Green-Barber and Old *BMC Zoology* (2019) 4:11
https://doi.org/10.1186/s40850-019-0047-8

BMC Zoology

RESEARCH ARTICLE Open Access

What influences road mortality rates of eastern grey kangaroos in a semi-rural area?

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Abstract

Background: Roads have major ecological impacts on wildlife. Vehicle collisions most frequently impact large herbivores due to their larger home range compared to smaller animals, and higher population density compared to carnivores. Kangaroos (*Macropus* spp.) account for a large proportion of reported wildlife vehicle collisions that occur in N S W, Australia. We aimed to evaluate what influenced road mortality of eastern grey kangaroos (*Macropus giganteus*) in a temperate rural/suburban region. The location of roadkilled kangaroos found on or near two 1 km stretches of road in Richmond NSW was recorded throughout 2014 and 2015. Weather and moon phase data were recorded for the date of each roadkilled kangaroo. Transects were setup on both roads, and multiple road and landscape features, including the width of roadside, fence construction, habitat type, and distance from street lights measured at 50 m intervals. Data were analyzed to explore which landscape features and temporal factors influenced the occurrence of a roadkill hotspot.

Results: More kangaroo road mortalities occurred during periods of low temperature and low rainfall, and these factors are likely to affect forage quality. Fewer mortalities occurred when rain was falling. A greater number of mortalities occurred during the waning gibbous phase of the lunar cycle. Significantly more road mortalities occurred a short distance from the end of a section of street lights.

Conclusions: The findings suggest that illumination influences the likelihood of kangaroo road mortalities. Large herbivores are particularly sensitive to habitat fragmentation because they need unrestricted access to large continuous habitat. Knowledge of factors that influence where and when kangaroos are most likely to cross roads can be used to inform more targeted management strategies and improve future road design and habitat connectivity to reduce the incidence of wildlife vehicle collisions.

Keywords: Landscape, *Macropus giganteus*, Macropod, Marsupial, Wildlife vehicle collisions, Roadkill hotspot

Background

Roads have multiple ecological impacts on wildlife including fragmentation of habitats and isolation of populations [1, 2]. Roads affect wildlife directly through road mortality, and also impact habitat use and dispersal due to habitat fragmentation, barrier effects and noise disturbance [3–6].

Wildlife are attracted to roadsides by resources that are rare or limited in other areas, including water and high quality foods [7–10]. Roads provide foraging areas and reduce predation pressures for some species [6]. Urban development reduces the available habitat and therefore roadside vegetation provides a significant proportion of suitable habitat in modified landscapes [11]. Animals that frequently cross roads to gain access to resources have an increased risk of road mortality. Roadkill hotspots are areas with a higher rate of wildlife vehicle collisions than other surrounding areas. Hotspots may result from resources or attractive habitat features occurring close to the roadside, or when two particularly valuable resources occur on opposite sides of the road causing animals to cross frequently. Hotspot analysis compares the features associated with areas of high wildlife vehicle collision rates, with areas of low wildlife vehicle collision rates [12–14]. Although some roadkill studies have examined the

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influence of landscape features, there are insufficient species specific studies that account for the different habitat preferences of different species in different areas [10].

Australia's road network covers over 810,600 km [15], and large terrestrial mammals such as eastern grey kangaroos account for a large proportion of wildlife vehicle collisions. Klöcker et al. [16] recorded the number of eastern grey kangaroos (*Macropus giganteus*), western grey kangaroos (*Macropus fuliginosus*), red kangaroos (*Macropus rufus*), common wallaroos (*Macropus robustus*) killed on a section of outback highway in far western NSW, and reported a roadkill rate of 0.03 kangaroos per km, per day, whilst Burgin and Brainwood [15] estimated that over 9 million kangaroos and wallabies are killed annually on Australian roads. Kangaroo vehicle collisions lead to high costs for drivers and insurance companies, in the tens of millions of dollars, through vehicle damage and human distress, injury and death [16, 17].

The behavioral responses of different species affect road mortality rates [18]. Some prey species avoid threats by freezing, increasing the amount of time spent on roads when vehicles are approaching, and results in a higher road mortality rate [18]. Large macropods reportedly respond to threats in different ways. Western grey kangaroos respond to a perceived threat by slowing down or standing still, whereas red kangaroos respond to threats by fleeing [18]. Eastern grey kangaroos are physiologically more similar to western grey kangaroos and are likely to react to perceived threats in a similar way and therefore likely exhibit similar antipredator behavioral adaptations, which increase their risk of road mortality.

Landscape features surrounding the road also influence the likelihood of road mortality [19]. Klöcker et al. [16] compared locations with a high incidence of eastern grey kangaroo road mortality with locations without a high incidence of road mortality on a stretch of highway in an arid region of Australia, and found no relationship between the taller patches of vegetation and road mortality. Other studies that have evaluated the effect of vegetation on road mortalities have focused on the reduced visibility caused by increased vegetation [12, 13]. Limited research has been conducted which modelled eastern grey kangaroos road mortality in Victoria [20], and non-species specific mortality hotspots have been evaluated in NSW [19]; however, insufficient species specific studies have been conducted which evaluate the influence of attractive landscape features on road mortality of eastern grey kangaroos in temperate regions or semi-rural/semi-suburban areas in NSW (New South Wales). We compare the spatial and temporal variables at locations and times that have high kangaroo road mortality, with areas of low kangaroo road mortality on roads adjacent to the Hawkesbury campus of Western Sydney University (WSU), NSW. and surrounding farmlands.

Results

Twenty three roadkilled eastern grey kangaroos were recorded on roadsides in the study area. The data showed a slight male bias with 60% of all kangaroo roadkill being male. Roadkilled males had a mean tail length of 90 cm (± 14), and a mean tail diameter of 8 cm (± 3). Roadkilled females had a mean tail length of 65 cm (± 12), and a mean tail diameter of 5 cm (± – 1).

Season, weather and moon cycle

The most roadkilled kangaroos (48%) occurred during winter (June–August) on dates with average minimum and maximum daily temperatures of 5.7 °C – 20.3 °C. Fewer road mortalities occurred on days with a higher minimum temperature (*P* value = 0.07) (Fig. 1). No kangaroo road mortalities occurred during summer. Most male kangaroo roadkill occurred during winter (83.33%) and the remainder occurred during autumn (16.67%); however, half of female kangaroo roadkill occurred during autumn (50%), and the rest occurred during spring (37.5%) and winter (12.5%). Kangaroo road mortalities occurred more frequently during months with lower rainfall, and significantly fewer mortalities occurred on days with recorded rainfall than on days with no rainfall (*P* value = 0.03).

The results of the likelihood ratio test showed that the overall effect of moon phase on road mortalities was not significant (likelihood ratio test = 7.85 df = 7 *P* value = 0.346). More mortalities occurred during moon phases with high illumination, although this result was also not significant (*P* value = 0.20). However, a significantly greater rate of road mortalities (47%) occurred during the waning gibbous phase compared with all other moon phases (*P* value = 0.02) (Fig. 2).

Effect of road and roadside width, and barrier type

Sites where kangaroo road mortalities occurred had a mean taller fence and narrower road and roadside than sites with no kangaroo mortalities; however, this was not statistically significant.

The majority of kangaroo road mortalities occurred near wire cattle fences (65%), the rest were near welded mesh fences (20%), and chain link fences (15%). No kangaroo road mortalities were recorded near sheet metal fences, wooden ranch fences or areas with no nearby fence. The majority of sites with multiple kangaroo road mortalities recorded throughout the study period were near wire cattle fences (60%), the rest were near chain link fences (20%), and welded mesh fences (20%). More male kangaroo road mortalities occurred near wire cattle fences (39%) and more female kangaroo road mortalities occurred near welded mesh fences (57%).

As kangaroos were likely to be crossing the road when mortalities occurred, it is important to consider fencing on the opposite side of the road from roadkilled kangaroos.

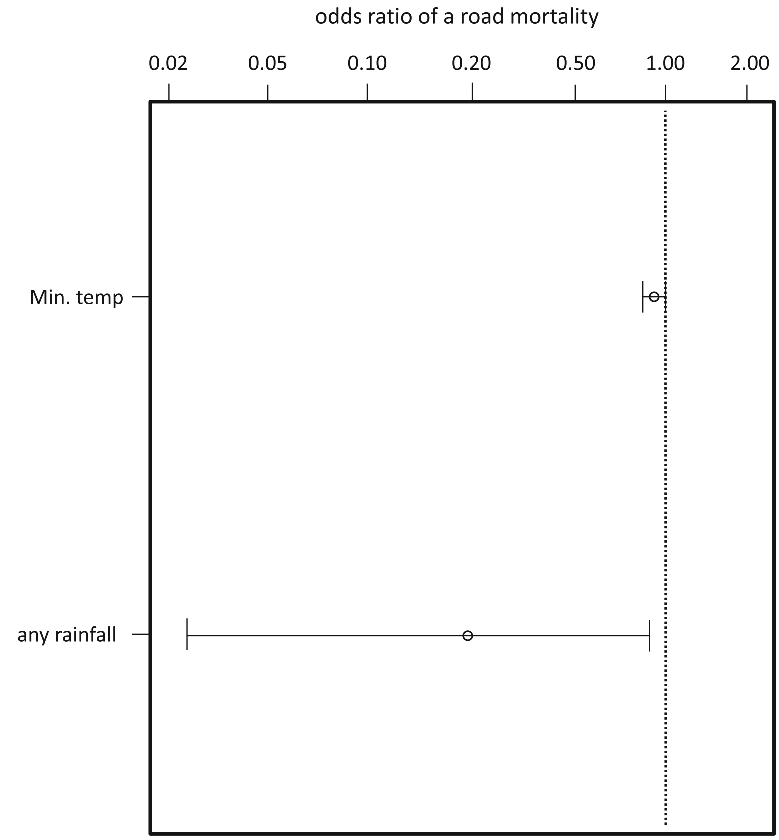

Fig. 1 The odds of a road mortality occurring in relation to the minimum temperature and rainfall

Most kangaroo road mortalities occurred in areas with wire cattle fences on both sides of the road (52%), followed by wire cattle fences on one side of the road and welded mesh fence on the opposite side (21%), and chain link fence on one side of the road and welded mesh fence on the opposite side (17%) (Fig. 3).

No significant difference was observed between the rate of road mortalities that occurred near fences categorized as 'easy' or 'hard' to pass through (*P* value = 0.13). The rate of road mortalities that occurred in areas with 'easy' to pass through fences on both sides of the road and areas with hard to pass through fencing on one side (*P* value = 0.39) or both sides (*P* value = 0.92) was not significantly different. The results of the likelihood ratio test also showed the effect of fence type on road mortality was not significant (Deviance = 0.90315, df = 2, *P* value = 0.64).

Effect of habitat

Areas with less than 20% canopy cover on both sides of the road accounted for most (42.5%) sample sites. The majority of remaining sites had less than 20% canopy cover on one side of the road, and either between 60 and 79% (17.5%), 80–100% (15%) or 40–59% (10%) canopy cover on the other side of the road. Only 10% of sample sites had greater than 20% canopy cover on both sides of the road, and 5% of sites had greater than 60% canopy cover on both sides of the road.

Almost 85% of all kangaroo road mortalities occurred adjacent to a woodland habitat; however, the association between mortalities and woodland habitat was not significant (*P* value = < 0.98). Kangaroo road mortalities occurred at all sites surveyed with woodland on both sides of the road, 52% of sites surveyed with woodland on one side of the road and grasslands on the other, and 33% of sites surveyed with grassland on both sides of the road (Fig. 4). The association between sites with woodland habitat on at least one side of the road was not significant (*P* value = 0.11). Sites with kangaroo road mortalities had a slightly higher average canopy cover (31 ± 37%) than sites with no kangaroo road mortalities (canopy cover 24 ± 34%); however, the difference was not significant (*P* value = 0.55).

Effect of vehicle speed and street lighting

The majority of kangaroo road mortalities (90%) occurred in areas where the speed limit was 80 km/h. Most kangaroo road mortalities occurred between 300 and 400 m (20%) and 800–900 m (20%) where speed limits increased from 60 km/h to 80 km/h. Only 15% of kangaroo road mortalities occurred within 100 m of where the speed limit increased. The association between the

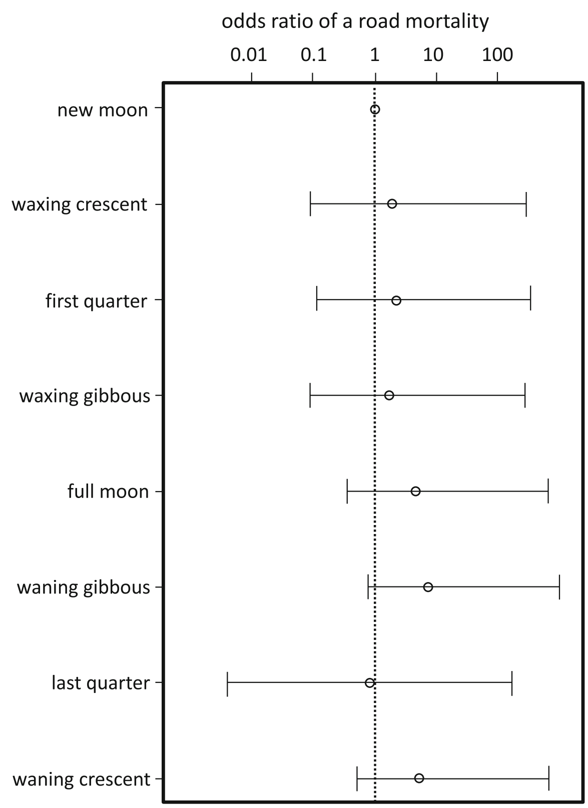

Fig. 2 The odds of a road mortality occurring in relation to the different moon phases

distance from the speed limit change and the occurrence of roadkill was not significant (*P* value = 0.18).

The majority of kangaroo road mortalities (95%) occurred on sections of road with no street lighting. Most kangaroo road mortalities (40%) occurred within 100 m of a street light, and the second most (35%) occurred between 100 and 200 m from a street light (Fig. 5). The distance from the nearest street light significantly affected the probability of roadkill occurrence (*P* value = 0.01).

Discussion

We investigated the occurrence of kangaroo road mortalities in the temperate, semi-rural area of Richmond NSW. A slight male bias of roadkilled kangaroos was observed. Increased kangaroo road mortalities occurred during periods of low temperatures and low rainfall, which corresponded to winter, as well as during moon phases with higher illumination and in unlit areas near street lights. No significant effect of habitat on kangaroo road mortality was observed; however, more mortalities occurred in areas with a woodland habitat on at least one side of the road and had a slightly higher percentage canopy cover than areas with no kangaroo road mortalities.

Male bias in road mortalities has previously been reported for eastern grey kangaroos and other macropods [21, 22]. Populations of eastern grey kangaroos, however, have a higher proportion of females [23–25]. Therefore the higher proportion of male kangaroo road mortalities is probably due to behavioral differences and larger home range that cause males to be more exposed to the risk of road mortality [22, 26–28].

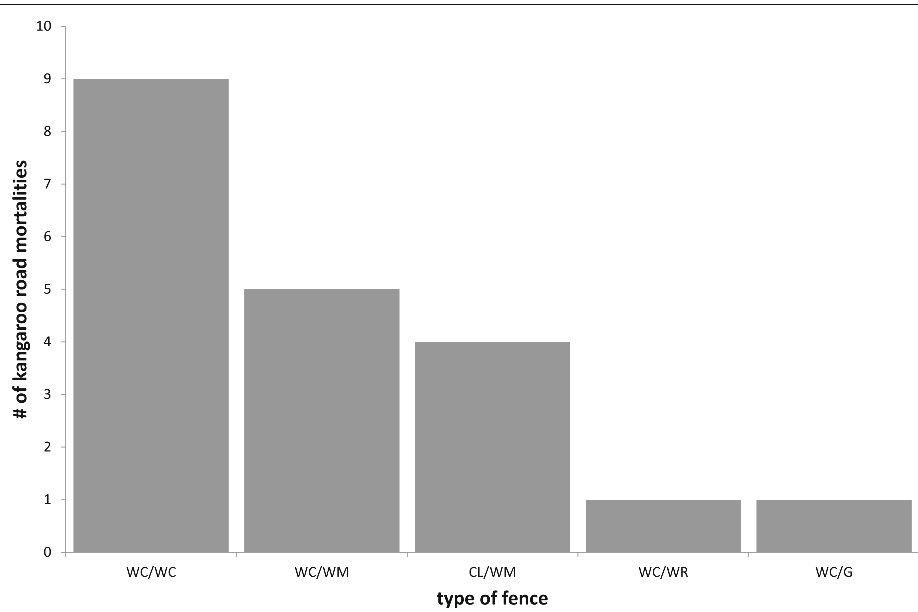

Fig. 3 The frequency of roadkilled kangaroos recorded near different combinations of fencing on both sides of roads. Key: WC = wire cattle fence, WM = wire mesh fence, CL = chain link fence, WR = wooden ranch fence, G = gap

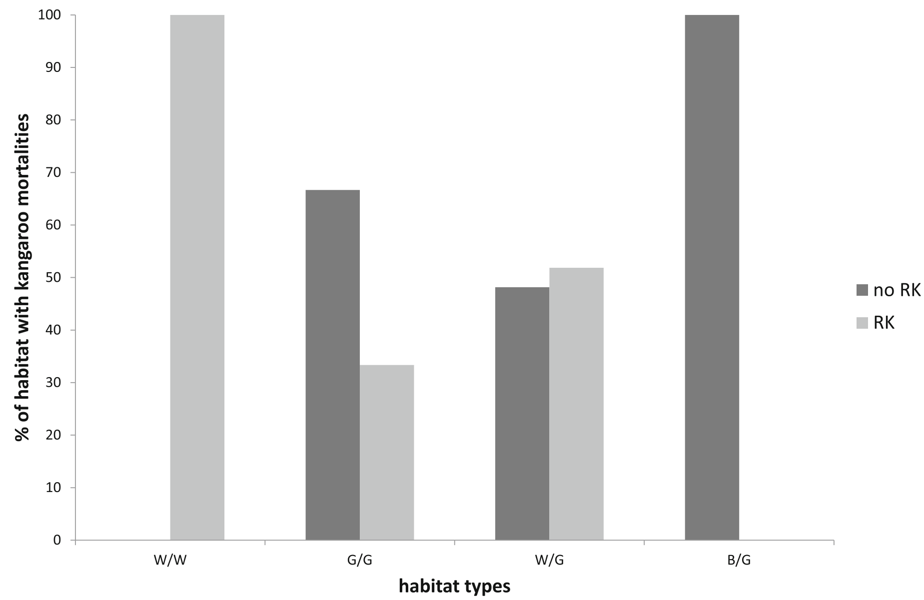

Fig. 4 The percentage of each habitat type where kangaroo road mortalities occurred (both sides of road). Key: W = woodland, G = grassland, B = built (eg. building or driveway), RK = roadkill present, no RK = no roadkill present. Only habitat combinations present within the study site were included in this graph

Male eastern grey kangaroos are larger than females [29], and this difference in body size may contribute to the male bias in road mortality. Road mortality involving larger species reportedly occur more often than smaller species and usually involves mammals rather than birds or reptiles [30]. Ford and Fahrig [31] suggested that body size may influence road mortality in two ways; smaller animals occupy less space which can allow vehicles to pass by or over the animal without hitting it; however, smaller animals are more difficult for a motorist to visually detect and actively avoid. The effect of body size may not be the same for species over a certain size. The smallest adult animal in the current study was a female kangaroo with a neck to tail base measurement of 32 cm and tail length of 40 cm so is still a relatively large animal and is likely to be visually detected. Female eastern grey kangaroos are not small

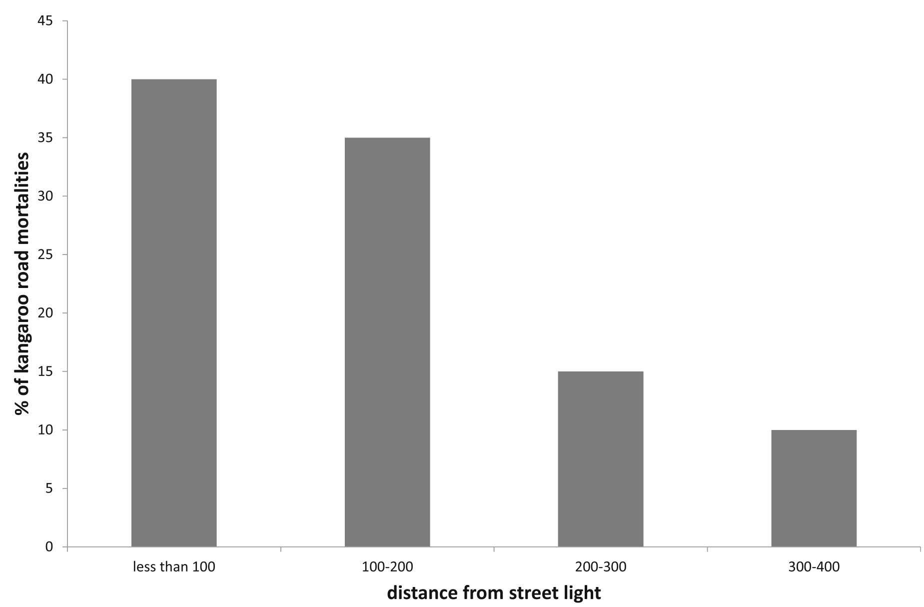

Fig. 5 The percentage of roadkilled eastern grey kangaroos recorded various distances from street lights

enough to safely pass beneath a vehicle without being hit. Therefore, the male bias observed is probably due to behavioral differences that cause males to cross roads more frequently or make them more difficult to actively avoid.

Most kangaroo road mortalities occurred during winter, perhaps due to a decrease in food availability and nutritional value, and is likely to cause kangaroos to travel further and cross roads more frequently to access resources over a wider area. An increase in kangaroo road mortality during winter is consistent with the findings of a study by Coulson et al. [32]. Winter has fewer hours of daylight, which is likely to result in an increased number of vehicles on the road outside daylight hours, and may also lead to extended hours of activity for nocturnal and crepuscular species of wildlife. Kangaroo road mortalities occurred more often in months with low temperature and low rainfall which most likely resulted in decreased pasture growth [33] and may have attracted kangaroos to high quality vegetation nearer the roadside or caused them to travel further to access high quality vegetation in other areas.

The findings of the current study indicate that significantly fewer road mortalities occurred on dates when there was rainfall. There is likely to be reduced visibility during rainfall, which could decrease the ability of drivers to detect an animal on the road. Therefore, if kangaroos were crossing roads at equal rates in different weather then kangaroo vehicle collisions should occur more frequently when it is raining. Fewer kangaroo road mortalities occurred when it was raining which suggests that kangaroos may be less active when it is raining and are less likely to cross the road in these conditions; however, this could also be a result of drivers reducing their speed when it is raining.

The majority of male kangaroo road mortalities occurred in winter; however, a high proportion of female kangaroo road mortalities occurred in autumn and spring. Male eastern grey kangaroos may range further in winter compared to females because of their larger body size [34, 35] and to access females from multiple groups. These results are consistent with the findings of Coulson et al. [32] that male kangaroos ranged further during winter to access a variety of habitats and resources, whereas females remained in the same area.

Significantly more kangaroo road mortalities occurred during the waning gibbous moon phase than any other phase of the lunar cycle. An increase in kangaroo road mortality around the full moon phase of the lunar cycle has been previously reported; however, this finding was based on four phases of the lunar cycle (rather than eight) [21, 36]. As the waning gibbous phase immediately follows the full moon it is likely that road mortalities during this phase have previously been reported as part of the full moon phase. Coulson [21] suggested that the observed increase in kangaroo road mortality around the full moon indicates that kangaroos are more active during this time, and as kangaroos are crepuscular, adequate moonlight illumination may allow for greater mobility than during times of complete darkness.

Built infrastructure acts as barriers, which may limit the direction in which animals can disperse. No significant influence of different fencing on kangaroo road mortality was detected in this study; however, more kangaroo road mortalities occurred near wire cattle fences than other fence types. Wire cattle fences are ‘easy’ for kangaroos to pass through, making it easier to access the road and roadside areas at these locations. Clevenger et al. [37] suggested that fencing along road sides can contribute to roadkill hotspots because they ‘funnel’ animals to cross roads in the areas where there are gaps in the fencing. Sections of fence that are easier to pass through than other fences along the same road are likely to produce a similar effect. One fence type is likely to allow kangaroos to pass through easily and enter the road area, where as the other fence type is presumably more difficult for the kangaroos to pass through and may prevent exiting from the road area, or vice versa.

No significant difference was observed between the number of kangaroo road mortalities in different habitats; however, more occurred in areas with a woodland habitat on at least one side of the road, and some had grassland habitat on the other side. Slightly more sample sites used in this study had woodland on one side of the road and grassland habitat on the other than any other habitat combination, which may have influenced the results. Kangaroos utilize a variety of habitats and regularly leave heavily wooded areas to access grassland habitats [38]. Therefore if different resources occur on either side of a road, then kangaroos are more likely to cross that road.

Woodland habitats create a greater visual cover which may provide perceived security for wildlife, but may also obstruct motorists’ ability to see wildlife and result in an increased incidence of roadkill [12, 13]. Areas with kangaroo road mortalities had a slightly higher percentage canopy cover than areas with no kangaroo road mortalities; however, most sample sites had less than 20% canopy cover on both sides of the road, so the true effect of canopy cover may not be reflected in these results.

Night time illumination varies temporally in relation to the moon cycle. The level of night time illumination also varies spatially due to the presence of artificial street lighting. Significantly more road mortalities occurred on sections of road with no street lighting but were within 200 m of street lighting. The sample sites were very close to evenly distributed between the varying distances from street lighting which further suggests that this finding is an accurate reflection of the effect of street lighting on kangaroo road mortality. Predatory species such as dingoes (*Canis lupus dingo*) and wild dogs increase activity in lighter conditions whereas prey species decrease activities in lighter conditions in response to a perceived increased risk to predators [39]. As a prey species, macropods are likely to prefer darker areas of the landscape to reduce their risk of predation [39]. Coulson [21] suggests that subdued lighting allows for increased mobility which may explain why kangaroos choose to traverse the edge of lit areas. Based on this it is speculated that the effect of the distance from street lighting on kangaroo road mortality would decrease as moonlight illumination increased; however, further investigation would be required to confirm this.

The location of street lights is likely to affect where wildlife cross roads, and may also impact motorists' ability to detect wildlife on the road. The distance at which wildlife on the road can be detected by drivers is significantly influenced by fur brightness, rather than body size [40]. As eastern grey kangaroos have dark fur they are likely to be detected at a shorter distance at night than species with brighter fur. The human retina is able to detect light at very low intensities. Cone receptors adapt to light change faster than rod receptors [41] resulting in it taking more time for the human eye to adjust from bright light to low light than it does to adjust from low light to bright light. Due to the retinas delayed adaptation from bright light to low light, it is likely that drivers are less able to see wildlife on or near roads in unlit areas that occur immediately after a well-lit area. These effects would be magnified when travelling at higher speeds.

Most kangaroo road mortalities occurred within an 80 km/h speed zone, and occurred at varying distances (100-900 m) from areas where the speed limit increased. The distance from the location where the speed limit increased from 60 km/h to 80 km/h did not have a significant effect on kangaroo road mortalities. Hobday A.J. and Minstrell [5] found that areas with higher vehicle speeds had increased road mortality for a variety of taxa; however, road mortality at lower speeds was higher for some species such as wallabies that often dash suddenly out of roadside vegetation. The findings of the current study support the suggestion of Hobday A.J. and Minstrell [5] that reduced vehicle speed is more effective in reducing road mortality for slower moving and slower reacting species, and less effective for faster moving species such as macropods that are still likely to be killed at lower speeds.

Conclusions

Based on the findings of this study, it appears that illumination influences the likelihood of kangaroo road mortalities. Warning drivers of the increased kangaroo activity during certain moon phases may assist in reducing kangaroo road mortalities. Temporary flashing signs have shown some success in reducing deer roadkill [42]. Flashing road signs that activate during times of high moon illumination should be trialed in areas with a high incidence of kangaroo road mortalities to evaluate whether this would be effective in reducing kangaroo road mortalities.

Alerting kangaroos to approaching vehicles may also assist in reducing kangaroo road mortalities. Virtual fence devices detect vehicle headlights, which triggers a virtual fence consisting of light and noise [43]. Originally designed for big game animals such as deer, virtual fences have also been shown to be effective in reducing roadkill rates of smaller macropods [43]. Therefore, these devices are likely to be effective in reducing road kill rates in larger macropods, and should be trialed in areas with high rates of kangaroo road mortality.

The results of this study indicated two possible road kill hotspots that would be suitable areas to trial flashing road signs and virtual fence devices. One hotspot was concentrated around the Londonderry Road / The Driftway intersection, and the other occurred midway between the Castlereagh Road/The Driftway intersection and the Castlereagh Road/Drift Road intersection.

Street lighting can be altered to reduce the likelihood of road mortalities and should be a consideration of urban design. It is recommended that lighting along roadsides should aim to be more uniform where practicable and not create gaps where wildlife will be funneled into areas of lower visibility and result in roadkill hotspots. Chachelle, Chambers, Bencini and Maloney [44] found that the construction of a large arched underpass reduced the likelihood of road mortality for western grey kangaroos without affecting their home ranges. Similar methods are likely to reduce road mortality in eastern grey kangaroos as the two species have many morphological and behavioral similarities. Eastern grey kangaroos have been reported to utilize underpasses; however, no studies have been conducted to evaluate their effectiveness in reducing road mortality rates [45]. Chachelle, Chambers, Bencini and Maloney [44] conducted their study on an area of highway that was completely fenced which is likely to have increased the success of this method and should be considered in future management plans.

Methods

Study area

Research was conducted on roads surrounding WSU Hawkesbury campus, a semi-rural site fragmented by university buildings and residential areas, but also fenced farm paddocks and woodlands (Fig. 6). The Hawkesbury campus of WSU is located in the semi-rural suburb of Richmond in the temperate zone of NSW.

Transects

To assess the landscape variation along the roadside, two 1 km transects were established with 20 sample sites

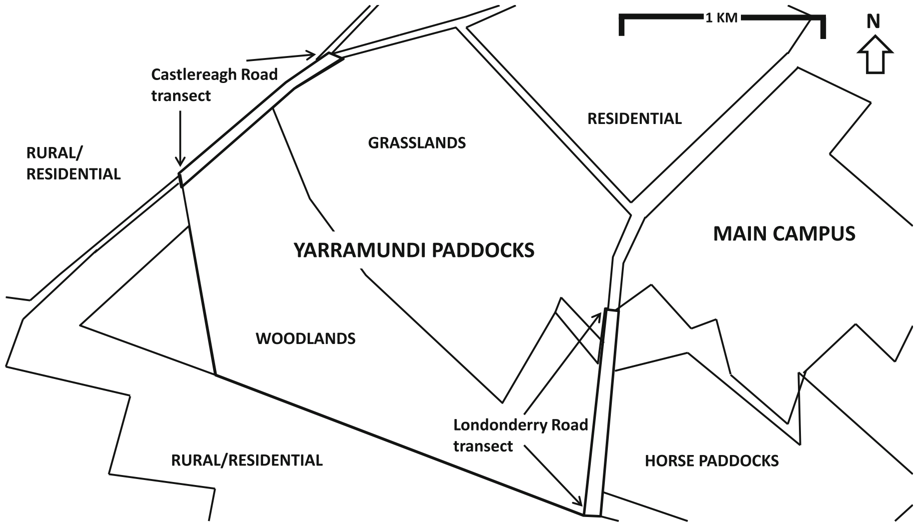

Fig. 6 Hawkesbury campus (WSU) and transects on Castlereagh and Londonderry Roads, Richmond, NSW (2016)

at 50 m intervals. Sample sites were 1x5m strips that ran perpendicular to the road. These transects were set up along Castlereagh Road (33°36′31.01″S/150°43′9.82″E - 33°36′12.12″S/150°43′39.18″E) and Londonderry Road (33°37′24.80″S/150°44′23.33″E - 33°36′54.14″S/150°44′28.73″E). Landscape variables were measured on both sides of the road at each 50 m interval.

Roadkill sampling

We checked roads daily. Only freshly deceased (within 24 h) eastern grey kangaroos were used for analysis. We recorded the GPS (Global Positioning System) location of roadkilled kangaroos with blunt trauma injuries consistent with vehicle collision found on or near roads in the study area between February 2014 and December 2015. We estimated the strike location of each collision based on the position of the kangaroo and the location of vehicle tire marks and blood. The gender and body measurements (testis circumference (males), head length, neck to tail base, foot length with and without toenail, tail length and tail diameter) of each animal were recorded. These morphometric measurements were chosen as they are commonly used to infer macropod body size and body condition [46–48].

Season, weather and moon cycle

Kangaroo vehicle collisions were assumed to have occurred during the evening prior to discovery. We recorded the season, maximum and minimum daily temperatures, average monthly rainfall, and moon phase for the date of each kangaroo road mortality. All weather data were obtained from Australian Bureau of Meteorology records from the closest weather station to the study site [49], and moon cycle data from the Sydney Observatory website [50].

Road, roadside and barriers

We recorded the following parameters at each transect interval; the width of area between the painted road edge and the nearest barrier (fence), the width of the road, and the height and type of construction of the fence (if present) on each side of the road. Fence construction types were categorized as a horizontal wire cattle fence (large flexible gaps > 20 cm), chain link fence (small flexible gaps < 10 cm), welded mesh fence (small rigid gaps < 10 cm), wooden ranch fence (large rigid gaps > 20 cm), or sheet metal fence (no gaps).

Habitat features

Canopy cover (%) and habitat type were recorded at each interval on each side of the road. The percentage of canopy cover was calculated using guidelines from Walker and Hopkins [51].

Habitat types were categorized as woodland (predominantly (> 50%) trees and shrubs), grassland (predominantly grass), or built environment (buildings and hard landscaping eg. concrete). Areas with woodland habitat on one side of the road and grassland habitat on the other side accounted for the majority (57.5%) of sample sites. Sites with grassland habitat on both sides of the road were the second most common (20%), closely followed by sites with grassland on one side of the road and built infrastructure on the other (17.5%). Very few sample sites had woodland habitat on both sides of the road.

Vehicle speed and street lights

The roads used in this study have both 60 km/h and 80 km/h speed zones. We recorded the distance of each roadkill from where the speed limit increases to 80 km/h. The majority of sample sites (95%) were in areas where the speed limit was 80 km/h. The sample sites used in the study were spaced at varying distances from where the speed limit changed from 60 km/h to 80 km/h. Most sample sites were further than 400 m (57.5%) from where the speed limit changed. The remaining sites were either within 100 m (12.5%), or between 100 and 200 m (10%), 200–300 m (10%), or 300–400 m (10%) from where the speed limit changed.

Both roads used in this study have sections with street lights and sections with no street lights. We measured the distance of each roadkill from the nearest street light. The sample sites used in the study were spaced at varying distances from the nearest street light. Most sample sites either were within 100 m (20%) or further than 400 m (35%) from the nearest street light. The remaining sites were either between 100 and 200 m (15%), 200–300 m (15%), or 300–400 m (15%) from the nearest street light.

Analysis

Data from 13 sample sites where roadkill were recorded, were compared with data from 27 sample sites where no roadkill were recorded. We analyzed data using Microsoft Excel 2010 and SPSS 2015 to determine which landscape features and environmental conditions influence the occurrence of road mortality in kangaroos.

A generalized linear model with a logistic link and binomial error for the presence of a road mortality was used to analyze the effect of different spatial and temporal variables. A Firth penalized likelihood method was used to allow for collinearity and low prevalence. We used a likelihood ratio test to evaluate the overall effect of moon phase, and the Breusch-Godfrey test to test for temporal autocorrelation. The fit of the data were evaluated using the Hosmer and Lemeshow goodness of fit test. Data for temperature, rainfall and moon cycle were plotted as odds ratios.

Residuals (the difference between observed and predicted values) must be independent of each other in order to assume that variables are not highly correlated. No evidence was found of autocorrelation in the temporal residuals (P value = 0.71). Results of the Hosmer and Lemeshow goodness of fit test found X-squared = 2.4, df = 8, P value = 0.97, suggesting that the generalized linear model used was a good fit for the data collected.

For analysis, we categorized the type of fence as either easy or hard. Easy fences included wire cattle fences and those with gaps between fencing as these areas were considered the easiest for kangaroos to pass through. We categorized all other fence types as hard due to more rigid construction and lack of larger gaps. Fence type on both sides of the road was treated as a three level variable, with "easy-easy", "easy-hard" or "hard-hard"; where "easy-easy" meant there was an easy type of fence for a kangaroo to pass on both sides of the fence. We used a likelihood ratio test to further evaluate the effect of fence type on road mortalities.

Abbreviations

±: Standard Deviation; GPS: Global positioning system; N S W: New South Wales; WSU: Western Sydney University

Acknowledgements

We would like to thank Bradley Evans for assistance with collecting field data, Russell Thomson for assistance with data analysis, and Hayley Stannard, Eden Hermsen, Jason Flesch, and Ricky Spencer for assistance in locating kangaroo road mortalities.

Authors' contributions

JMGB and JMO participated in the study conception and study design. JMGB was responsible for data collection and data analysis. JMGB wrote the initial draft of the manuscript, which was reviewed critically by JMO. Both the co-authors participated in revising the manuscript. Both authors read and approved the final manuscript.

Funding

The purchase of equipment used in data collection was funded by Western Sydney University. Jai Green-Barber was supported by an Australian Postgraduate Award Scholarship during the design of the study, and the collection and analysis of data.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Animal ethics (#A10297), and biosafety (#B10414) approvals were obtained from the Western Sydney University Animal Care and Ethics Committee and Biosafety and Radiation Safety Committee respectively. A NSW scientific license (#SL101256) was obtained from the National Parks and Wildlife Service.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 18 July 2019 Accepted: 24 September 2019
Published online: 17 December 2019

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