Comparison of road kills in peri-urban and regional areas of New South Wales (Australia) and factors influencing deaths

Shelley Burgin[1,2] and Meredith Brainwood[1]

[1]College of Health and Science, University of Western Sydney – Hawkesbury campus, Locked Bag 1797, South Penrith Distribution Centre, Australia 1797.

[2]Corresponding author: A/Prof. Shelley Burgin, College of Health and Science - Hawkesbury campus, University of Western Sydney Locked Bag 1797, South Penrith Distribution Centre, Australia 1797.

ABSTRACT

Road kills were counted in peri-urban Sydney and in regional New South Wales on roads with different volumes of traffic. Initial studies were conducted in late winter. Approximately equal numbers of birds and mammals were observed dead, while herpetofauna were absent. Most species killed were native, however, the species impacted and frequency of mortality events differed across regions of New South Wales. Higher numbers were killed on medium traffic volume roads (eg. major secondary roads, minor highways) than on low volume local traffic roads or major highways. Roads with verges that were slashed had more deaths than stretches that had vegetated verges. Overall, more deaths were recorded on roads with a physical barrier (eg. fence, cutting) on one side of the road than in areas were there was no such barrier. More deaths were observed in rural areas than in peri-urban areas. Our results confirm that there is no one 'quick fix' that will overcome the generic problem of roadkills. Regional solutions that identify and address the main species adversely affected by collision mortality are required.

Key words: collision, animal deaths, road barrier, roadside vegetation

Introduction

Several recent studies in Australia have examined the impact of road collision mortality (roadkill) on native animals (eg. Ramp *et al.* 2005; Klocker *et al.* 2006; Ramp and Ben-Ami 2006; Ramp *et al.* 2006). Some studies focused on a single road (Ramp *et al.* 2005; Klocker *et al.* 2006), or roads in a single reserve (Ramp and Ben-Ami 2006; Ramp *et al.* 2006). Each of these studies provides an excellent snapshot of the level of impact of collision mortality on a distinct suite of animals, or a single species (Ramp and Ben-Ami 2006) in a particular habitat type. Ramp and Ben-Ami (2006) surveyed swamp wallabies *Wallabia bicolor* in a long established coastal reserve in southern Sydney. They estimated 0.04 wallabies were killed per kilometre, per day, based on a 6 month survey of 22 km of roads in 2003. Based on a similar survey over 6 months of 21 km of minor highway in the arid zone of far north-western New South Wales, Klocker *et al.* (2006) estimated a roadkill rate of 0.03 kangaroos per kilometer, per day. Both of these rates of roadkill comprised around 10% of the local population. Despite the marked difference in environmental and road conditions, there is a surprising congruence in these derived kill rates. Acknowledging the similarity of these rates of roadkill, and extrapolating this to encompass in excess of 810,600 km of sealed and unsealed roads in Australia in 2004 (Australian Bureau of Statistics), this suggests that more than 9 million kangaroos and wallabies may be killed on Australian roads every year. While this astonishing figure does not include all the other native animals affected by collision mortality, it does begin to demonstrate the severity of this impact for Australia's fauna.

Construction of roads is the first step in agricultural and urban expansion, instigating a process of landscape modification that results in habitat reduction (Bennett 1991; Trombulak and Frissell 2000), and fragmentation and/or isolation of remnants (Goosem 2001). Animals are directly impacted through mortality attributed to the construction event, or from vehicle collision. Less direct effects include disturbance through alteration to the environment and creation of boundaries between potential habitats (Deverley and Stouffer 2000). These barriers to free movement inhibit dispersal, often resulting in modification of behaviours within species groups (Dyer *et al.* 2002; Lee *et al.* 2004; Shine *et al.* 2004). Increasing competition with humans as a result of road facilitated expansion interferes with freedom of movement within areas and dispersal to other areas (Goosem 2001; Rondinini and Doncaster 2002). Thus the presence of a road can alter habitat ranges and disrupt local biological integrity of endemic populations (Burgman and Lindenmayer 1998).

With increasing road use there is a higher risk of vehicle-animal collisions which generally result in danger to humans, vehicle damage and animal mortality (Finder *et al.* 1999; Weir 2002). Recent models have been developed with the assumption that a collision occurs when an animal and a vehicle are on the same part of the road at the same time (Jaarsma *et al.* 2006). While this model acknowledges that a collision results when an animal hits a vehicle, or a vehicle hits an animal, many studies focus on the human impact from animal collisions (Weir 2002). This emphasis on human impacts has resulted in many

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studies being focused on large mammals (Finder *et al.* 1999; Hubbard *et al.* 2000), although more recently, the effects on smaller mammals, birds and amphibians have been reported (Cain *et al.* 2003; Clevenger *et al.* 2003; Joly *et al.* 2003; Baker *et al.* 2004). In general, studies focus only on single species, or limited groups of animals, and tend to be based around major transport linkages (but see Ramp *et al.* 2005).

A number of methods have been trialed to reduce the exposure of animals to collision-based mortality (roadkill). This has included creation of faunal underpasses (Clevenger *et al.* 2001; Taylor and Goldingay 2003), use of exclusion fencing (Putman 1997), and reflectors (Ramp and Croft 2006). Unfortunately the success of this kind of de-fragmenting activity tends to be highly specific with, for example, many species excluded by the size or length of the underpass (Clevenger and Waltho 2000; Clevenger *et al.* 2001). They also do nothing to compensate for the loss of habitat and increased disturbance due to edge effects, and little to counter the direct threat to biodiversity simply from the disruption of movement that inhibits dispersal of animals. The ultimate success of remediation programs require a deeper understanding of road-based and landscape impacts to identify factors that are major contributors to loss of wildlife by collision mortality. To address this shortfall in knowledge, predictive models have been developed to identify factors that may be related with roadkill hotspots (Ramp *et al.* 2005), traffic flow (Langevelde and Jaarsma 2004), or road based behaviours (Jaeger *et al.* 2005).

The subtext that underlies each of the cited studies is that endemic fauna create specific problems, and that successfully reducing animal deaths on roads is generally the result of remedial activities directed towards the problem species. Few studies have been based in Australia, and until recently they have tended to focus on the relative successes of remedial activities trialed elsewhere (Jones 2000; Ramp and Croft 2006). Within Australia, research has been directed toward animal mortality on high volume major transport links, such as national highways (AMBS 2001a,b,c; Taylor and Goldingay 2003; Ramp *et al.* 2005). Little attention has been given to the variation in roadkill among different ecosystems, or on roads of a different size (but see Goosem 2001; Forman *et al*. 2003).

In this study our aim was to identify which animals in Australia are most impacted (ie. most often killed) and where (ie. regional or rural vs peri-urban, high traffic flow vs medium or low traffic)? We also explore which adjacent land uses abut roads where mortality events occur, and whether there are differences between urban and rural roads in species and numbers of animals killed.

Methods

This study is multi-focal. The first aspect of the study was directed at providing an overview of animal groups killed in different regions of New South Wales (rural and semi-rural). The second aspect focused on relating kill events to road-based factors and/or adjacent landscapes (ie. traffic and spatial features along peri-urban and rural roads).

Initial surveys (surveys of contributing factors in regional and peri-urban areas)

Roadkills were identified (where possible) and recorded for each of four regional studies, including Southern Tablelands, Northern Tablelands, Central Tablelands and (peri-urban) western Sydney (Table 1a). In rural and peri-urban surveys, each roadkill was recorded along with details of road width, traffic volume and speed restrictions, adjacent land use and fencing. For the peri-urban survey, additional habitat data recorded included vegetation type and structure, potentially influencing species impacted and their incentive to cross roads; proximity to water, also creating an incentive to cross roads; and culverts, which offer alternative passage across a road.

Descriptions of roads and environs were used to develop a set of predictive characteristics to identify areas where higher numbers of road mortalities were likely to occur. Roads were classified by a combination of road width and traffic volume, derived from the road classification. Roads more than three lanes were classed as high traffic volume (>10 m high); main roads with two lanes were classed as medium traffic volume (<10 m medium); and secondary roads with two lanes were classed as low traffic volume (<10 m low).

Roadkill species from regional New South Wales and peri-urban areas in western Sydney were analysed with road environment factors comprising road width, traffic volume, adjacent land use and fencing. The peri-urban data set was also correlated with vegetation type and structure, proximity to water, and culverts. These were used as the basis to predict potential roadkill hotspots on peri-urban and rural roads.

Testing the predictions

Sample sites selected to test the developed predictions were 50 m in length, with no replicate within 1 km (2 km for rural sites). They were located away from intersections and bends with reduced visibility. A 5m wide strip immediately adjacent to the road edge was searched on foot, and roadkill animals identified and recorded. Roads were surveyed in each of the three road classifications: >10 m high; <10 m medium; <10 m low. Four replicates in each road category were sampled for presence/absence of a physical barrier (eg. fence, embankment), for both mown road edges, and vegetated road edges.

Peri-urban prediction test sites were surveyed across western and southwestern Sydney and lower sections of the Blue Mountains (Table 1b). These sites were all located in 80 km/h areas, with no houses adjacent to the roadside. Sites defined as rural were located more than 5 km from the nearest urban limit in the New England and Central Tablelands regions of New South Wales (Table 1b).

Numbers and identities of roadkills were recorded to test the null hypothesis that there was no difference between road characteristics in roadkill sites, for peri-urban, rural, and a combined data set. A second hypothesis tested whether the presence of a physical barrier (such as a fence or inclined embankment) further increased numbers of animals killed in collision events. ANOVAs and Tukey-Kramer HSD tests for paired comparisons of means were used to identify significant differences in roadkills in site groupings (Sall *et al.* 2001).

Table 1. Summary of areas sampled for (a) preliminary, and (b) prediction testing surveys of roadkills in various regions of New South Wales.

(a) Survey route (Diagnostic set)	Dates(s)	Distance (km)
Southern Tablelands – Sydney to Jindabyne (return x2)	26-27/6/02 and 21-27/7/02	1800km
Northern Tablelands – Sydney to Gloucester Tops (return)	8-10/6/02	611km
Central Tablelands – Sydney to Cowra via Orange (return)	13/8/02	570km
Peri-urban western Sydney (Wiseman's Ferry, Glossodia, Wallacia, Parramatta)	30/6-16/702	560km
Contributing factors survey (Windsor, Rooty Hill, Lethbridge Park, Londonderry)	June-July, 02 (30 days)	31.3km/day (970km)
(b) Survey route (predictive set)	**Date(s)**	
New England region – New England Highway (Armidale – Guyra), Black Mountain Road, Waterfall Way (Armidale – Wollomombi), Inverell Road	10-11/12/03	
Central Tablelands region – Great Western Highway (Hartley – Lithgow), Jenolan Caves Road, McKanes Falls Road	13-14/12/03	
Peri-urban western Sydney – Great Western Highway (Emu Plains and Bullaburra), Mulgoa Road, Fairlight Road (Mulgoa), Park Road (Wallacia), Northern Road (Luddenham and Londonderry), Castlereagh Road, Smith Road (Castlereagh), East Wilchard Road (Castlereagh), Cranebrook Road, Whitegates Road (Londonderry)	11-12/1/04	

Results

Identity of roadkill victims

Species killed in road collisions reflected a seasonal composition. Initial surveys were conducted in late winter and approximately equal numbers of bird and mammal species were recorded and no reptiles (Table 2). Most species killed in each faunal group were native. Species impacted, and the frequency of mortality events, differed across regions of New South Wales (Table 3). Most animals were killed (6.32/100 km) in the central west and peri-urban western Sydney (3.39/100 km). Data collected for the northern region reported a dearth of kills on the roads sampled. This may result from extensive exclusion fencing on much of the route, and maintenance of the remaining section of road by local council (M. Brainwood, pers. obs.). In general, mammals were killed more frequently than birds, and in the central west and peri-urban Sydney introduced species were killed more often than native species.

Factors identified in higher mortality areas

Significantly higher numbers of animals were killed on medium traffic volume roads such as major secondary roads and minor highways than on high volume major highways or on low volume local traffic roads (Table 4). More deaths were observed on medium traffic roads than on major highways, which in turn recorded more deaths than on local traffic roads, although neither of these differences was significant. For all road types, roads with slashed or mown edges recorded more deaths than roads with vegetated verges, a trend that was maintained within each road class.

Table 2. List of species identified as roadkills in the four regions of New South Wales.

Mammals (11 species)			
Native (6 species)		**Introduced (5 species)**	
Bush Rat	*Rattus fuscipes*	European Rabbit	*Oryctolagus cuniculus*
Brushtail Possum	*Trichosurus vulpecula*	Domestic Cat	*Felis catus*
Ringtail Possum	*Pseudocheirus peregrinus*	Domestic Dog	*Canis familiaris*
Wombat	*Vombatus ursinus*	Red Fox	*Vulpes vulpes*
Eastern Grey Kangaroo	*Macropus giganteus*	Sheep	*Ovis aries*
Red-necked Wallaby	*Macropus rufogriseus*		
Birds (10 species)			
Native (7 species)		**Introduced (3 species)**	
Magpie	*Gymnorhina tibicen*	Common Myna	*Acridotheres tristis*
Crested Pigeon	*Ocyphaps lophotes*	Chicken	*Gallus gallus*
Magpie Lark	*Grallina cyanoleuca*	Spotted Turtle-dove	*Streptopelia chinensis*
Purple Swamphen	*Porphyrio porphyrio*		
Sulphur-crested Cockatoo	*Cacatua galerita*		
Tawny Frogmouth	*Podargus strigoides*		
Pacific Black Duck	*Anas superciliosa*		

Table 3. Animals recorded as killed on roads during preliminary surveys from different regions of New South Wales.

Fauna killed	Peri-urban	North	South	West
Roadkills recorded (n)	18	2	25	36
Rabbit	4		2	1
Bush Rat		1		
Fox/Dog	3		6	11
Possum	2			
Cat	2			
Wombat			3	
Kangaroo			11	6
Wallaby			1	
Sheep				4
Magpie	2	1		3
Common Myna				2
Swamphen	1			
Turtle-dove	2			
Cockatoo				1
Frogmouth	2			1
Black Duck	1		1	
Unidentified			1	7
Distance traveled (km)	560	611	1800	570
n Kills/100km	3.39	0.33	1.39	6.32

Table 4. Determination of factors best correlated with roadkill events recorded in (a) peri-urban, and (b) rural areas (nsd: not significantly different).

SAMPLE AREA	FACTOR (ranked by number of kills)	F or t statistic	p>F or p>t	df
Peri-urban	Road width: (<10m) > (<10m)	2.818	0.0201	12
	Edge: mown > not mown	2.2119	0.0543	12
	Traffic volume: med> high	2.7529	0.0224	12
	low> high	2.9403	0.0165	12
	med> low	nsd		12
	No water > water	nsd		12
	No culvert > culvert	nsd		12
	Fence: barrier>no barrier	2.4734	0.0231	12
Rural areas	Edge: mown > not mown	2.1448	0.0503	23
	Traffic volume: med> high	nsd		23
	low> high	nsd		23
	med> low	2.0739	0.0502	23
	Fence: barrier>no barrier	2.3895	0.0297	23

Collectively, more deaths were recorded on roads that had a physical barrier, such as a fence or embankment along one side, than on roads without such a barrier to movement.

These trends were consistent across peri-urban and rural areas. For peri-urban areas, there was no apparent relationship between roadkill events and proximity to water, type of vegetation, adjacent land use, or presence/absence of a culvert under the road.

Testing the validity of observed factors

Numbers of roadkills in peri-urban Sydney were lower than for rural areas (Table 3). More roadkill events were recorded on narrow roads (<10m), and more of these were on medium volume traffic flow roads (Table 5). On peri-urban roads more animals were killed where there was a fence or other barrier on one side, and more kills occurred at sites where road edges were mown. In rural areas, more animals were killed overall on medium traffic roads, more on roads with mown (slashed) edges, and more on roads with a barrier present (Table 6). Higher numbers of animals were killed on roads with slashed edges where traffic volume was medium and low.

When data for animals were pooled across all sites survey, more kangaroos were killed on medium volume traffic

Table 5. Results of ANOVAs for sampling of roadkills in peri-urban sites to test predictive characteristics (results in bold indicate differences are significant; italics indicate results are different to predicted).

Analysis of	Compared with	F ratio	Prob > F	Student's t test of means	Result
Total kills	traffic volume	0.5802	0.5637	-0.19894 -0.15831 -0.22672	high>medium high>low medium>low
	edge slashed (mown)	0.3753	0.5431	-0.17128	not mown> mown
	barrier present	4.0872	0.0489	0.00117	barrier>no barrier
Kills in high traffic (>10m)	edge slashed (mown)	0.3664	0.5536	-0.31669	mown>not mown
	barrier present	4.2000	0.0596	-0.01746	barrier>no barrier
Kills in medium traffic (<10m)	edge slashed (mown)	2.9721	0.1053	-0.10504	not mown> mown
	barrier present	2.9721	0.1053	-0.10504	barrier>no barrier
Kills in low traffic (<10m)	edge slashed (mown)	1.0000	0.3343	-0.14310	mown>not mown
	barrier present	1.0000	0.3343	-0.14310	no barrier> barrier

Table 6. Results of ANOVAs for sampling of roadkills in rural sites to test predictive characteristics (results in bold indicate significant differences).

Analysis of	Compared with	F ratio	Prob > F	Tukey-Kramer test of means	Result
Total kills	traffic volume	6.2133	0.0038	0.5595 -0.5030 -1.0834	medium >>low medium ≥high high ≥low
	edge slashed (mown)	10.4919	0.0021	0.51713	mown >>not mown
	barrier present	4.2746	0.0435	0.02762	barrier >>no barrier
Kills in high traffic (>10m)	edge slashed (mown)	2.5735	0.1310	-0.3209	mown ≥not mown
	barrier present	1.5181	0.2382	-0.5556	barrier ≥no barrier
Kills in medium traffic (<10m)	edge slashed (mown)	7.4485	0.0122	0.5002	mown >>not mown
	barrier present	3.7640	0.0653	-0.1092	barrier ≥no barrier
Kills in low traffic (<10m)	edge slashed (mown)	5.9062	0.0291	0.05035	mown >>not mown
	barrier present	3.0625	0.1020	-0.07520	barrier ≥no barrier

roads, with mown edges and with some kind of fence or barrier to movement (Table 7). Birds were victims of roadkill events more frequently on narrow (<10m) roads, with medium volume traffic flow, and mostly with mown road edges. Foxes were also killed more frequently on narrow roads with medium volume traffic flow, but not linked with mown edges or presence of a fence or barrier. More rabbits were killed on medium volume traffic roads, but not linked with any other factors. In contrast, more turtles were killed on low volume traffic roads, and again, were not linked with any other road environment factor.

Discussion

Most species killed by collision on roads were native species. Due to the timing of the study (late winter), herpetofauna were not collected presumably because they would have tended to be inactive. However, since there are no substantial populations of introduced reptiles and frogs in the areas covered by the survey, any of these taxa killed would have been endemic. It can be concluded, therefore, that collision with motor vehicles has a greater impact on native species than on feral species. In another New South Wales survey (Sydney to Longford Eastern Gas Line, 1999-2000), Doody *et al.* (2003) collected 45 reptile specimens, 24 mammals, 19 frogs, 14 birds and one fish, with the bulk of these kills being native species. Undoubtedly their findings were biased for frogs since the trench had standing water in some areas, at least part of the time, and at least some species would have been attracted to potential breeding sites.

Most roadkills recorded were mammals, although this may have been seasonally biased, or affected by the reduced persistence of smaller skeletons. Again, proportions varied among regions. Higher numbers of roadkills recorded on rural roads is most likely a reflection of larger populations in the area. A survey by Klocker *et al.* (2006) of a rural road, and another by Ramp and Ben-Ami (2006) based on roads in a peri-urban reserve, both found that, for kangaroos and wallabies, numbers killed in vehicle collision events were approximately 10% per annum of local populations. Clevenger *et al.* (2003) also observed difference in patterns of mortality (numbers and species impacted) on different road types. Similarly, Clarke *et al.* (1998) noted significantly higher fatalities on high and medium traffic volume roads compared to low volume roads.

Of the native bird species recorded as roadkills, most were in peri-urban surveys (Table 2). Of these, magpies and magpie larks prefer clearings and avoid forests, while crested pigeons and purple swamphens graze in open areas but take flight to the cover of trees (Slater *et al.*

Table 7. Analysis of predictive factors correlated with roadkill events recorded in all surveys (peri-urban rural areas; nsd: not significantly different).

SPECIES	FACTOR	F statistic	P>F	df
All roadkills	Road width (>10m,<10m)	nsd		55
	Traffic volume (med>high>low)	6.2133	0.0038	55
	Edge (mown>not mown)	10.4919	0.0021	55
	Fenced>unfenced	4.2746	0.0435	55
Kangaroos	Road width (>10m,<10m)	nsd		42
	Traffic volume (med>high>low)	3.8678	0.0291	42
	Edge (mown>not mown)	6.1445	0.0174	42
	Fenced>unfenced	5.3431	0.0259	42
Rabbits	Road width (>10m,<10m)	nsd		25
	Traffic volume (med>low>high)	4.0122	0.0320	25
	Edge mown, not mown	nsd		25
	Fenced, unfenced	nsd		25
Turtles	Road width (>10m,<10m)	nsd		9
	Traffic volume (low>med>high)	2.9537	0.0487	9
	Edge mown, not mown	nsd		9
	Fenced, unfenced	nsd		9
Birds	Road width (>10m,<10m)	4.5371	0.0139	36
	Traffic volume (med>high>low)	6.8254	0.0094	36
	Edge mown, not mown	5.2187	0.0327	36
	Fenced, unfenced	nsd		36
Foxes	Road width (>10m,<10m)	3.1675	0.0462	14
	Traffic volume (med>high>low)	7.1425	0.0056	14
	Edge mown, not mown	nsd		14
	Fenced, unfenced	nsd		14

1994). Tawny frogmouths are forest residents that hunt low in clearings similar to those created by vegetated road edges. Sulphur-crested cockatoos have become common in urban fringe areas and will feed from the road surface, particularly in rural areas (Burgin and Saunders 2007) during harvest season. While none of these bird species is considered vulnerable, their behaviours cause them to be attracted to open road edges.

Many of the native animals affected by collision mortality are active in early evening or after dark, with many of them seeking open grassy areas to feed during these hours (see Osawa, 1989). Foraging along road edges in poor light and after dark makes them harder to see for drivers, and thus harder to avoid. Possums, kangaroos and wallabies will all move towards forest vegetation in response to perceived danger, perhaps taking them into the path of an oncoming vehicle (Jaeger *et al.* 2005; Jaarsma *et al.* 2006). Wombats are slow-moving and unable to quickly avoid oncoming traffic. Many of the introduced mammals that are killed on roads are predatory, including foxes, domestic cats and dogs, and may be killed while they are feeding on other fresh roadkills. Again, their feeding and flight behaviours make them susceptible to collision mortality events.

Use of faunal underpasses in conjunction with exclusion fencing has significantly reduced collision mortality on major road transport routes (AMBS 2001abcd). However, these underpasses are expensive and difficult to introduce subsequent to completion of road construction activities. On smaller roads the expense is generally prohibitive, yet our results for these roads show a high level of collision mortality for a range of animal species. This trend was also reported in a survey of alpine roads in southern New South Wales by Ramp *et al.* (2005), who suggested that animals do not perceive roads carrying low and medium volume traffic as a threat. Reduced numbers of roadkills on low traffic volume roads no doubt reflects the increased opportunity to safely cross the roadway. This contrasts with the findings of Lee *et al.* (2004) and Klocker *et al.* (2006), who also reported a high incidence of collision mortality events on roads with a low volume of traffic. Minor highways such as these, however, would be classified as medium volume roads in this survey.

The use of exclusion fencing in conjunction with fauna underpasses, is in direct contradiction to the opinion that exclusion fencing exacerbates the fragmentation processes arising from construction of the road (Underhill and Angold 2000). Goosem *et al.* (2001) recommended the use of behavioural techniques to steer animals towards the underpass, and away from the road surface. These techniques included the use of avoidance of open spaces immediately adjacent to the road, and planting of food plant species near the mouth of the underpass to attract animals.

Use of behavioural responses on medium and low volume traffic roads that encourage animals away from the road surface may provide viable alternatives to the construction of under- or overpasses. Again, however, there are problems associated with the range of responses exhibited by different species, and the need to develop optimal and workable compromises. Contradictions occur in animal behaviour with feeding in open or mown areas coupled with response to danger by movement to more vegetated areas. The presence of some kind of barrier, such as embankments and safety or other fencing, to animals being able to quickly access a route to safety has been identified as coincident with increased numbers of roadkill events in all areas surveyed (DPIW&E 2003). Regional solutions that identify the main species adversely affected by collision mortality can tailor road edge management practices accordingly.

A number of problems were associated with collection of data, particularly in peri-urban surveys. Roadkills in city council areas tend to be removed rather than pulled to the roadside (G. Hunter, Penrith City Council). Smaller animals such as birds, amphibians and reptiles have small bones and are quickly crushed beyond recognition or completely consumed by predators. Seasonal differences are also apparent in behaviour patterns for many species. Greater movement of individuals is associated with spring and mating behaviour, increasing the risk of collision mortality for animals during this period. Winter torpor reduces the level of movement by individuals, and provides an explanation for the absence of reptiles from the preliminary surveys (Table 2, 3). In rural areas counts for slashed road edges may have been artificially higher than for uncleared edges where dense vegetation may have obscured small amounts of remains that would have been exposed after slashing, and counted.

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References

AMBS, 2001a. *Fauna Underpass Monitoring: Stage 1. Final Report Brunswick Heads*. Report to NSW Roads and Traffic Authority. Australian Museum Business Services, Sydney.

AMBS, 2001b. *Fauna Underpass Monitoring: Stage 1. Final Report Herons Creek*. Report to NSW Roads and Traffic Authority. Australian Museum Business Services, Sydney.

AMBS, 2001c. *Fauna Underpass Monitoring: Stage 1. Final Report Bulahdelah to Coolongolook*. Report to NSW Roads and Traffic Authority. Australian Museum Business Services, Sydney.

AMBS, 2001d. *Fauna Underpass Monitoring: Stage 1. Final Report Taree*. Report to NSW Roads and Traffic Authority. Australian Museum Business Services, Sydney.

Baker, P. J., Harris, S., Robertson, C. P. J., Saunders, G. and White, P. C. L. 2004. Is it possible to monitor mammal population changes from counts of road traffic casualties? An analysis using Bristol's red foxes *Vulpes vulpes* as an example. *Mammal Review* **34**: 1-16.

Bennett, A. F. 1991. Roads, Roadsides and Wildlife Conservation: A review. Pp. 99-118 in *Nature Conservation 2: The role of corridors*, edited by D. A. Saunders and R. J. Hobbs, Surrey Beatty and Sons, Chipping Norton.

Burgin, S. and Saunders, T. 2007. Parrots of the Sydney region: population changes over 100 years. Pp. 185-194 in *Pest or Guest: The Zoology of Overabundance*, edited by D. Lunney, P. Eby, P. Hutchings and S. Burgin. Royal Zoological Society of New South Wales, Mosman.

Burgman, M. A. and Lindenmayer, D. B. 1998. *Conservation Biology for the Australian Environment*. Surrey Beatty and Sons, Chipping Norton.

Cain, A. T., Tuovila, V. R., Hewitt, D. G. and Tewes, M. E. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. *Biological Conservation* **114**: 189-197.

Clarke, P. G., White, P. C. and Harris, S. 1998. Effects of roads on Badger (*Meles meles*) populations in southwest England. *Biological Conservation* **86:** 117-124.

Clevenger, A. P. and Waltho, N. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* **14:** 47-56.

Clevenger, A. P., Chruszcz, B. and Gunson, K. E. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* **38**: 1340-1349.

Clevenger, A. P., Chruszcz, B. and Gunson, K. E. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biological Conservation* **109**: 15-26.

Deverley, P. and Stouffer, P. 2000. Effects of roads on movements by understorey birds in mixed-species flocks in Central Amazonian Brazil. *Conservation Biology* **15**: 1416-1422.

Doody, J., West, P., Stapley, J., Welsh A., Tucker, A., Guarino, E., Pauza, M., Bishop, N., Head, M., West, G., Pepper, A. and Jones, A. 2003. Fauna by-catch in pipeline trenches: conservation, animal ethics, and current practices in Australia. *Australian Zoologist* **32**: 410-419.

DPIW&E, 2003. Sharing the road with wildlife. Department of Primary Industries, Water and Environment, Hobart. http://www.dpiwe.tas.gov.au/inter.nsf/WebPages/SJON-52B4P4?open.

Dyer, S.J., O'Neill, J.P., Wasel, S.M. and Boutin, S. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology* **80:** 839-845.

Finder, R. A., Roseberry, J. L. and Woolf, A. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning* **44**: 77-85.

Goosem, M. 2001. Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. *Wildlife Research* **25:** 351-364.

Hoffman, R. 1995. *The impact of roads upon native Australian fauna: an analysis of the mechanisms available to reduce roadkills and habitat fragmentation within Australia*. Australian National Internship Program, Melbourne

Hubbard, M. W., Danielson, B. J. and Schmitz, R. A. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management* 64: 707-712.

Jaarsma, C.F., van Langevelde, F. and Botma, H. 2006. Flattened fauna and mitigation: Traffic victims related to road, traffic, vehicle, and species characteristics. *Transportation Research Part D* **11:** 264-276.

Jaeger, J.A.G., Bowman, J., Brennan, J., Fahrig, L., Bert, D., Bouchard, J., Charbonneau, N., Frank, K., Gruber, B. and von Toschanowitz, K.T. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behaviour. *Ecological Modelling* **185:** 329-348.

Joly, P., Morand, C. and Cohas, A. 2003. Habitat fragmentation and amphibian conservation: building a tool for assessing landscape matrix connectivity. *Comptes Rendus Biologies* **326:** S132-S139.

Jones, M. E. 2000. Road upgrade, road mortality and remedial measures: impacts on a population of eastern quolls and Tasmanian devils. *Wildlife Research* **27**: 289-296.

Klocker, U., Croft, D.B. and Ramp, D. 2006. Frequency and causes of kangaroo-vehicle collisions on an Australian outback highway. *Wildlife Research* **33:** 5-15.

Lee, E., Klocker, U., Croft, D.B. and Ramp, D. 2004. Kangaroo-vehicle collisions in Australia's sheep rangelands, during and following drought periods. *Australian Mammalogy* **26:** 215-226.

Merriam, G. and Saunders, D. A. 1993. Corridors in Restoration of Fragmented Landscapes in *Natures Conservation 3: Restoration of Fragmented Ecosystems* edited by D. A. Saunders and R. J. Hobbs. Surrey Beatty and Sons, Chipping Norton.

Osawa, R. 1989. Road-kills of the swamp wallaby, *Wallabia bicolor*, on North Stradbroke Island, South-east Queensland. *Australian Wildlife Research* **16:** 95-104.

Putman, R.J. 1997. Deer and road traffic accidents: options for management. *Journal of Environmental Management* **51:** 43-57.

Ramp, D. and Ben-Ami, D. 2006. The effect of road-based fatalities on the viability of a peri-urban swamp wallaby population. *Journal of Wildlife Management* **70:** 1615-1624.

Ramp, D. and Croft, D.B. 2006. Do wildlife warning reflectors elicit aversion in captive macropods? *Wildlife Research* **33:** 583-590.

Ramp, D., Caldwell, J., Edwards, K.A., Warton, D. and Croft, D.B. 2005. Modeling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. *Biological Conservation* **126:** 474-490.

Ramp, D., Wilson, V.K. and 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: 348-359.

Rondinini, C. and Doncaster, C.P. 2002. Roads as barriers to movement for hedgehogs. *Functional Ecology* **16:** 504-509.

Sall, J., Lehman, A. and Creighton, L. 2001. *JMP Start Statistics: A guide to statistics and data analysis*. SAS Institute Inc (Duxbury), California.

Shine, R., Lemaster, M., Wall, M., Langkilde, T. and Mason, R. 2004. Why did the garter snake cross the road? Effects of roads on movement and the location of mates by garter snakes (*Thamnophis sirtalis parietalis*). *Ecology and Society* **9:** 9-21.

Slater, P., Slater, P. and Slater, R. 1994. *The Slater Field Guide to Australian Birds.* Rigby Publishers, Adelaide.

Taylor, B.D and Goldingay, R.L. 2003. Cutting the carnage: wildlife usage of road culverts in north-eastern New South Wales. *Wildlife Research* **30:** 529-537.

Trombulak, S. C. and Frissell, C. A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* **41:** 18-30.

Underhill, J. E. and Angold, P. G. 2000. Effects of roads on wildlife in an intensively modified landscape. *Environmental Review* **8**: 21-39.

van Langevelde, F. and Jaarsma, C.F. 2004. Using traffic flow theory to model traffic mortality in mammals. *Landscape Ecology* **19:** 895-907.

Washington, H. 1998. *Road Management on the Urban-Rural Fringe. A Report on Pilot Studies in Hornsby and Wollondilly Shires*. Hawkesbury-Nepean Catchment Management Trust, Windsor.

Weir, E. 2002. Collisions with wildlife: the rising toll. *Canadian Medical Association Journal*: **166**: 775