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Patterns and composition of medium and large vertebrate roadkill, based on six annual surveys along two adjoining highways in south-eastern Queensland, Australia

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Abstract. Six annual single-pass roadkill surveys along two adjoining rural Queensland highways near Carnarvon Gorge National Park revealed 612 medium-size to large vertebrates, representing more than 18 taxa. Most were mammals (92%), particularly macropods. Losses averaged 0.26 animals km^{-1} $year^{-1}$ (range = 0.17–0.33), with variation possibly reflecting road repair/reconstruction and record seasonal rainfalls. Annual roadkill totals for the 390-km highway were projected to be over 5000 vertebrates, with more than half being large macropods. A consistent hotspot or ecological trap was noted along a 17-km high-traffic-volume stretch north of Roma. Because the sparsely populated outback is habitat for much Australian wildlife, multiyear baseline data are vital to identify the magnitude of the problem and inform future research.

Additional keywords: animal–vehicle collisions, citizen science, ecological trap, macropod, wildlife management.

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Introduction

Roads are essentially an ecological trap – a situation in which a sudden anthropogenic change in the environment causes a disconnect between cues that an organism uses to make normally adaptive behavioural decisions and the outcomes resulting from such decisions (Schlaepfer *et al*. 2002). Foraging animals are often attracted to the verges (roadsides) of bitumen (asphalt) roadways, particularly in arid regions, because any water that runs off the pavement creates a localised flush of vegetative growth. Also, increasing urban development along rural roads may result in local environmental conditions more favourable than natural bushland for wildlife. Over evolutionary time, being attracted to such areas would be adaptive. However, now such behaviour has become increasingly maladaptive because it increases the vulnerability of foraging and migrating animals to being struck by passing vehicles and likewise threatens the carrion feeders attracted to their remains.

Forman and Alexander (1998), Coffin (2007) and Van der Ree *et al*. (2015) have reviewed the ecological impacts of roads. Australian efforts to mitigate animal–vehicle collisions are of increasing priority, particularly where iconic or endangered species are impacted (e.g. koalas: see Goldingay *et al*. 2018; cassowaries: see Dwyer *et al*. 2016; Lumholtz's tree kangaroos: see Shima *et al*. 2018; eastern quolls, Tasmanian devils: see Jones 2000). Klöcker *et al*. (2006) point out that collisions with vehicles substantially impact kangaroo populations. In a recent study in an urban area of south-eastern Queensland (Brunton *et al*. 2018) vehicles accounted for 73% of all kangaroo deaths over a two-year period. These findings underscore the need for long-term data on roadkill in different settings. Here I report vertebrate roadkill mortality from six annual surveys along a 390-km segment of rural highways between Roma and Moura in south-eastern Queensland, Australia.

Methods

The state-controlled two-lane highways surveyed in this study (Carnarvon Highway and Dawson Highway) are in a relatively sparsely populated part of south-eastern Queensland, Australia, on the western slope of the Great Dividing Range ~500 km north of Brisbane and ~200 km south-west of Rockhampton (Fig. 1). From 2008 to 2014 (except 2012, due to an itinerary change), between 20 May and 3 June we recorded roadkill spotted along 390 km of adjoining sections of two rural highways. One count started ~5 km after departure from Roma, traveling north on the Carnarvon Highway; these data were collected between 1500 and 1730 hours. This highway passed through Injune (~92 km north of Roma), and ended at the turnoff onto the Carnarvon Development Road leading to Carnarvon Gorge National Park, near Rewan, a distance of ~200 km. The other count began where the previous one ended, but four days later, and continued north on the Carnarvon Highway to Rolleston, then east on the Dawson Highway, ending at the Dawson River ~20 km west of Moura, a distance of ~190 km. Data for this second count were collected between 0800 and 1030 hours. Land adjacent to both highways was predominantly pastoral property, with occasional agricultural development (oats, cotton, corn, and *Leucaena*, a perennial legume forage crop). May–June monthly mean maximum temperatures recorded at the Roma Airport averaged 22.2°C (range = 19.6–25.0) and rainfall averaged 23.4 mm (range = 4.6–49.0), although record heavy rains occurred

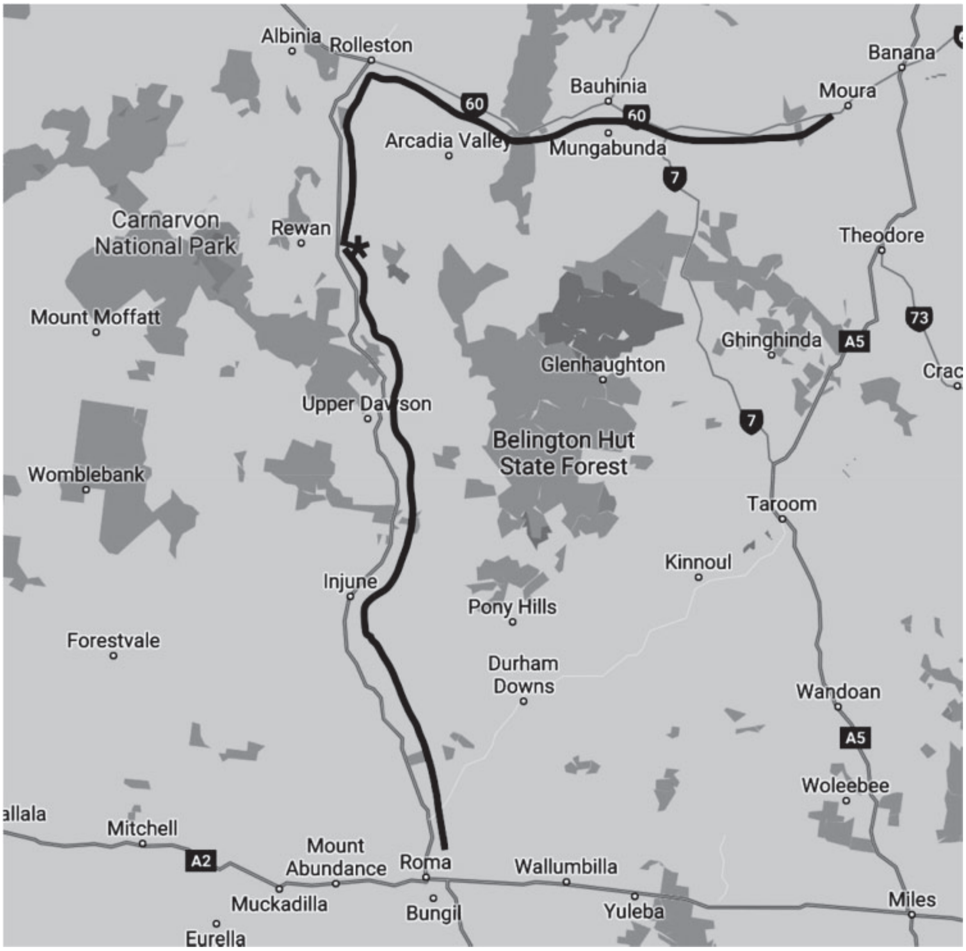

Fig. 1. Map of the study area. Bold line shows the 390-km highway section between Roma and Moura surveyed for roadkill six times over seven years (2008–14, except 2012). Roadkill counts began ~5 km after leaving Roma (population 6848, 2016 census), headed north on the Carnarvon Highway and then east on the Dawson Highway, and ended where the road crosses the Dawson River before Moura (population 1899, 2011 census); counts were suspended for ~7 km on either side of Injune and Rolleston. Asterisk near Rewan indicates the turn-off to Carnarvon Gorge National Park where the first sampled section ended (Segments 1–11: Fig. 2) and the second (Segments 12–21) began.

between February and April in 2010 and 2011 (Bureau of Meteorology 2018). Various sections of the sampled highways were undergoing extensive road construction during the years of the study.

Together with the coach driver and author, successive teams of two citizen-scientists sitting in the front of a moving motor coach collected the raw data, continually scanning the highway, including 5–10 m of the verge (shoulder) on either side. To enable all citizen scientists to participate, the route was divided into 21 consecutive 17-km segments (consistent from year to year), and each team gathered data for one segment over ~10 min; smooth transitions between successive observer teams were facilitated via the coach audio system. For ~7 km on either side of the towns of Injune and Rolleston data collections were temporarily suspended, an arbitrary decision intended to minimise human population–related variables.

Whenever possible, roadkill data included identity (common name), assisted by reference to Zell (2006). However, none of the observers were expert naturalists. After conversations with local people, carcass conditions were subjectively categorised as 'fresh' (intact and estimated to be <2 days old), 'aging' (flattened and/or partly decomposed, estimated to be ~3–6 days old), or 'old' (desiccated and/or dismembered, estimated to be ~7–14 days old). Due to the speed of the coach (average 90–100 km h^{-1}), detection and identification of small birds, lizards, amphibians, and smaller mammals was less reliable but these were included whenever possible.

For each highway segment, oncoming vehicles were counted. Because knowledge of actual daily traffic volume for each 17-km highway segment was unavailable, this count served as a proxy. To cross-check our proxy counts as a measure of traffic volume, we retrieved from government records average daily traffic counts for six locations that lay along our route on the sampled highways (Queensland Government Data 2019). Comparison of the government-collected data and our six sample averages at those similar locations yielded a correlation of r^2 = 0.831. This evidence supports use of this proxy.

Results

The six samples recorded 612 roadkilled vertebrate animals (average = 102 year^{-1}, range = 68–130) At least 18 distinct taxa were represented (Table 1). Six or more species of marsupials (96% of which were kangaroos and wallabies) accounted for approximately half of the roadkill total (313 of 612). The third most common roadkill (16%) was the rabbit. Birds and reptiles, less frequently noted, represented at least eight species. About one of four remains (24%) were identifiable only as mammals due to their deteriorated condition.

Overall, segment-by-segment traffic volume patterns showed a strong positive correlation (r^2 = 0.846) to roadkill counts (Fig. 2). However, increasing traffic volume along the route each year did not correlate directly with wildlife mortality. Whereas traffic volume on the sampled highways grew rather steadily over the study period (Fig. 3), roadkill numbers (average = 0.26 km^{-1}, range = 0.17–0.33) varied from year to year (Fig. 4), being highest in the first two years, but lowest in 2010 and 2011, indicating the complexity of the roadkill situation.

The most deaths (77.3%) and highest traffic volume (89%) occurred on the Carnarvon Highway between Roma and the Carnarvon Gorge National Park turn-off (Segments 1–11: Fig. 2), equivalent to ~0.4 animals km^{-1} year^{-1}. One area in particular (Segment 3: Fig. 2), was especially dangerous for wildlife. Nearly 25% of all the roadkill recorded on the Carnarvon Highway occurred along this segment, ranging from 9 to 33 losses annually (average = 19.6). In contrast, along the section from the Carnarvon Park turn-off to the Dawson River (47% of the total distance surveyed, Segments 12–21: Fig. 2), which carried only 11% of the traffic volume, roadkill numbers accounted for only 23% of the total, equivalent to 0.12 km^{-1} year^{-1}.

Making the broad assumptions that our sample data would be the same regardless of date collected (i.e. no variation in

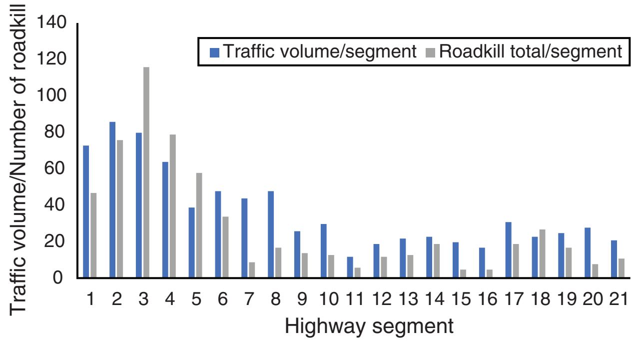

Fig. 2. Overall relationship between traffic volume and roadkill along two contiguous south-eastern Queensland rural highways, based on totals of six yearly samples. The route was arbitrarily divided into 21 segments, each 17 km long, numbered sequentially from Roma to the Dawson River. The turn-off to Carnarvon Gorge National Park is between Segments 11 and 12.

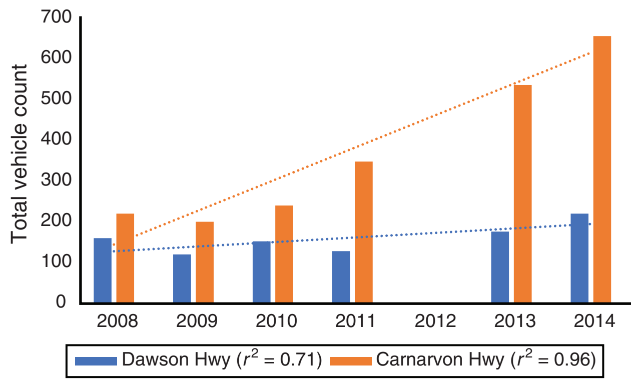

Fig. 3. Six annual samples of oncoming traffic volume based on data collected on the same dates (20 May to 3 June) from a motor coach moving along the Carnarvon and Dawson Highways.

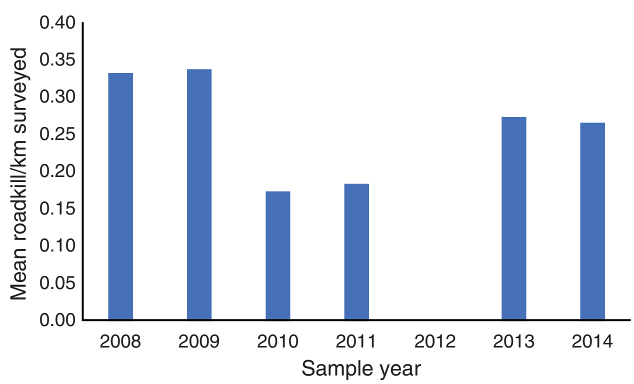

Fig. 4. Average number of dead medium-sized to large vertebrates km^{-1} encountered along the two-lane highway system from Roma to the Dawson River.

Table 1. Roadkilled medium-sized to large vertebrates tallied in six annual single-pass counts along a 390-km section of two adjoining rural Queensland highways

Taxon	Fresh (<2 days)	Aging (~3–6 days)	Old (~7–14 days)	Total
Mammals:	120	173	271	564
Wallaby	57	43	68	168
Kangaroo	30	40	62	132
Bettong	1	0	0	1
Rabbit	13	47	36	96
Possum	5	2	2	9
Cow	3	1	0	4
Fox	0	2	0	2
Echidna	1	1	0	2
Pig	0	2	0	2
Flying fox	1	1	0	2
Bandicoot	1	0	0	1
Indiscernible mammal	8	34	103	145
Birds:	16	18	6	40
Kite	6	4	2	12
Wedge-tailed eagle	1	2	0	3
Kookaburra	2	0	1	3
Cockatoo	3	0	0	3
Apostle bird	1	1	0	2
Indiscernible bird	12	104	15	65
Reptiles:	1	3	4	8
Snake	1	1	2	4
Lizard	0	2	2	4
Grand total	137	194	281	612

environmental conditions, animal behaviour, or traffic volume) and assuming a roadkill persistence time of one week (Taylor and Goldingay 2004; Santos *et al.* 2011; Teixeira *et al.* 2013), our findings may be extrapolated to obtain an annual roadkill rate. This results in projected annual roadkill totals for the 390-km highway of over 5000 vertebrates (total roadkill recorded divided by 6 samples, then multiplied by 52 weeks), with more than half being large macropods.

Discussion

Both the high levels of vehicle-induced mortality and the composition of taxa reported in this study are generally consistent with previously published reports, particularly with regard to the toll suffered by macropods. In a five-year study in Queensland, Rowden *et al*. (2008) found that macropods comprised 44.8% of the reported roadkill, a similar value to ours (Table 1). Brunton *et al*. (2018) found that kangaroo populations in an urban area of south-eastern Queensland declined precipitously over a two-year period, with vehicle collisions accounting for nearly 75% of this loss.

Had roadkill counts been made in other months or times the species composition and totals would likely have been different. The apparent relationship between high rainfall in 2010 and 2011 and reduced roadkill rates suggests that counts during the wet season would be lower. This extra precipitation improved overall foraging conditions in the surrounding bush, probably reducing the relative attraction of roadside vegetation over subsequent periods when we counted the roadkill. Other factors that may have influenced results include the fact that traffic volume counts were made at different hours on the two highway sections, and likely varied temporally due to commuting, etc. Traffic counts no doubt vary seasonally as well, particularly in relation to peak visitation times for Carnarvon National Park.

Our roadkill counts were likely underestimates. Some injured animals die away from the road and hence remain undetected. Carcasses are scattered by subsequent passing vehicles, eaten or removed by scavengers and predators, or reduced to skeletons by ants and other decomposers (Santos *et al*. 2011). Smaller carcasses are more easily removed by scavengers, whereas larger ones are more likely to be left *in situ* as scavengers feed on them. Heat, low humidity, and other weather factors also reduce carcass persistence. In our study, the observation that almost half (281 of 612) of the roadkill was characterised as 'old' (Table 1) is consistent with these explanations.

Year-to-year variability in roadkill numbers and composition is supported by others' findings. Reported macropod mortality rates have ranged from 0.44 km^{-1} $year^{-1}$ (Coulson 1982) to 11.0 km^{-1} $year^{-1}$ (Klöcker *et al*. 2006). Bond and Jones (2014) reviewed 12 Australian roadkill studies and found that macropods comprised 0–94% of the animal mortality reported. Such variability underscores the value of multiyear sampling, and helps explain the wildlife mortality differences we found between the two highway sections censused.

Reasons why Segment 3 near Injune was consistently a mortality hotspot were not obvious, but this deadly situation deserves further study. High traffic volume, high speed limits, topography that impedes driver vision, and locally high population densities have been postulated to favour the development of a roadkill hot spot (Dwyer *et al*. 2016; Lima Santos *et al*. 2017). Some studies suggest that landscape attributes (e.g. gullies, type and extent of vegetation) and adjacent land usage (urban, agricultural, pasture, etc.) can be factors (e.g. Coulson 1982; Klöcker *et al*. 2006).

The decline we observed in roadkill numbers after 2009 was unexpected, especially since traffic volume increased. Environmental novelty resulting from on-going construction during these years may have altered roadside verge areas in ways that made them less attractive to wildlife. Reduced speed in construction zones likely also reduced roadkill. Although construction-related noise might have been a factor, it would seem less important for macropods, since most of their collisions occur at night (Coulson 1982; Osawa 1989).

Efforts to mitigate roadkill losses are drawing increasing attention, and protection of Australia's unique fauna has been a major focus of this work (e.g. Dwyer *et al*. 2016; Goldingay *et al*. 2018; Shima *et al*. 2018). More species-specific research is needed in order to better tailor mitigation efforts to the behavioural ecology of particular species. For the greatest impact, initial mitigation efforts should target known hotspots. The sparsely populated outback comprises a substantial portion of the habitat of much of Australia's wildlife, which will be increasingly vulnerable as the pace of anthropogenic modifications of the environment continues to quicken and transport infrastructure increases, bringing increased habitat fragmentation and increased traffic volume.

Conflicts of interest

The author declares no conflicts of interest.

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