tessellaris*, *E. drepanophylla* woodland on an undulating clay flat or depression between *E. drepanophylla* on low hills.
8	39, 68, 245	23.79	24.98	*Eucalyptus tereticornis* emergent from stream fringing forest; *E. platyphylla*, *E. tereticornis* tall woodland on adjacent western alluvial flat, and *E. drepanophylla* woodland adjacent eastern ridge.
9	0			*Eucalyptus drepanophylla* open forest on ridge crests and hills with isolated *E. platyphylla* and *E. tereticornis* in low pockets.
10	8, 31, 54, 64, 69, 92, 98, 105, 131, 238	25.24	28.60	*Corymbia tessellaris*, *Eucalyptus raveretiana*, *Melaleuca* sp. and rainforest elements in stream fringing forest. Adjacent broad alluvial flat supporting tall open woodland of *E. tereticornis*, *E. platyphylla*, *C. tessellaris* and *C. dallachyana*. Open forest of *E. platyphylla*, *E. tereticornis*, *E. drepanophylla*, *C. tessellaris* on adjacent undulating low rises, lower slopes and associated low ridges.
11	0			*Corymbia tessellaris*, *E. platyphylla* ± *E. drepanophylla*, *E. tereticornis*, *Melaleuca viridiflora* open forest or woodland on low hills and undulating flats.
12	42, 51, 82, 90, 108, 132, 205, 216, 247	31.71	34.94	*Eucalyptus drepanophylla* ± *E. tereticornis* woodland or open forest on ridges and hills dissected by ephemeral drainage lines supporting *E. tereticornis* open woodland. Ridges slope to the west to *E. tereticornis*, *E. platyphylla* woodland on undulating flats.
13	0			*Eucalyptus drepanophylla* open forest to woodland on hills and ridge crests without minor drainage lines.
14	3, 74, 85, 130, 133, 141	35.90	37.46	Stream fringing rainforest community with *Corymbia tessellaris*. *Eucalyptus tereticornis*, *E. drepanophylla* open forest on adjacent low hills.
15	0			No data.
16	1, 29, 62, 73, 86, 87, 100, 101, 112, 146	37.76	41.50	*Eucalyptus drepanophylla* woodland on hills dissected by ephemeral creeks supporting well-developed *E. tereticornis* open forest and *E. tereticornis* on adjacent alluvia.
17	0			*Eucalyptus drepanophylla* tall woodland on hills and ridges without minor drainage lines.
18	28, 53, 91, 99, 109, 249, 252	42.57	45.99	Grassland with emergent *Eucalyptus tereticornis*, *Eucalyptus tereticornis* grassy open woodland.

Note: 'Koala records code' refers to a unique number identifying individual mapped road kill locations (Melzer unpubl. data). 'Chainage' refers to a distance in km (±0.01 km) from the DTMR reference point in Nebo to a surveyed marker along the highway. Whilst the vegetation and landform element descriptions represent the situation along the highway, they extend beyond the highway road reserve and are part of a broader remnant landscape.

Table 2. Environmental attributes attributed to highway stretches (minus rare attributes) used in the data analyses.

Attributes	Definition	Code
Koalas	Number of records within each highway stretch	
Vegetation attributes	Presence or absence of characteristic tree species	
	Eucalyptus tereticornis	BG
	Eucalyptus platyphylla	PG
	Eucalyptus drepanophylla	BLIB
	Corymbia tessellaris	MBA
	Melaleuca fluviatilis	PB1
Landform elements	Stream banks	
	Alluvial flats	
	Minor drainage lines	
	Lower slopes	
	Ridge crest/upper slopes	
	Hills	

Note: Vegetation attribute codes are derived from species common names: BG, Qld blue gum, *E. tereticornis*; PG, poplar gum, *E. platyphylla*; BLIB, broad-leafed ironbark *E. drepanophylla*; MBA, Moreton bay Ash, *C. tessellaris*; PB1, paperbark 1 *Melaleuca fluviatillis*.

endpoint of each stretch was logged as distance in km (±0.01 km) from the DTMR reference point in Nebo using DTMR surveyed 'chainage' markers. Broad vegetation descriptions, from field inspections, were made of each road stretch (Table 1). Discrete attributes were derived from the vegetation and landscape description. These included prominent tree species and the types of landform element (Speight 2009) (Table 2). One highway stretch without data (Stretch 15) and rare data (presence/absence of *E. raveretiana*, *Corymbia dallachyana*, *C. erythrophloia*, *Melaleuca viridiflora* Table 3) were removed from analysis. The remaining set of 17 samples (highway stretches) with 11 variables (Table 2) was analysed using the multivariate analytical software package *Community Analysis Package* (Pisces Conservation Ltd, www.pisces-conservation.com). Data were investigated using 'agglomerative cluster analysis' (Ward's – Euclidian distance) for the existence of natural grouping in the data set. An analysis of similarity (ANOSIM) was applied to see whether the groups identified in the 'agglomerative cluster analysis' were significantly different. The R-statistic was used to indicate the significant differences among the groups. Our examination of those stretches encompassing koala road kills and stretches free of road kills suggested that the koala records may occur across an environmental gradient. Consequently, the clusters and associated attributes were examined using 'detrended correspondence analysis' (Hill and Gauch 1980) (DECORANA). This method maps the relationship between sites and attributes, and it is considered particularly useful when data are derived along environmental gradients.

Results

Interpreting the pattern of koala road kills

The 69 koala road kill records had an uneven distribution along the Peak Downs Highway from Nebo Junction to Hazledean. Sixty-nine occurred in 11 highway stretches, with koala records ranging from 2 to 10 per stretch. Among these, Stretch 6 included two isolated records (800 m apart). There were no road kill records associated with the remaining seven stretches (Table 1). The vegetation and landform attributes varied among stretches (Table 3). The dendrogram (Fig. 2) exhibited two major divisions and four significant groups (ANOSIM R = 0.769, P = 0.001). The first level division separated groups 1 and 2 from groups 3 and 4. Groups 1 and 2 were characterised by alluvial flats (Group 1) and lower ridge slopes supporting *C. tessellaris* (Group 2). Groups 3 and 4 were characterised by ridge upper slopes, ridge crests and hills.

The DECORA ordination arranged the clusters and attributes into a generally horizontal pattern (Fig. 3) reflecting a landscape gradient from lowland landform elements and associated tree species (left) to highland elements and tree species (right). The ordination clearly resolved the four groups evident in the dendrogram (Fig. 2). Groups 1 and 2 are at the lowest end of the landscape gradient. Group 4 is at the upper end of the gradient. Group 3 is intermediate. Groups 1, 2 and 3 are associated with koala road kills. There are no kills in Group 4. The highest kill records were associated with groups 1 (N = 5, mean road kills = 5.6, s.d. = 2.9) and 2 (N = 4, mean road kills = 6.5, s.d. = 4.5), with lesser counts for Group 3 (N = 3, mean road kills = 5, s.d. = 3.6) (Table 1).

Discussion

This paper examines the distribution of koala road kills along Central Queensland's Peak Downs Highway as it traverses the Clarke-Connors ranges between Nebo Junction to Hazledean, and identifies an association of road kill occurrence with landform and vegetation attributes.

Koala road kills occurred across a landscape gradient with road kill occurrence highest in lowland habitat and declining upslope to zero in highland habitat. The road kills were associated with (1) streams and associated alluvia where the dominant vegetation included *E. tereticornis* and *E. platyphylla*; (2) ridges supporting *E. drepanophylla* open forest/woodland, where the ridge immediately abutted a stream or alluvia; as well as (3) mid-lower slopes dominated by *E. drepanophylla*, where the slopes were dissected by

Table 3. Summary of all stretch associated attributes (number of road kill records and presence/absence of vegetation and landscape features) arranged in cluster groupings (see Fig. 2).

Cluster groups	Stretch number	Koalas	BG	PG	BLIB	BIB	MBA	GG	VBBW	PB1	PB2	Stream banks	Alluvial flats	Minor drainage	Lower slopes	Ridge crests/ upper slopes	Hills
1	1	4	+	+	−	−	−	−	−	−	−	+	+	−	−	−	−
	7	4	+	−	+	−	+	−	−	−	−	−	+	−	−	−	−
	8	3	+	+	+	−	−	−	−	−	−	+	+	−	+	−	−
	16	10	+	−	+	−	−	−	−	−	−	−	+	+	−	−	+
	18	7	+	−	−	−	−	−	−	−	−	−	+	−	−	−	−
2	5	9	+	+	+	−	+	−	−	+	−	+	+	−	+	−	−
	10	10	+	+	+	+	+	+	−	+	−	+	+	−	+	−	−
	11	0	+	+	+	−	+	−	−	−	+	−	−	−	+	−	−
	14	7	+	−	+	−	+	−	−	−	−	+	−	−	+	−	−
3	3	4	+	+	+	−	−	−	−	+	−	−	+	+	−	+	+
	12	9	+	+	+	−	−	−	−	−	−	−	+	+	−	+	+
	6	2	+	+	+	−	−	−	−	−	−	−	+	−	−	+	+
4	2	0	−	−	+	−	−	−	−	−	−	−	−	−	−	+	−
	9	0	−	−	+	−	−	−	−	−	−	−	−	−	−	+	+
	17	0	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−
	13	0	−	−	+	−	−	−	−	−	−	−	−	−	−	+	+
	4	0	+	−	+	−	−	+	+	−	−	+	−	−	−	+	+
Not included	15	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: ND, no data. Vegetation attribute codes are derived from species common names: BG, Qld blue gum, *E. tereticornis*; PG, poplar gum, *E. platyphylla*; BLIB, broad-leafed ironbark, *E. drepanophylla*; BIB, balck ironbox, *E. raveretiana*; MBA, Moreton bay ash, *C. tessellaris*; GG, ghost gum, *C. dallachyana*; VBBW, variable-barked bloodwood, *C. erythrophloia*; PB1, paperbark 1, *Melaleuca fluviatilis*; PB2, paperbark 2, *M. viridiflora*.

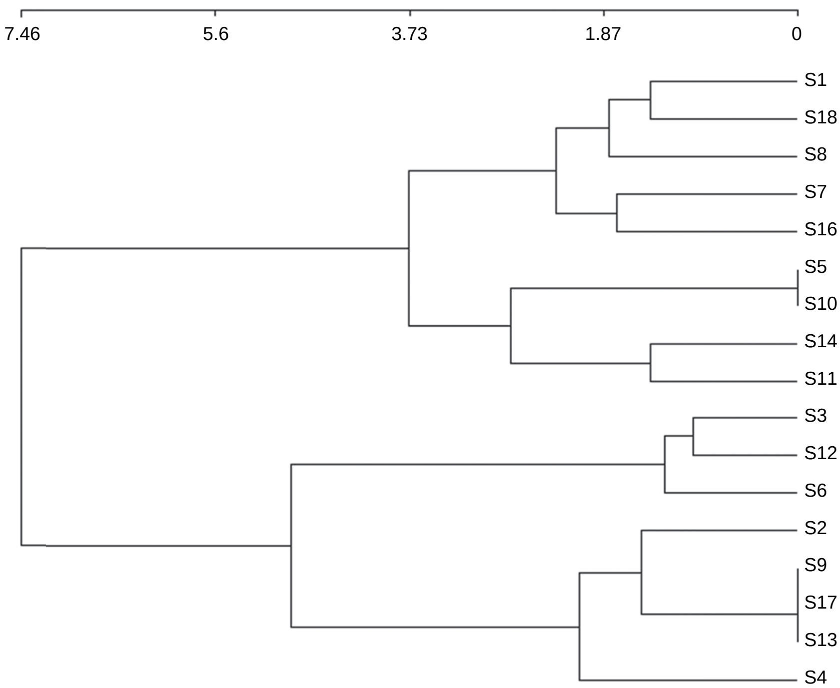

Fig. 2. Grouping of highway stretches derived from an 'agglomerative cluster analysis' using Ward's method and Euclidean distance. Rare data have been removed. There are two major divisions and four significant groups. Group 1: S1, S18, S8, S7, S16; Group 2: S5, S10, S14, S11; Group 3: S3, S12, S6; Group 4: S2, S9, S17, S13, S4. Groups 1, 2 and 3 are associated with koala road kill records. There were no road kill records in Group 4. The *X* axis represents the distance between the clusters at the time they were analysed.

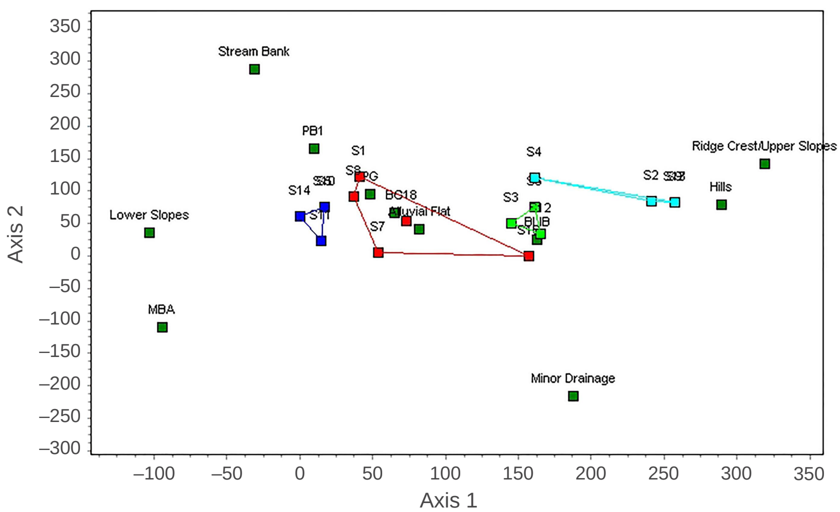

Fig. 3. DECORANA ordination of highway stretch attributes. Rare data excluded. Axis 1 follows a landform gradient from stream bank and lower slopes (left) to upper slopes, ridge crests and hills (right). Groups are arranged, left to right, Group 2, Group 1, Group 3, and Group 4. Koala road kill records were associated with Groups 1, 2 and 3. There were no road kill records for Group 4.

minor drainage lines fringed by *E. tereticornis* ± *E. platyphylla* or on adjacent minor alluvium. Koala kill records were absent from *E. drepanophylla* open forest/woodland on the upper slope or crest of ridges and on hills not associated with drainage lines.

The agglomerative clustering results largely reflect the *a priori* division of highway stretches into two classes, those with and those without koala road kills. There were two exceptions, however, Highway Stretch 11 clustered with group 2 despite having no koala road kill records. Highway Stretch 6, with two road kill records (800 m apart), clustered with Group 3. The vegetation description for highway Stretch 11 suggests that road kills would be expected there. Further investigation is required to ascertain koala usage of that area, and what additional attributes could explain why this highway stretch had a low koala kill frequency. A field inspection of highway Stretch 6 revealed that the two road kill records were each associated with a minor (first order) drainage line fringed by a narrow band of *E. tereticornis* ± *E. platyphylla*. The analysis suggests that a separate highway stretch should have encompassed these two road kill records and that two additional stretches without records should be established each side of that stretch.

Other studies and anecdotal accounts indicate that koalas occur in the open forests on the upper slope or crest of ridges and on hills along the highway route (Ellis *et al.* 2018, K. Harris pers. comm., A. Melzer pers. obs.). The road kills within the study area occurred within an extensive, mostly intact koala habitat landscape. Consequently, questions around habitat patch effects or habitat connectivity do not arise. Rather the question is about why koala road kills were clustered within a broadly occupied koala habitat. Generally, wildlife road kill probability (or risk) seems to be higher in the vicinity of a species' optimal habitat (e.g. Roger *et al*. 2012; D'Amico *et al*. 2015; Balčiauskas *et al.* 2020) although that is not always the case (Santos *et al.* 2013). We know from more intensive studies elsewhere in the region (Melzer 1995) that within an occupied habitat koala abundance is greatest on alluvial flats and adjacent lower ridge slopes, with a widespread lower density koala population on the surrounding ridges and hills. Also, in a wide-ranging survey of koalas across the Clarke-Connors ranges, Ellis *et al*. (2018) most frequently located koalas on the lower slopes and stream flats. So, it is likely that the landscape associated with the kill clusters (groups 1,2 and 3) represents habitat where koala abundance is relatively high and hence the road kill risk is high.

The analysis did not take account of the engineered structural characteristics of the broader road verge associated with the topographical features of the road reserve. This was because along the section of highway studied, the morphology of the road verge closely correlated with the landform element. Road verges on ridge crests and upper slopes were more likely to be characterised by taller/steeper cuttings through the ridges and steep batters over gullies. On the lower slopes, broader valleys and alluvial flats, these engineered features were most likely to be lower, shorter, and less steeply inclined (Fig. 4).

It is possible that koalas may be more willing to approach a road where the engineered structures provide the least impediment to movement, and conversely, they may be less inclined to approach a road across a long steeply inclined cutting or batter. More work on koala distribution across the entire landscape, and on koala behaviour around batters and cuttings is required to address this. However, it is likely that any consideration of road kill risk would require the inclusion of both habitat and road engineering parameters.

Despite the limitations, the results provide a basis for the classification of road kill risk and hence, provide a guide to focus potential investment in protective infrastructure. Currently this classification requires field assessment as existing mapping tools, in Qld at least, are at too coarse a scale to resolve smaller landscape and vegetation attributes or provide insufficient information for a desk-top assessment. For example, Qld regional ecosystem (RE) classification and mapping, which incorporates land zone and vegetation attributes (Sattler and Williams 1999), is too coarse to resolve the high road kill risk landscape and vegetation attributes in complex terrain. The RE classification and mapping encompassing Stretch 6 is a polygon combining REs 11.12.1a (90%) and 11.3.4 (10%). This conflates hills and lowlands on granite supporting *E. drepanophylla* (cluster groups 2, 3 and 4) and alluvium associated with rivers and creeks, supporting

Fig. 4. Road verges associated with lower slopes, broader valleys and alluvial flats (top) and ridge crests and upper slopes (bottom) on the Peak Downs highway between Nebo and Eton. Examples from Stretch 14 (top) and Stretch 13 (bottom). (Photos A. Melzer 2021).

E. tereticornis (cluster Group 1). This fails to resolve the first order streams linked to the road kill records in this stretch. In another example, terrain modelling in conjunction with water course and drainage mapping (QGlobe 2021) resolves the minor streams associated with this stretch but does not provide information on soils or vegetation attributes. Field assessment on ground or airborne, is required to undertake the classification at a suitable scale. Finally, the landscape analysis undertaken here has provided a result that gives direction to koala road kill hotspot modelling (e.g. Schlagloth 2018*a*, 2018*b*).

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. The authors declare no conflict of interest.

Declaration of funding. This project was funded by the Queensland Department of Transport and Main Roads.

Acknowledgements. The support from Queensland Department of Transport and Main Roads for research on koalas and road threats is appreciated. *Fauna Rescue Whitsunday* volunteers undertook road kill surveys and provided coordinates for each record. Their largely volunteer and in-kind support for this project is greatly appreciated. Ian Denley produced the map for Fig. 1.

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