Dust as a contributor to the road-effect zone: A case study from a minor urban road in Australia.

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Abstract

The road-effect zone is a concept developed to describe the impact of influences such as noise, vibration, light and dust associated with roads and traffic on the surrounding area. These factors have been shown to have a variety of environmental effects, including acting as a barrier to the movement of some animals while others actively seek the road verge as a preferred habitat. Although many aspects associated with the road-effect zone have been investigated, the influence of dust remains poorly understood. Gap Creek Road is a minor road near Brisbane in south-eastern Queensland, Australia which traverses a dense eucalypt forest reserve. In 2010, the formerly dirt road was upgraded by sealing and realignment, primarily to improve the safety of motorists. The present study compares pre- and post-construction dust levels within the forest, and the diversity and abundance of ground-dwelling mammals near and far from the road. Prior to the upgrade, dust levels were extremely high with deposition rates equivalent to a major daily dust storm. The key influence of the upgrade was the almost complete elimination of this dust production; hence, we predicted that small mammal species richness and abundance near the road would increase significantly after the upgrade. Pre-upgrade trapping surveys confirmed that the forest supported a diverse and abundant community of ground-dwelling mammal species with eight species detected, including in highly dust-affected sites next to the road. Following the upgrade, there was little change in the abundance of species, though some (mainly *antechinus*) were significantly more abundant away from the road and several additional native species were detected near the road. Interestingly, the abundance of house mice, formerly common beside the road, was found to decline markedly after the upgrade. These results suggest that, in certain environments, dust may have far less impact on ground-dwelling mammals than expected.

Introduction

Urbanisation is now recognised as a principal cause of extinctions during the current century (Marluff 2001), a direct result of the relentless growth of the human population and the requirement for new settlements. As urban centres expand, so do the road networks connecting these areas as well as the continual upgrading of roads to cope with increasing numbers of vehicles (Garcia-Gonzalez *et al.* 2012). As a result, road networks are among the most pervasive forms of human impact on the global environment (St. Clair 2003). The influence of roads on the landscape and on the species living in adjacent habitat is now a central concern for conservation biologists (Clark *et al.* 2010) and is the main focus of the relatively new research field of road ecology (Forman *et al.* 2003; Beckman *et al.* 2010).

Roads act as a physical impediment to the movements of many animals, decreasing access to essential resources and mates (Fahrig & Rytwinski 2009; Taylor & Goldingay 2011). While some species adapt to the presence of roads (FitzGibbon & Jones 2006; Ruiz-Capillas *et al.* 2013), others move away or treat the road as a barrier (Benítez-López *et al.* 2010). Failure to cross roads may subdivide animal populations, sometimes permanently (Mata *et al.* 2008; Glista *et al.* 2009). Such impediments to movements may result in inbreeding, reducing genetic diversity, increased susceptibility to local extinction and reduced ability to recolonise suitable areas (Corlatti *et al.* 2009; Jackson & Fahrig 2011).

A central concept in road ecology is that of the road-effect zone, the area surrounding and including the surface of the road that is influenced by the road in a variety of ways (Forman *et al.* 2003; Eigenbrod *et al.* 2009). These influences include acting as a barrier or filter to animal movements, especially smaller, ground-dwelling species (Bennett 1991; Goosem 2000; Rytwinski & Fahrig 2007). The extent to which a road acts as a barrier depends on a wide range of factors including the width of the gap between habitat on either side, the relative mobility of the species affected, the volume of traffic, and on the significance of various products associated directly with the vehicles using the road (Bennett 1991; Jaeger *et al.* 2005). These ‘traffic products’ include chemical emissions, noise, vibrations, light and dust (Sures *et al.* 2001; Jaeger *et al.* 2005). Of these, only noise has been investigated in detail and has been shown to contribute significantly to the road-effect zone, in some cases extending many kilometres from the road (Benítez-López *et al.* 2010; Kociolek *et al.* 2011; see also Fahrig & Rytwinski 2009).

The possible influence of dust in this context appears to have been relatively neglected, perhaps because most research attention has been focussed on major roads that are almost always sealed (Brock & Kelt 2004; Garcia-Gonzalez *et al.* 2012). Minor, unsealed roads, however, make up a considerable proportion of the road network in many countries (Forman *et al.* 2003) and, as these typically produce dust products that drift into the surrounding environment, it is important to assess the extent to which dust contributes to the road-effect zone (Farmer 1991). Dust is known to be beneficial (providing mineral nutrients) to roadside vegetation at low levels (Farmer 1991), but may seriously impede photosynthesis over certain thresholds (Thompson *et al.* 1984). Dust adhering to grass has been shown to increase tooth abrasion in some grazing species (McNaughton *et al.* 1985), apparently leading to the avoidance of dust-affected areas (Ndibalema *et al.* 2007). Little is known, however, about the influence of dust on smaller ground-dwelling species living beside the road. Although many such species are reluctant to cross even small roads (Goosem 2000; Clarke *et al.* 2010), they

often occur at high densities immediately adjacent to the roadside (McGregor *et al.* 2008; Ruiz-Capilla *et al.* 2013). Most studies, however, have not included dust among the environmental variables considered.

South-eastern Queensland (SEQ), one of Australia's fastest growing urban areas (abs.gov.au/ausstats/abs@nsf/Queensland), is centred on Brisbane, the largest city within a region of over 2 million people. Gap Creek Road, an important minor road in the western suburbs of Brisbane, traverses a large forest reserve known to support high faunal diversity (Jones *et al.* 2012). Much of this unsealed road was often corrugated and extremely dusty. In 2007 Brisbane City Council (BCC) assessed the road as posing significant environmental and societal impacts associated with poor visibility and road alignment (Barnett *et al.* 2007).

Following extensive community consultation, Brisbane City Council undertook to upgrade the largely unsealed 6 km section of Gap Creek Road between Kenmore Hills and The Gap (Fig. 1). This work occurred between January and July 2010. To address community concerns about expected increase in vehicle use and speeds, BCC commissioned a comprehensive ecological investigation of the upgrade (Jones *et al.* 2012). This study found an increase in traffic volume but not vehicle speeds following the upgrade, as well as a significant increase in the rate of road-kill (Jones *et al.* in press).

One of the most conspicuous features of the original road was the excess levels of dust evident on the ground and lower vegetation immediately adjacent to the road (Jones *et al.* 2012). While numerous studies have reported relatively high abundances of small mammals in roadside habitats (e.g., Rytwinski & Fahrig 2007; Ruiz-Capillas *et al.* 2013), we predicted that, because the amount of dust present beside the road at this site was so great, local mammal species would be unlikely to live close to the road. Hence, we hypothesised that species richness and abundance would be significantly greater at greater distances from the road, where dust levels would be lower. Furthermore, as the upgrade included sealing the road, effectively eliminating the production of dust, we predicted that species richness and abundance of small mammals present near the road would be significantly greater after the upgrade. Therefore, the present study focused on quantifying the amount of dust being deposited at increasing distances from the road before the upgrade, and comparing the diversity and abundance of small mammals near and far from the road, both before and after the upgrade.

Methods

Study sites

The study was undertaken along Gap Creek Road in western Brisbane, Queensland, Australia, connecting the suburbs of Kenmore Hills and The Gap (Fig. 1). The terrain is hilly with the altitude ranging from 45 m to 155 m above mean sea level over the 6 km length of road. The median annual rainfall is about 1100 mm.

Four study sites were established along the unsealed sections of the road and were used for all dust and mammal detection studies (Fig. 1). Sites 1 and 2 were at 27°28.340'S, 152°55.524'E (114m ASL) and were west and east of the road, respectively. Sites 3 and 4 were located approximately 450 m to the north at 27°28.118'S; 152°55.568'E (125m ASL) and were west and east of the road, respectively. These sites were established prior to construction along the unsealed section of the road explicitly to allow comparison of mammal abundances in relation to dust levels before and after the upgrade.

Dust levels

Dust levels were measured using two different methods: dry deposition traps and real time PM₁₀ sediment concentration.

Dry deposition measurement and processing. Glass Bead Deposition Traps (GBDT), used to quantify deposited dust, consisted of PVC boxes (0.42 x 0.32 x 0.12 m) placed on a 2 m high tripod. Two layers of 12 mm glass beads placed in the box prevented re-entrainment of trapped dust (Figure 2). When set up, the traps were covered with 20 mm chicken wire to prevent the collection of leaves and to dissuade birds from stealing the beads.

At each of the four sites, a 60 m transect running perpendicular to the road was established with four traps positioned 20 m apart at 0 m, 20 m, 40 m, and 60 m from the road. GBDTs were left out for six intervals of approximately one month (mean trap exposure period 29.6 days) with the pre-construction monitoring period occurring over between May 2008 and January 2009. The November 2008 samples were disrupted by a major storm event, which damaged two tripods (both in site 2, at 20 m and 40 m); data from these distances are therefore absent from the final month. Overall, the GBDT assessment of dust levels consisted of 24 GBDT months at distances of 0 m and 60 m from the road and 23 GBDT months at distances of 20 m and 40 m from the road (a total of 94 GBDT months).

The deposition boxes had fitted lids which were removed at the start and replaced at the end of each monitoring period for transportation back to the laboratory. Dust was extracted from the traps in a series of washing and drying procedures. Initially, coarse organic materials (such as leaves, twigs and insects) were removed using tweezers and their coating of dust rinsed off. Dust was removed from the glass beads and box with distilled water and a spatula. The resulting water and sediment were decanted into a 2 l beaker placed in an oven at 40° C to reduce the volume of water to less than 50 ml. Once approximately 50 ml was reached, the 2 l beaker was rinsed and decanted into a pre-weighed 100 ml beaker, oven-dried again and dry sediment mass determined gravimetrically.

High-resolution particle size analyses of the dust were conducted using a Beckman Coulter Multisizer 3. Samples were analysed in a minimally-dispersed condition which approximates the natural, aeolian transport-stable condition of the dust, but entails a small level of dispersion as the method requires samples to be analysed in a fluid medium. Samples were added to an electrolyte (3% tri-Sodium Orthophosphate ($\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$)) and gently stirred to create a homogeneous mixture prior to analysis. Subsamples were analysed using 280, 140 and 50 μm tubes with an analytical range of 1.0 to 180 μm .

Real time PM_{10} sediment concentration. DustTrak™ sensors (TSI, Minnesota) are portable, battery-operated laser photometers, used here to provide real-time mass concentration of particulates with an aerodynamic size of $<10 \mu\text{m}$ (PM_{10}). These instruments have been used to monitor dust storm activity within Australia (Leys *et al.* 2008) and overseas (Zobeck & Van Pelt 2006). While the deposition traps provided data on total sediment movements, the DustTrak sensor provided an indication of the frequency of dust entrainment events (i.e. blown dust due to vehicles). The DustTrak sensor was operated during monthly trips to Gap Creek Road from May to October 2008. It was set up at the same position every month at site 1 approximately 2 m from the road. The device was programmed to take a reading every second and to record the average every minute. Measurements of less than 0.025 mg/m^3 were considered to be background readings given the instruments sensitivity and as such, time (min) of dust activity greater than this threshold are reported here. The DustTrak recorded for a total of 1194 minutes, giving an average of 199 minutes every month.

Mammal trapping surveys

Small mammal trapping transects were established close ('Near': 2-5 m from the edge of the road) to the road and away ('Far': 80-100 m from the road) from the road at each of the four sites. Transects were established at each site running parallel to the road and approximately

100 m in length, consisting of ten Elliot traps placed at ground level approximately 10 m apart, with two cage traps (56 cm x 20 cm x 20 cm) placed at either end of the transects. All traps were baited with a peanut butter and oats balls with sesame seeds, while the cage traps were also baited with bacon and banana.

Each trapping survey was conducted over three nights, with traps being placed and baited late in the afternoon and checked soon after dawn the following day. All captures were processed, identified and temporarily marked (by painting the inside of the ear with coloured whiteboard marker to enable confirmation of recaptures) and released at the place of capture. A trapping survey therefore consisted of a total of 24 traps (Elliot and cage) in four sites over three nights, giving a total of 288 trap-nights per survey. The data presented here summarise two pre-construction surveys (June 2009 and September 2009, a total of 576 trap-nights) and six post-construction (August, October and December 2010 and February, September and December 2011, a total of 1728 trap-nights). All results presented here have been converted to captures per day of survey.

Monthly hair-funnel surveys were conducted over a more extensive period of time than the trapping surveys, being conducted monthly between June and November 2008 pre-construction and between August 2010 and January 2011 post-construction. Five hair-funnels (Faunatech Pty Ltd) fitted with sticky sampling wafers were baited with peanut butter and oats balls, bacon and banana and placed evenly along the same Near and Far transects used for trapping surveys. Funnels were left undisturbed for a month (28-31 days). At the end of the survey, the wafers were collected and sent to an independent identification expert (K. Sullivan, Griffith University) for examination. Thus, each hair funnel transect represents 150 (30 night x 5 traps) trap-nights of surveillance per transect or 1200 trap-nights per survey period. Overall, we obtained 7200 trap-nights of surveillance before construction and 6000 after construction.

Means of captures for sites and treatments were compared by Student t-tests and any relationship between capture abundances and dust levels was assessed using Pearson's Correlation.

Results

Dust levels

Dry deposition

Over 500 g of sediment was deposited in the traps over the eight-month pre-construction sampling period. The source of this sediment was predominately emissions from Gap Creek Road, although other sources (such as quarrying activities) may have contributed small quantities. The high levels of vegetation cover surrounding Gap Creek Road ensured that the site in general was not susceptible to wind erosion activity.

The mean dust deposition rate across all sampling locations was $1.41 \pm 0.12 \text{ g m}^{-2}$ per day, accumulating to 514.65 g m^{-2} per year. Deposition traps closest to the road had the highest rates of dust deposition (Figure 3). As distance from the road increased, dust deposition decreased. A distinct decrease in particle size was also evident between the 0 m and 40 m traps (Fig. 4). This is reflected in the shift in the modal size from ~ 38 to $28 \mu\text{m}$ and in an increase in the amount of sediment of $2 - 20 \mu\text{m}$ (i.e. displacement between the green and red lines in these size classes in Fig. 4). Interestingly, the coarse $100 \mu\text{m}$ fraction did penetrate up to 40 m into the forest, highlighting the fact that emitted dusts from the road surface are able to permeate within the open forest structure.

Real-time PM_{10} sediment concentration

Real-time mass concentration measurement provides an indication of the frequency of dust entrainment events (i.e. road emissions due to vehicles). Due to security concerns, the DustTrak sensor was only operated during times when researchers were on-site, limiting dust frequency analysis to six pre-construction and five post-construction surveys. Although run times averaged 199 minutes pre-construction and 90.2 minutes post-construction (Table 1), the sampling periods coincided with the peak morning traffic session and may be regarded as representative of maximum daily dust displacement.

On average (Table 1), both the cumulative and maximum sediment concentrations were an order of magnitude higher before construction compared to after, with mean cumulative concentration following the upgrade being only 12% of dust level recorded pre-construction. Interestingly, the highest readings, pre- and post-upgrade were both obtained in September, though the sediment concentration recorded for 2011 was a fraction of the corresponding sample in 2008.

Mammal diversity and abundance

Trapping Surveys

Ground-dwelling mammals were surveyed by trapping twice before construction and six times after construction. A total of 316 animals were captured, equating to an average of

12.17±7.59 animals per survey pre-construction and 13.50±9.50 animals per survey post-construction; there was no statistical difference between these means.

A total of eight taxa of ground-dwelling mammals were captured. These were yellow-footed antechinus (*Antechinus flavipes*), buff-footed antechinus (*Antechinus mysticus*), common dunnart (*Sminthopsis murina*), northern brown bandicoot (*Isodon macrourus*), bush rat (*Rattus fuscipes*), swamp rat (*Rattus lutreolus*), black rat (*Rattus rattus*) and house mouse (*Mus musculus*). (Note that the presence of the two species of antechinus (Baker 2011) was confirmed only after the completion of fieldwork and is reported here as a single taxon, *Antechinus* sp.). Table 2 presents the mean number of captures per day for each species separated for pre-construction (Before) and post-construction (After) periods and for the Near and Far transects (combined).

Although Near and Far transects shared five of the eight species captured (assuming both species of antechinus were present in both), there were some minor differences in species recorded, with swamp rats captured only at Near sites and northern brown bandicoot only at Far sites. There were also small but important differences in species richness between pre- and post-construction samples: swamp rats and black rats were detected at the Near sites and common dunnart appeared at the Far sites only after construction.

Two native taxa, the antechinus group and the bush rat, together made up 78.8% of all captures. Of the numerous species captured both before and after construction, only two were found differ significantly (Table 2): more antechinus (both species combined) were captured at Far transects compared to Near sites (T-test: $T = 8.76$, d.f. = 5, $p < 0.02$), while the capture rate of house mice dropped significantly in Near sites following construction (T-test: $T = 7.55$, d.f. = 5, $p < 0.04$). Moreover, the species was not detected post-construction in Far sites (Table 2).

The change in abundance of the two introduced species, the black rat and house mouse, is worth reiterating. Before construction, the proportion of introduced species at the Near sites was almost half of all captures, but about 12% of captures away from the road (Table 2). After construction, however, there was a major decline in numbers of both species captured, with the proportion of captures of introduced species after construction being less than half that prior to construction.

Hair-funnel surveys

Ground-dwelling mammals were also surveyed using baited hair-funnels, deployed along the same Near and Far transects used for the trapping surveys. This technique detects the presence of animals through the collection of hair over the month-long duration of each survey, and also enables multiple species to be detected during the same period of time. Thus, the data gives evidence for the presence of species but does not infer abundance. It also provides an alternative method of detection and is especially useful for species known to be wary of traps or too small or large to be captured.

The results of the hair funnel survey largely confirmed the findings of the trapping surveys, with all trapped species being detected and again, antechinus were by far the most frequently recorded taxon (Table 3). The funnels did, however, detect two species not trapped, long-nosed bandicoot and cat, although both were found in very few funnels (only one in the case of the cat).

While the detections of species by trapping and hair funnels were similar for most Near and Far, Before and After combinations, the hair funnels failed to detect northern brown bandicoot and bush rat in the Near/Before sites and bush rats in the Far/Before sites. On the other hand, species not caught but detected by funnels were black rats in Near/Before and swamp rats in Far/After sites. Significantly, the funnels confirmed the absence of house mice from Far/After sites.

A Pearson's Correlation between captures abundances and dust levels from the closest dust traps was found to be non-significant ($R^2 = 0.17$, d.f. = 48, $p = 0.24$).

Discussion

The past decade has witnessed a dramatic increase in our understanding of the ecological and environmental impacts of roads and traffic, and in the development of methods of mitigating these impacts (Beckmann *et al.* 2010). While much of the research on these issues has been focused on large roads with heavy traffic loads, the significance of even small roads also needs to be recognised (Rytwinski & Fahrig 2012). Numerous studies on the movements of a range of taxa living near minor roads have reported a strong disinclination for animals to cross the road (e.g., Robson & Blouin-Demers 2013), sometimes to the extent of the road forming a permanent physical barrier to movement, regardless of traffic levels (Oxley *et al.* 1974). On the other hand, some species have been found to prosper in the ruderal and grassy habitat along the road verges and their movements may be enhanced by the provision of a vegetated road corridor (Brock & Kelt 2004, Rytwinski & Fahrig 2007).

The impact and influence of dust along roads is complex and poorly understood, especially with respect to organisms living beside roads (Ndibalema *et al.* 2007). Dust deposition on the vegetation may have a range of effects on individual plants. Significant dust accumulation has been shown to reduce the pigment content of plants beside unsealed roads (Prusty *et al.* 2005), reducing the capacity to photosynthesise. Interestingly, it has also been found that plant species differed greatly in their capacity to hold dust on leaves, potentially impacting on the plant community structure in the long-term. Anthony (2001) found that nutrients derived from the dust enhanced the growth of leaf epiphytes, whilst stimulating epiphytic growth reduced the net photosynthetic capacity of each leaf, leading up to 20% reduction in leaf photosynthesis. This increase in the nutrient status of the foliage raises questions as to whether invertebrate and vertebrate herbivores find the foliage more attractive. Moreover, although the presence of dust on leaves may deter foraging (Ndibalema *et al.* 2007), it is unknown whether heavy levels of dust at ground level influences the abundance of ground-dwelling animals.

Prior to the upgrade, Gap Creek Road consisted of two short segments of unsealed road, 200 m and 800 m in length respectively, located within the densely forested section of the road and both on significant gradients. Despite these sections adding only a kilometre of dirt surface to the overall road, they were the primary source of very considerable levels of dust on either side of the road. The deposition methods employed to assess dust levels prior to the upgrade obtained an average rate of 514.65 g m⁻² annually, an extraordinary level equivalent to a major inland dust storm (Leys & McTainsh 1999), but one experienced on most days and within a dense forest. This deposition rate was higher by a factor of seven than the average rate obtained by Leys & McTainsh (1999) for dust deposition rates from agricultural fields in south-eastern Australia. At a global level, Middleton (1997) found that dust deposition rates varied from 4.3 to 200 g m⁻² per year depending on distance from source. The Gap Creek Road study area can be viewed as being at source and therefore a high deposition rate is expected; nonetheless, the annual rate recorded was extremely high.

Moreover, although there was a clear reduction in the mean size of dust particles with increasing distance into the forest, we found that even the coarse 100 µm particles penetrated as far as 40 m from the road. As was visibly evident during fieldwork, virtually all upper-leaf surfaces below 1.5 m were thickly coated in a powdery coating, while the leaf litter layer was completely covered in white dust up to about 12 m from the road. Although assessing the influence of this dust on plant growth and function was well beyond the scope of the present study, numerous studies (e.g. Thompson *et al.* 1984, Farmer 1991) have shown major impacts from even moderate levels. It is highly likely that the impact of roadside dust at Gap Creek Road on vegetation would have been considerable.

The influence of sealing the dirt sections of the road on dust levels was dramatic. While we were unable to continue the deposition methods post-construction, the real-time detection methods indicated that dust levels after the upgrade were on average only 12% of pre-construction levels during the busiest traffic periods. Furthermore, only once during the post-construction surveys did dust levels achieve the threshold level of 0.025 mg m^{-3} .

An early expectation of the research team was that the massive levels of dust so clearly evident close to the road would serve as a significant deterrent to the presence of ground-dwelling mammals, and that the expected reduction of dust levels would result in increased abundances of animals close to the road. Thus, we predicted that mammal species richness and abundance would be higher at sites further from the road compared to sites next to the road. Following the upgrade, we predicted an increase in species and numbers in sites close to the road with less differences between near and far sites.

The diversity of mammals living in the forest at the site prior to construction was found to be unexpectedly rich, with eight species detected of which six were native. The most abundant taxa were two native mammals, antechinus and bush rats, which together comprised almost 80% of all captures. Contrary to our predictions, however, the extremely dusty roadside supported relatively high numbers of four native species, including common dunnart, as well as the highest densities of house mice recorded (Table 2). While the numbers of antechinus and bush rats were both significantly higher at the sites away from the road, only two additional species (northern brown bandicoot and black rat) were detected at these far sites, and neither in large numbers.

Following the upgrade of the road, and the marked reduction in dust levels, the main changes in the mammal fauna were distinct increases in the abundances of both the commonest species at the far sites and an increase in species richness near the road, with swamp rats and black rats being detected close to the road for the first time. Interestingly, the upgrade was also associated with a significant decline in the number of house mice detected, especially close to the road.

Overall, the influence of the upgrade on the ground-dwelling mammal fauna appeared to be far less pronounced than anticipated. This was primarily due to the fact that the dusty roadside was occupied by more individuals of more species than expected; despite the apparently unsuitable conditions present at the ground level, the most conspicuous component of a local road-effect-zone – the excessive dust – appeared to have little influence on animals living immediately adjacent to the road. Similar findings have been reported for several small mammals in North America, where, despite seemingly unsuitable environmental conditions,

Stephen's kangaroo rats (*Dipodomys stephensi*) in California and white-footed mice (*Peromyscus leucopus*) in Ontario, were both found in unexpectedly high numbers on or adjacent to roads (Brock & Kelt 2004; Rytwinski & Fahrig 2007).

What is not known yet, however, is the critical issue of whether these animals, though living in good numbers on either side of Gap Creek Road, are willing to cross the road. Numerous studies have found that even narrow roads can act as a significant barrier to the movements of small mammals, even the absence of high levels of traffic (Rytwinski & Fahrig 2012). A more complete assessment of the road barrier effect at Gap Creek Road will require a detailed investigation of this important issue.

The upgrading of Gap Creek Road provided an excellent opportunity to investigate the potential impact of changing the conditions of a minor road within a location with high biodiversity values. This road is unusual in being an urban transport route within a large city, yet one traversing a large contiguous tract of intact forest. Being a route that joins suburban areas also increases the importance of the local authorities attempting to enhance road conditions for the safety of motorists. However, the presence of an increasingly busy road in a conservation reserve also raises concerns about the possible impact of the upgrade, with an increase in road-kill being anticipated (Jones *et al.* in press).

This before-and-after monitoring project enabled several important issues to be addressed and provided some key findings of relevance to the continuing development of the field of road ecology in Australia. First, the discovery of healthy and diverse communities of ground-dwelling mammals living immediately adjacent to an extremely dusty road suggests that we have much to learn about the ecological conditions that may be tolerated by wildlife. There is no doubt, however, that the dust levels associated with the unsealed road would have had a major ecological impact on the lower-level plant life, almost certainly impairing photosynthesis and reducing growth. Therefore, the reduction of these dust levels following the upgrade is likely to result in pronounced recovery of these plants and the enhancement of habitat values for ground-dwelling fauna living beside the road. Of concern, however, is the disturbance associated with the construction process that is likely to lead to the establishment of a range of ruderal weed species.

The section of forest traversed by the road was found to support high levels of ground-dwelling mammals, despite the impact of the dust. However, we were unable to verify whether any of the species present were able to cross the road; this remains an important question. In numerous species, even small roads can act as partial or complete barriers to the movements of smaller terrestrial species.

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Figure captions

Figure 1. Gap Creek Road, Brisbane, Australia showing location of the four study sites

Figure 1. Glass Bead Deposition Trap (GBDT) (a) showing glass bead layers; (b) supported at a sampling height of 2 m.

Figure 3. Deposition trap data for each of four sites either side of Gap Creek Road. Deposition rates at each position are averaged over the 8 months.

Figure 4. Particle-size distribution of deposited dust collected at 0 m from road (red) and 40 m into the forest (green).

Figure 1

Figure 2

Figure 3

Figure 4

Table 1. DustTrak sampling at Gap Creek Road summary for before (unsealed) and after (sealed) construction.

Road Condition	Sample Date	Cumulative sediment concentration (mg m⁻³)	Maximum sediment concentration (mg m⁻³)	Percentage of time when sediment conc > 0.025mg m⁻³	Run time (mins)
Before	14 May 2008	6.47	0.38	25	256
	13 June 2008	2.35	0.06	3	368
	11 July 2008	1.51	0.17	9	180
	22 Aug 2008	1.40	0.13	13	97
	26 Sept 2008	13.99	0.51	69	155
	31 Oct 2008	2.79	0.16	25	141
	<i>Mean</i>	4.75	0.23	-	199.7
After	30 Oct 2011	0.29	0.01	0.0	40
	1 Feb 2011	0.09	0.006	0.0	33
	2 Feb 2011	0.22	0.12	0.0	57
	3 Feb 2011	0.64	0.016	0.0	182
	12 Sept 2011	1.76	0.031	0.7	139
	<i>Mean</i>	0.60	0.037	-	90.2

Table 2. Mean numbers ($\pm$ SD) of ground-dwelling mammals captured per day at Near and Far sites and Before and After periods (corrected for number of samples).
(*includes both yellow-footed and buff-footed species and assumes both were present in each site)

Species	Near/Before	Near/After	Far/Before	Far/After
<i>Antechinus</i> sp.*	0.85 $\pm$ 0.21	1.78 $\pm$ 1.02	4.00 $\pm$ 0.00	4.43 $\pm$ 1.97
Common dunnart	0.80 $\pm$ 0.50	0.44 $\pm$ 0.28	0	0.50 $\pm$ 0.79
Northern brown bandicoot	0	0	0.15 $\pm$ 0.15	0.05 $\pm$ 0.10
Bush rat	0.65 $\pm$ 0.49	1.78 $\pm$ 2.25	2.65 $\pm$ 1.01	2.83 $\pm$ 2.31
Swamp rat	0	0.05 $\pm$ 0.01	0	0
Black rat	0	0.17 $\pm$ 0.13	0.65 $\pm$ 0.35	0.50 $\pm$ 0.28
House mouse	2.00 $\pm$ 0.30	0.33 $\pm$ 0.50	0.30 $\pm$ 0.01	0
**Total captures	26	75	47	168
Mean captures	4.35$\pm$0.92	4.55$\pm$2.59	7.75$\pm$1.58	8.31$\pm$3.24
Species richness	5	7	6	6
Total introduced (%)	46.3	12.0	12.8	5.3

** Note that these totals are based on differing numbers of samples.

Table 3. Mean detections ($\pm$ SD) of mammals per hair-funnel at Near and Far sites and Before and After periods. (NB: SD less than 0.01 rounded up). (*includes both yellow-footed and buff-footed species and assumes both were present in each site)

Species	Near/Before	Near/After	Far/Before	Far/After
Antechinus sp.*	0.70 $\pm$ 0.11	0.63 $\pm$ 0.25	0.58 $\pm$ 0.25	0.69 $\pm$ 0.23
Common dunnart	0	0.02 $\pm$ 0.01	0	0.01 $\pm$ 0.01
Northern brown bandicoot	0	0	0.05 $\pm$ 0.01	0.07 $\pm$ 0.01
Long-nosed bandicoot	0	0	0	0.06 $\pm$ 0.01
Bush rat	0	0.01 $\pm$ 0.01	0	0.04 $\pm$ 0.01
Swamp rat	0	0.04 $\pm$ 0.01	0	0.09 $\pm$ 0.01
Black rat	0.04 $\pm$ 0.01	0.08 $\pm$ 0.13	0.04 $\pm$ 0.01	0.15 $\pm$ 0.03
House mouse	0.22 $\pm$ 0.01	0.14 $\pm$ 0.01	0.02 $\pm$ 0.01	0
Cat	0	0.02 $\pm$ 0.01	0	0
All captures	0.96$\pm$0.14	0.94$\pm$0.28	0.69$\pm$0.24	1.11$\pm$0.15
Species richness	4	8	5	8
Total introduced (%)	26.2	26.5	6.9	14.7