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Temporal trends in use of fauna-friendly underpasses and overpasses

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Abstract. The impact of roads on local biodiversity is a major issue associated with urbanisation. Compton Road is a major east-west arterial road in the southern suburbs of Brisbane, south-east Queensland, which, in 2004-5, was up-graded from two to four lanes. In an attempt to minimise the impact of the larger road on local wildlife populations, a range of fauna crossing structures were constructed at the site. Monitoring of road-kill was undertaken for four months prior to construction and following the completion of construction. Assessment of the use of two underpasses and a large overpass ('land-bridge') started six months after construction using sand tracking in underpasses and scat sampling on the land-bridge. An initial 26 week-long period of intensive monitoring was undertaken August 2005 to February 2006 followed by monthly monitoring June 2006 to June 2007. On average, 1-5 tracks per day were detected in the underpasses at the start of the survey, increasing steadily to about 42 tracks per day by February 2006. The monthly survey showed regular use of the underpasses by a wide range of species and species-groups, the most abundant being 'rodents', most likely *Rattus* species, both native and introduced. The land-bridge was also used continuously by three species of macropod (red-necked wallaby *Macropus rufogriseus*, swamp wallaby *Wallabia bicolor* and Eastern grey kangaroo *Macropus giganteus*) with brown hare *Lepus capensis* becoming increasingly common in summer 2006. The exclusion fencing was extremely effective in preventing most road-kill, except following human-related breaches in the fence.

Introduction

Roads often have major impacts on faunal populations inhabiting surrounding areas. Such impacts may be due to attributes of the road, including traffic volume and road width, and may be direct (such as fatalities and the severing of routes of movement) and indirect (such as via disturbance due to noise and pollution)(Bennett 1991; Forman *et al.* 2003). The intrusion of a road through previously intact areas can act as a major barrier to movements and pose a significant risk to animals that do attempt to cross (Oxley *et al.* 1974; Bennett 1991; Jones 2000; Forman *et al.* 2003). Forest remnants, especially those in areas affected by urbanisation, are often surrounded or bisected by roads, presenting a major obstacle to animals attempting to disperse or move between remnants. As a result, local populations of fauna frequently become marooned in increasingly isolated patches, inevitably increasing their susceptibility to decline and extirpation (Bennett 1991; Jones 2000; Goosem 2001; Taylor and Goldingay 2004).

In response to community concerns over increasingly conspicuous road-kill and a desire to enhance connectivity between forest fragments, road engineers have begun to include a variety of mitigation measures in their designs. Initially, roadside exclusion fencing was adopted, with some success in reducing wildlife-vehicle collisions (Clevenger *et al.*

2001; Forman *et al.* 2003). However, these fences often create an even greater barrier between habitats when used as the only method to protect local wildlife populations (Bennett 1991). In order to reduce the barrier effects of roads and roadside exclusion fencing, and therefore to increase connectivity of habitats and facilitate wildlife movements, numerous wildlife overpasses and underpasses have been constructed. The first purpose-built wildlife passages were in Europe and North America in the mid-1900s (Forman *et al.* 2003) and a wide range of overpasses and underpasses have since been introduced on new and existing roads across both continents, with clear evidence of use for certain species (see e.g. Foster and Humphrey 1995; Yanes *et al.* 1995; Clevenger and Waltho 2000; Mata *et al*. 2005; Goosem *et al*. 2006).

It has only been in recent years, however, that Australian road authorities have started to construct underpasses and overpasses to connect forest remnants divided by roads (Hunt *et al.* 1987; Goosem 2001; Goosem *et al.* 2001). Wildlife crossing structures have now been purposefully built in a range of locations and conditions, including in the Victorian Alps (specifically for the mountain pygmy-possum *Burramys parvus*)(Mansergh and Scotts 1989), at Brunswick Heads in northern New South Wales (Taylor and Goldingay 2003), and in the Atherton Tablelands in northern Queensland (Goosem *et al.* 2001, 2006). In 2004, a diverse array of fauna crossing and road-kill mitigation structures were constructed on Compton Road in south-eastern Queensland.

Compton Road is a major east-west arterial located in the south of the Brisbane metropolitan area. It services some of the fastest growing urban areas in Australia and has experienced increasingly heavy traffic loads over the past decade. One section of Compton Road separates the nationally significant Karawatha Forest from Kuraby Bushland immediately to the north. Both areas are crucial components of the Greenbank Corridor, a series of relatively contiguous areas of subtropical bushland recognised as being of critical importance to the maintenance of biodiversity in a region experiencing exceptional population pressure (Veage and Jones 2007).

During 2004, 1.3 km of Compton Road dividing the two areas of bushland (Karawatha and Kuraby) was upgraded from two to four lanes. Concerns over the impact of this larger road on the integrity of Karawatha Forest resulted in extensive consultations of the design of a range of mitigation features to be integrated into the upgrade constructions (see Chenoweth 2003; Mack 2005). Completed in early 2005, this site has one of the largest concentrations of fauna-crossing structures in a single location anywhere in the world (Fig. 1). These include: specialised road-side exclusion fencing; two faunal underpasses with ‘wildlife furniture’; three wet culverts with an artificial pond; a series of ‘glider poles’ (erected along the length of the land-bridge); three arboreal rope bridges connecting the tree canopy on either side of the road; and a ‘land-bridge’ (overpass) spanning the entire width of the new road (Fig. 2).

Several surveillance projects are being conducted to assess the effectiveness and use by wildlife of these various structures (see Veage and Jones 2007). A significant part of the motivation to obtain reliable and systematic data on fauna use of these facilities related to ongoing scepticism on the efficacy of such expensive constructions. Despite numerous North American and European studies (van der Ree *et al*. (2007) reviewed 123 such studies) demonstrating regular use of both purpose-built and existing culverts by a wide variety of species, in Australia it is not unusual to hear claims that such structures simply are ineffective or to read statements suggesting that these expensive features primarily benefit feral species, particularly mammalian predators.

An important additional concern is the likelihood that considerable periods of time may be required before local animals are sufficiently familiar with the structures to use them (Hunt *et al.* 1987). For example, Clevenger and Waltho (2005) suggested that local populations may require two to four years to 'adapt' to the presence of such structures. In the Northern Hemisphere, road ecologists frequently warn against expectations of early use of passages, especially in less disturbed areas (Mata *et al*. 2005). As Australian local governments and road agencies show increasing interest in the mitigation of the ecological impacts of roads, it is crucial that reliable monitoring data is readily available, especially of long-term patterns of use. Finally, it is important to discern the extent to which animals are actually using the structures to cross the road, as a crucial aim of the provision of the facilities is the overcoming of the road's barrier effect (Bennett 1991); crossings are necessary for gene flow and the reconnection of populations and is a fundamental element for claims of success (Aars and Ims 1999).

Here we report on the monitoring of terrestrial faunal use of two underpasses and the land-bridge at Compton Road, as evidenced by sand tracking (for the underpasses) and systematic scat sampling (for the land-bridge). The monitoring was undertaken in two periods: an initial intensive 26-week study started six months from the end of construction (August 2005-January 2005); and 13 monthly surveys (June 2006-June 2007). Together, these two phases spanned a total of 29 months. In addition, to assess the effectiveness of the exclusion fencing, we compared the amount of road-kill for the four months immediately prior to the commencement of work with data following the completion of construction.

The aims of this study were to:

1. assess the use of the two faunal underpasses by terrestrial vertebrates as indicated by sand tracking, and to determine the extent to which animals were crossing the road;
2. assess the use of the land-bridge by medium to large terrestrial mammals as indicated by scat counts; and

3. compare levels of road-kill rates on the road before and after the construction of the exclusion fence.

Methods

Study Site

Karawatha Forest is a large remnant forest of approximately 950 ha situated on the southern fringe of Brisbane (Stewart 1997). Its vegetation cover consists mainly of dry eucalypt forest and woodland with heath understoreys and contains lagoon systems that provide important habitat (Kordas *et al*. 1993). The forest contains 324 plant species and supports a wide range of native vertebrate species (Kehl and Corben 1991; Kordas *et al*. 1993). The northern boundary of the forest is separated from Kuraby Bushland by Compton Road; this area consists of similar vegetation to that of Karawatha Forest and contains many of the same fauna species (Stewart 1997). Human disturbance of the structures and immediate vicinity is minimal although there is frequent weekend trail bike use of the lower slopes of the Kuraby side of the land-bridge.

Two specifically designed fauna underpasses were constructed under Compton Road during the up-grade in 2004. Both are 2.4 m high, 2.5 m wide and 48 m long and contain three levels: a lower cement level for water flow; a raised cement level with rocks as 'furniture'; and two shelves, one small wooden shelf attached to the wall of the underpass and raised half-log railing, both of which run the full length of the underpass (Fig. 3). The raised cement level is 1.6 m wide and 0.4 m above the ground, leaving a height of 2 m from this level. The lower cement level and wooden shelf are 0.9 m and 0.25 m wide respectively.

The two faunal underpasses (A and B) are structurally identical except for a large pipe passing through the middle of underpass A and a drainage grate in the ceiling. The pipe inhibits crossings through the underpass by animals using the shelf (but does not impede passage along the concrete surface beneath), while the grate allows some light into the underpass about half way along its length. Underpass A is also positioned immediately beside three wet culverts and a well-vegetated artificial pond. Low shrubby vegetation occurs very close to the Karawatha Forest entrance of underpass A and both entrances of underpass B. The Kuraby Bushland entrance of underpass A, however, opens onto a concrete apron next to an artificial pond surrounded by dense reed-banks and other aquatic plants.

The land-bridge is hourglass shaped (see Forman *et al.* 2003) with an arc length of 70 m, a base width of 20 m and a mid-width of 15 m (Fig. 2). The slope of the batters toward the forest on either side is 1:3 but 1:2 toward the road (Mack 2005). The top of the structure is 8 m above the road, with 5.4 m clearance within each tunnel. The roadside exclusion fence continues unbroken over the land-bridge from the forest edges on either side of the road. A thick layer of mulch covers the span and a large number of local shrub, trees and grass species have been planted across the bridge to provide cover for wildlife using the structure. The exclusion fence is 2.48 m high and constructed of rubberised metal mesh extending directly into the ground for a depth of 5 cm. A 1 cm thick sheet of industrial rubber is attached to the base of the fence to a height of 48 cm and inserted slightly into the soil, forming a continuous barrier along the entire length of the fence. A solid sheet of rolled metal 59 cm in width, intended to deter animals attempting to climb the mesh, is attached to the fence on the forest side with the lower edge 1.38 m above the ground.

Sand tracking (underpass monitoring)

Sand strips were established inside both ends of the two faunal underpasses, approximately 1-2 m from the edge to minimise disturbance from rain or wind. The sand strips were approximately 1-2 cm thick, 1 m wide and covered the entire width of the raised section of the underpasses. Smaller sand strips were also set up on the shelves; these were approximately 0.5 cm thick and 0.5 m wide.

The sand was smoothed using a combination of the back of a nail rake (as recommended by Taylor and Goldingay 2003) and the flat part of a hand spade on the morning of a monitoring day, and checked for prints early the following morning. Monitoring was undertaken intensively (twice weekly) from 9th August 2005 to 6th February 2006 for 26 weeks and monthly from June 2006 to June 2007, providing a period of monitoring spanning 29 months with a gap between March and June 2006. Intensive surveys of both underpasses were undertaken for a total of 26 weeks, although only 19 weeks of underpass data were able to be used in the analyses due to disturbance by rain, wind or humans.

The underpass, sand strip, direction of movement and species identity of all visible tracks (spoor) detected in the sand strip were recorded. A full crossing of the underpass was assumed when tracks reliably identified as the same taxon, same size and moving in the same direction, were discerned in the sand strips at both ends of an underpass on the same date.

Tracks were identified as accurately as possible using the information and diagrams in Triggs (2004), Morrison (1981) and measurements given in Menkhorst and Knight (2004). All tracks were assigned to one of 16 categories or as an unknown. The categories were: rodent, house mouse, dasyurid, bandicoot, possum, wallaby, echidna, cat, dog, hare, agamid lizard, large skink, snake, small bird and other bird (see Table 1 for details of likely mammal species). For certain categories (e.g., rodent), unequivocal identification to species was not possible; instead, a list of the most likely species was developed, based on species known to occur in Karawatha Forest (Karawatha Forest Protection Society, unpublished data).

Scat collections (land-bridge monitoring)

Assessment of the use of the land-bridge was limited to species producing detectable scats. Weekly scat collections were conducted on the land-bridge for a period of 26 continuous weeks, commencing on 10th August 2005 and concluding on 8th February 2006. An additional 'snap-shot' sample was undertaken for two weeks during June 2007. The land-bridge was divided into three zones: zone one (the southern slope of the bridge side facing Karawatha Forest); zone two (the flat top and central section of the bridge); and zone three (the northern slope facing Kuraby Bushland). Scats were collected from each zone by crossing diagonally across the zone four times and constantly searching either side of the chosen route. As zones one and three were approximately 30% larger in area than zone two (675 m^2 versus 450 m^2), the time devotes to searching for scats was scaled accordingly: 15 minutes for zones one and three and ten minutes for zone two.

All scats were collected in separate zip-lock bags labelled with the date and zone, and identified using Triggs (2004), Morrison (1981) and scat samples collected from known species of those likely to be found in Karawatha Forest. The identification and abundance of scats collected from each zone was recorded. Scats from feral cats, dogs and foxes proved too difficult to reliably differentiate so were pooled into the single category of 'feral carnivore'.

Road-kill surveys

A four-month survey of the section of Compton Road to be up-graded was undertaken twice weekly until immediately prior to the start of construction activity associated with the up-grade (April-July 2004). Surveys of the road were not possible during construction but recommenced in the first week following the end of construction (February 2005). Since that time, road-kill surveys have been undertaken weekly until June 2007, providing consistent monitoring for a total of 29 months post-construction. The initial survey was conducted on foot with the observer walking along both sides of the road. In the post-construction phase, Brisbane City Council health and safety concerns limited these surveys to observations from a vehicle driven at the speed limit (70 km/hr) along the road in both directions during the early morning (05.00-06.30). All birds, mammals and reptiles larger than a blue-tongued skink *Tiliqua scincoides* were included. All specimens were identified to species where possible but were not removed or examined. However, location details were compared on each survey to ensure that no specimens were counted more than once. It is acknowledged that the change in the methods used for road-kill monitoring significantly limited the comparability of the data collected before and after construction. This was especially likely to bias the detectability of smaller taxa, most importantly resulting in an underestimation of these animals during the post-construction period.

Data analysis

For all analyses comparing the two faunal underpasses, weekly numbers of tracks and taxa were used by pooling the two days of surveys for each week. A Pearson's correlation was used to assess the relationship between numbers of tracks or taxa and time. Student's t-tests were conducted to compare the mean abundance of tracks and the number of taxa (categories) obtained weekly for the two underpasses.

Analyses performed on the scat collection data were similar to that performed on the sand tracking data. A Pearson's correlation between number of weekly scats collected and week was conducted and an Analysis of Variance was conducted on the overall abundance of scats and on the number of taxa (species) to compare whether all zones are being used equally by wildlife. Finally, a comparison of the proportions of taxa using the land-bridge over equivalent two-week periods during 2006 and 2007 was performed using a Contingency Test (Chi-squared).

Results

Fauna use of underpasses

A wide range of mainly small species used both underpasses throughout the study. A total of 1141 tracks of vertebrates were detected, 966 during the 26 weeks of intensive surveys and a further 175 during the 13 monthly surveys (Table 2). The initial surveys in August 2005 yielded a mean of about 1-5 individuals per day but usage increased steadily thereafter, peaking at about 42 tracks per day at the end of week 26 in January 2006 (Fig. 4). The correlation between weekly track detections and time was highly significant ($r = 0.88$, d.f. = 17, $P < 0.0001$) indicating a distinct linear increase in use of the underpasses through this period of the survey. The monthly surveys, which started five months later, revealed a similar seasonal pattern with lower rates of use in the winter and peaks of activity in mid-summer: totals of 30 per day were obtained for January 2007 (Fig. 4).

Overall use of the two underpasses was similar throughout the study (46.3% of all tracks for A, 53.7% for B during the intensive surveys; 49.1% for A, 50.9% for B during monthly surveys). Furthermore, the mean (±SD) number of animals using each underpass each day was also similar during both periods of the survey: 3.36±4.38 and 3.90±7.89 per day during the intensive survey and 6.62±4.52 and 6.85±8.02 for the monthly survey, for A and B respectively. None of these comparisons were statistically different.

The individual tracks were categorised into 16 taxa groups; only 37 (3.2%) could not be identified and are included together as 'unknown' (Table 2). The mammal taxa category, the most likely species and other possible species are listed in Table 1. The category 'rodents' accounted for the largest proportion – almost a third – of all tracks detected by the sand tracking (Table 2). The most likely species to have made these tracks were an introduced and native *Rattus* species (black rat and swamp rat) but were unable to be reliably distinguished (see also Triggs 2004). Tracks of house mouse were also relatively common (10.1%). The only dasyurid species detected, common dunnart, was identified with certainty on 17 occasions (1.5%). All of these small mammals combined accounted for almost half of all animals using the underpasses. Including bandicoots, these taxa of medium and small mammals comprise 59.7% of all tracks (Table 2).

The taxa producing the second most common tracks (22.5%; Table 2) were reptiles, mainly a variety of medium-sized lizards, all of which were likely to be diurnal. Similarly, 65 (5.7%) tracks were made by birds of various species. When combined with the reptiles, largely diurnal taxa made up 28.2% of all tracks (Table 2).

Cats and dogs (feral or/and domestic) were detected on 42 and 19 occasions respectively, together accounting for 5.4% of all tracks (Table 2).

Northern brown bandicoots were the third most common track detected (Table 2) and exhibited a distinctly seasonal pattern of presence in their use of the underpasses. Having been recorded only occasionally during most of the year, rates of underpass use by bandicoots peaked abruptly in mid-summer: 7 were detected on one night in January 2006 and 18 in January 2007. Other medium-sized species were detected far less often: three times for brown hare and twice for short-beaked echidna. Larger species such as red-necked wallabies, although common on the land-bridge (see below), were detected in the underpasses on three occasions only. Possums, however, were detected in the underpasses 16 times, with 11 of these being during the initial 19 weeks.

Full crossings of the road through the underpasses were highly variable among the taxa and between surveys (Table 2). The only taxa for which no individuals made crossings were wallabies, echidnas and hares, all of which were found in relatively small numbers. Excluding the diurnal taxa (birds and reptiles), the percentage of other taxa crossing the road through the underpasses varied from 0% to 88.9% during the two survey periods. Relatively few (3.6% and 5.9% for the two survey periods respectively) of the otherwise abundant 'rodent' category made full traverses of the road compared to 21.4% and 12.9% of house mice respectively (Table 2). Overall, 9.9% of all animals detected in the underpasses during the intensive surveys completed full crossings, compared to 27.4% during the monthly surveys (Table 2).

An innovative component of the design of the underpasses was the inclusion of a shelf, attached to the concrete wall of the culvert. It was hoped that this feature might facilitate the passage of smaller species to use the underpass without having to move along the relatively open area of the underpass floor. A total of 355 separate tracks were detected in the sand placed on the shelves in both underpasses, made up of 204 ‘rodents’, 77 house mouse, 53 reptiles, 16 birds, and 5 dasyurids. When compared to the total number of individuals of each of these taxa entering the underpasses, these figures indicate that 55.1% of ‘rodents’, 67.0% of house mouse, 20.6% of reptiles, 24.6% of birds, and 29.4% of dasyurids used the shelves. Overall, 31.1% of all tracks were detected on the shelves.

Fauna use of the land-bridge

A total of 1266 vertebrate scats were collected on the land-bridge over the intensive survey of 26 weeks. There was no linear relationship between the total number of scats collected weekly and time ($r = -0.3182$, $P = 0.5241$; Fig. 5).

The total number (and percentage) of scats collected for the zones was 465 (36.73%) for zone one (the southern slope of the land-bridge), 42 (3.32%) for zone two (the top of the land-bridge) and 759 (59.95%) for zone three (the northern slope). There was a significant difference ($F = 33.10$, d.f. = 2, 25, $P < 0.0001$) in the mean weekly number of scats between each of zones one (17.89±1.94), two (1.62±0.32) and three (29.19±3.68), with zone three having significantly higher scat abundance and zone two having the lowest scat abundance.

Scats from seven different taxa were collected on the land-bridge. Brown hare scats accounted for 76.1% of all scats collected during the intensive surveys, with red-necked wallaby the next most abundant (14.8%)(Table 3). Initially, macropods dominated the number of scats collected. These began to decrease noticeably after week 11 as brown hare scats began to increase (Fig. 5). Scats from eastern grey kangaroos, swamp wallabies, possums, echidnas and feral carnivores were also collected from the land-bridge but in much smaller numbers.

A two-week scat sampling survey was conducted during June 2007 and compared with data for the equivalent period in June 2006 (Table 4). This ‘snap-shot’ comparison indicates that most of the dominant species using the land-bridge in 2006 were present a year later and that scats of the macropod species were considerably more abundant in 2007. A more detailed comparison of these data (Table 4, excluding ‘feral carnivores’ because of low numbers) revealed significantly less red-necked wallabies and more of both swamp wallabies and grey kangaroos in 2007 (X^2 =56.71, d.f. = 4, P <0.0001). Both brown hare and feral carnivore scats were collected in similar amounts, the latter remaining relatively rare.

Road-kill surveys

A total of 13 terrestrial vertebrates of ten species were detected as road-kill during the four-month pre-construction survey (Table 5). These included three common ringtail possums, two macropods (red-necked wallaby and swamp wallaby), three birds, two reptiles (both snakes) and a dog and a cat, both of which were likely to have been roaming domestic animals rather than feral animals. In the four months immediately following the end of construction, despite the presence of the exclusion fencing, two large animals were detected that had been killed on the road. The single red-necked wallaby was able to reach the road because of a large hole deliberately cut in the fence, whereas the wood duck appears to have been hit while landing on the road during the night. In the 29 months (to June 2007) since the completion of construction, only a further three vertebrates have been added to this list, including another red-necked wallaby, again making use of breach due to vandals.

Given the change in methods between the pre- and post-construction phases of these surveys, it is possible that the latter data underestimates all taxa except larger species.

Discussion

The main aims of the present study were to monitor use by wildlife of two underpasses and the land-bridge after six months of the opening of the structures, and to continue to survey these structures for a further two years. The results demonstrated clearly that both structure types were used quickly and regularly by a considerable diversity of wildlife taxa, that some individuals of numerous species made full crossings of the road by using the underpasses and that, despite seasonal and drought effects, use continued throughout the study.

Fauna use of underpasses

Although numerous studies have shown that many species do make use of underpasses, several workers have stated that regular use may not be well established for months or years (see Hunt *et al.* 1989; Foster and Humphrey 1995; Clevenger and Waltho 2005). Mata *et al.* (2005), for example, suggested that even after four years animals may still be habituating to the structure. The present study commenced within six months of the completion of construction; large-scale physical disturbance of the local environment was clearly evident, most of the plantings remained small and the ends of the underpasses and the existing forest remained distinctly separated. Moreover, while the length of the underpasses was 48 m, the actual distance between the bushland areas on either side was 58-65 m. Thus the remaining physical disturbance and the distance between the forest edges led us to expect little underpass use by fauna so soon after construction (see also Findlay and Bourdages 2000). Nonetheless, we found clear evidence of vertebrate activity in the underpasses from the start of the surveys and this continued throughout the study. Similarly, Goosem *et al*. (2006) found that while some species of small mammal used underpasses in tropical rainforest almost immediately after construction, other species present in the area had not used the structures even after four years.

The distinct increase in overall activity associated with the increase in warmer weather found in both years was due to increases in small mammal activity and has been observed in numerous international studies (Rodriguez *et al*. 1996; McDonald and St. Clair 2004; Ng *et al*. 2004; Goosem *et al*. 2006). Seasonality of animal movement and dispersal is well documented with the advent of breeding seasons and warmer weather often accounting for increases in animal movement (Bennett 1991; Law and Dickman 1998). The 'rodent' group, house mouse and northern brown bandicoots, were all detected in much greater numbers during December and January of the intensive surveys but this pattern was not repeated the following year; the monthly surveys of 2006/7 revealed increases in bandicoot numbers only (18 were detected in 24 hours for January 2007). The low numbers of small mammals recorded in the latter was almost certainly due to the continuation of the severe drought conditions affecting the entire region throughout the study period; concurrent trapping studies in the adjacent bushland similarly found extremely low numbers of all small mammal species (Garden *et al.* 2007; D. Jones unpublished data). The resilience of the bandicoots is, therefore, particularly noteworthy (FitzGibbon and Jones 2006).

Both underpasses were used by similar numbers of animals. With few exceptions, most taxa were detected in both underpasses and during both surveys. Small mammals, primarily rodents, were by far the most frequent users of the underpasses, although bandicoots comprised a significant proportion of the total. Regular use of underpasses by small mammals, especially rodents, has been frequently reported in both Australian (e.g., Abson and Lawrence 2003; Taylor and Goldingay 2003; Goosem *et al.* 2006) and Northern Hemisphere (Yanes *et al.* 1995; Rodriguez *et al.* 1997; McDonald and St. Clair 2004; Ng *et al.* 2004) studies. Far less common are reports of lizards using underpasses, the primary exceptions being Spanish studies (Rodriguez *et al*. 1996; Mata *et al*. 2005). This taxon was the second most abundant detected in the present study, although few appeared to make crossings (Table 2).

A crucial goal of these surveys was an assessment of the extent to which individuals of the different taxa were using the underpasses to cross the road. Being almost 50 m in length, movements through the entire length of the concrete structure necessitated a substantial journey for a small animal. Nonetheless, significant numbers of individuals did make full crossings: about 16% of all animals entering the underpasses each day during the intensive surveys and about 30% during the monthly surveys. The proportion of animals crossing was highly variable for taxa but was more likely for large species such as possums, bandicoots and cats and dogs. On average, we estimated about one animal made a crossing per night, although this would certainly be higher during the summer.

There has been considerable discussion on the optimal dimensions and design of fauna-friendly crossing structures (Clevenger and Waltho 2000, 2005; McDonald and St. Clair 2004). Numerous field studies have confirmed that different dimensions appear to favour different taxa, with larger species much more likely to use larger structures (Clevenger and Waltho 2005). Although many purpose-built passages have been designed for larger species (the Compton Road underpasses, for example, were intentionally designed to be large enough to accommodate a wallaby), several recent studies have found that small mammals are much more likely to use smaller, enclosed passages (Mata *et al*. 2005), even when these were relatively long (Rodriguez *et al*. 1997; cf. Yanes *et al*. 1995). McDonald and St. Clair (2004) determined that small mammals preferred to move through passages with more proximate cover, such as provided by circular culverts 0.3 m in diameter to larger (3 m) open passages. Other studies have shown that proximity to cover at the ends of the passages is especially important (Rodriguez *et al.* 1997).

The present study also included an assessment of the use of raised shelves. Significant numbers of animals used these features, with 20% of 'rodents' and 40% of all dasyurids entering the underpasses travelling above the floor.

Fauna use of the land-bridge

The construction of overpasses or land-bridges to facilitate wildlife passage has been employed less often than have underpasses (Magnus *et al.* 2004), but these structures have been used by a range of typically larger mammalian species (Clevenger *et al*. 2000; McDonald and St. Clair 2004). Again, numerous workers have argued that these large and obtrusive structures may be actively avoided by many species (see Little *et al.* 2002). The aims of this part of the present study were to determine whether wildlife made use of the land-bridge and to identify the species involved. We employed passive monitoring approaches (scat sampling) that addressed both aspects but did not attempt to estimate the number of animals involved. While scat sampling techniques have been used to estimate numbers of animals in other studies (e.g., Johnson *et al.* 1987; Johnson and Jarman 1987), detailed information on species-specific and location-specific defecation rates and scat decay rates would be required (Laing *et al.* 2003); such data are currently unavailable. Our data, therefore, relate to the abundance of scats only and cannot be used to infer abundances of species or individuals.

Patterns of faunal use of the land-bridge were very different to those observed in the underpasses. Scat abundances varied considerably over time and between surveys and included numerous apparently low activity periods (Fig. 5) reflecting significant changes in the activity levels of the main animals using the structure. Contrary to expectations, swamp wallaby scats were collected from the top of the land-bridge within three weeks of construction (D. Jones, unpublished data). At the start of the present study, large numbers of scats of three macropod species and brown hares were detected on the structure, although red-necked wallabies were by far the most abundant macropod.

This unexpectedly rapid use of the structure (cf. Clevenger and Waltho 2005; Mata *et al*. 2005) appears most likely to have been associated with the unintentional growth of weedy grasses germinating from the mulch used to cover the entire structure. These grasses may have been especially attractive as foraging resources within the forests were probably very restricted due to the prolonged drought conditions at the time. The decline in use of the land-bridge by the macropods may therefore, have been related to the exploitation of this ephemeral resource, a situation aggravated by the dramatic increase in the numbers of brown hares, similarly attracted to the grasses (see Finch *et al.* 2003). The attraction of grazing animals to the structure by the growth of these grasses may have been important in the apparently rapid familiarity of the structure by these species, and suggests that intentional seeding of the land-bridge may be a valuable means of facilitating their use by target species.

The comparison of scats over equivalent two week periods in 2006 and 2007 suggested that use of the land-bridge had continued throughout the study period. Indeed, the proportion of total macropod scats collected was significantly higher in 2007 compared to the previous year. Again, this is almost certainly due to the dramatic growth in plantings and grasses clearly evident over the entire land-bridge. Given the impact of the drought on the vegetation of the surrounding bushland, the continued growth of fresh plants probably provided a valuable foraging resource for local herbivorous species.

Effectiveness of exclusion fencing

Although of short duration, the pre-construction survey of road-kill did provide valuable quantitative data on rates of road-kill and, with a contemporaneous study of road impacts within the same region (Buchanan 2005), confirmed that possums and wallabies were the most common large vertebrates being killed on local roads. The effectiveness of the fencing was demonstrated partially by the clear reduction on reported fatalities of larger species. Comparing the raw data from the four-month period prior to and following the completion of construction showed a reduction from 13 to two animals killed, and only a further two over the entire 29 month post-construction period. However, it must be borne in mind that the post-construction surveys were strongly biased toward the detection of larger species; it is possible that smaller species, especially small mammals, were killed but not detected.

It is also noteworthy that the only wallaby fatalities occurring during this period were associated directly with human-induced breaches in the fence. Clearly, continuous monitoring of the fence is crucial for the fence to function as an effective barrier; the exploitation of breaches in the fence occurred soon after they appeared (both wallabies were killed less than 12 hours of the breaches being noticed). In combination with easily accessed safe passages under and over the road, fences are an essential component of the obvious success of the Compton Road structures.

Management implications

This study, using simple yet effective non-invasive monitoring approaches, has demonstrated clearly that a wide range of species used the fauna-friendly road-crossing structures at Compton Road, and that this usage started soon after construction and continued thereafter. In contrast to Northern Hemisphere suggestions of lengthy periods of adaptation and habituation, our findings indicated relatively early use of both underpasses and overpasses followed by regular use, strongly suggesting rapid habituation. Nonetheless, the sand tracking methods employed was unable to reliably distinguish among the several important taxa, thereby limiting the clarity of the findings. For example, while large numbers of the 'rodents' category used the underpasses early, we are unable to state which species were involved. In an important study from North Queensland, Goosem *et al*. (2006) found early use by some species while others appear to avoid the structures entirely for years. A critical improvement of methods should involve the reliable identification of species.

These surveys confirmed that a wide range of small and medium-sized mammal species were the dominant users of the underpasses. As numerous studies (Rodriguez *et al.* 1996; McDonald and St. Clair 2004; Ng *et al.* 2004; Mata *et al*. 2005) have found that these taxa prefer smaller structures with denser, more proximate cover, use of the relatively large underpasses could almost certainly be enhanced by the inclusion of small-mammal specific 'furniture' such as hollow logs and pipes along the open floor of the underpass. Furthermore, the considerable use made of the raised shelves indicates that such features could be incorporated into existing culverts and underpasses as a means of encouraging increased use by small species.

The remarkably rapid and continuing use of the land-bridge by each of the three species of macropod can be strongly attributed to the provision of an attractive foraging resource on the structure itself. While the growth of grasses in the landscaping mulch was an unintended event, it appears to have been highly influential in attracting these animals onto the structure and possibly advancing the process of habituation. The on-going growth of plants has continued to attract these and other species over several years. We would, therefore, advocate intentional planting of appropriate vegetation as a means of facilitating herbivorous species use of such overpasses.

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Table 1. Mammal taxa categories associated with tracks identified in sand plots with most likely species listed along with other possible species known to occur locally

Mammal taxa category	Most likely species	Other possible species
Rodent	Bush rat *Rattus fuscipes* Black rat *Rattus rattus*	Swamp rat *Rattus lutreolus* Yellow-footed antechinus *Antechinus flavipes*
House mouse	House mouse *Mus musculus*	-
Dasyurid	Common dunnart *Sminthopsis murina*	Common planigale *Planigale maculata* Yellow-footed antechinus
Bandicoot	Northern brown bandicoot *Isoodon macrourus*	-
Possum	Common brushtail possum *Trichosurus vulpecula*	Common ringtail possum *Pseudocheirus peregrinus*
Wallaby	Red-necked wallaby *Macropus rufogriseus*	-
Echidna	Short-beaked echidna *Tachyglossus aculeatus*	-
Cat	Domestic or feral cat *Felis catus*	-
Dog	Domestic or feral dog *Canis familiaris*	Red fox *Vulpes vulpes*
Hare	Brown hare *Lepus capensis*	-

Table 2. Total numbers of tracks of vertebrate taxa (see Table 1 for mammal categories) detected in sand plots of underpasses A and B for intensive and monthly surveys, with percentage of total of each taxa that made full crossing.

Taxa or categories	Intensive surveys (Period 1) tracks per day					Monthly surveys (Period 2) tracks per day					Total tracks detected in both periods (and %)
	Underpass A		Underpass B		% crossings Period 1	Underpass A		Underpass B		% crossings Period 2	
	Total tracks detected	Number per day	Total tracks detected	Number per day		Total tracks detected	Number per day	Total tracks detected	Number per day		
Rodents	79	0.59	257	1.93	3.6	24	1.85	10	0.77	5.9	370 (32.4)
House mice	59	0.44	25	0.19	21.4	14	1.08	17	1.31	12.9	115 (10.1)
Dasyurids	7	0.05	0	0.00	28.6	4	0.31	6	0.46	0.0	17 (1.5)
Bandicoots	52	0.39	87	0.65	17.3	14	1.08	26	2.00	40.0	179 (15.7)
Possums	9	0.07	2	0.02	18.2	1	0.08	4	0.31	40.0	16 (1.4)
Wallabies	1	0.01	2	0.02	0.0	0	0.00	0	0.00	-	3 (0.3)
Echidnas	1	0.01	1	0.01	0.0	0	0.00	0	0.00	-	2 (0.2)
Cats	6	0.05	27	0.20	48.5	7	0.54	2	0.15	88.9	42 (3.7)
Dogs	10	0.08	0	0.00	40.0	2	0.15	7	0.54	66.7	19 (1.7)
Brown hares	0	0	2	0.02	0.0	0	0.00	1	0.08	0.0	3 (0.3)
Birds	39	0.29	21	0.16	20.0	4	0.31	1	0.08	0.0	65 (5.7)
Reptiles	167	1.26	76	0.57	1.6	13	1.00	1	0.08	0.0	257 (22.5)
Frogs	0	0.00	0	0.00	0.0	2	0.15	14	1.08	62.5	16 (1.4)
Unknowns	17	0.13	19	0.14	5.6	1	0.08	0	0.00	0.0	37 (3.2)
TOTAL	447	3.36	519	3.90	9.9	86	6.62	89	6.85	27.4	1141 (100.0)

Table 3. Total numbers (and percentages) of scats of vertebrate taxa collected for the three zones of the land-bridge

Taxa or category	Zone 1	Zone 2	Zone 3	Total scats (%)
Red-necked wallaby	133	8	46	187 (76.1)
Swamp wallaby	8	5	3	16 (1.3)
Grey kangaroo	39	3	18	60 (4.7)
Possum	4	0	4	8 (0.6)
Short-beaked echidna	5	0	1	6 (0.5)
Brown hare	262	25	676	963 (76.1)
Introduced predator	21	1	4	26 (2.1)
Total	472	42	752	1266 (100)

Table 4. Total numbers (and percentages) of scats of vertebrate taxa collected for all zones of the land-bridge for during two weekly surveys in winter 2006 and 2007

	2006			2007		
Taxa or category	**Week 1**	**Week 2**	**Total(%)**	**Week 1**	**Week 2**	**Total(%)**
Red-necked wallaby	37	8	45 (46.3)	22	8	30 (19.2)
Swamp wallaby	0	7	7 (7.2)	30	8	38 (23.1)
Grey kangaroo	8	1	9 (8.0)	16	4	20 (12.7)
Brown hare	17	17	34 (35.0)	17	48	65 (41.6)
Introduced predator	2	0	2 (0.1)	2	1	3 (1.8)
Total	64	33	97 (100)	87	69	156(100)

Table 5. Animals detected as road-kill on Compton Road during (a) four months prior to construction (February-June 2004), (b) four months following construction (February-June 2005), and (c) times since (June 2005 to June 2007)

Taxa	**Pre-construction (four months)**	**Post-construction (four months)**	**Period from (24 months)**
Red-necked wallaby	1	1	1
Swamp wallaby	1		
Common ringtail possum	3		1
Northern brown bandicoot	1		
Cat	1		
Dog	1		
Pheasant coucal *Centropus phasianus*	1		
Torresian crow *Corvus orru*	1		
Australian wood duck *Chenonetta jubata*		1	
Unidentified bird	1		
Brown tree-snake *Boiga irregularis*	1		
Small-eyed snake *Cryptophis nigrescens*	1		
Carpet python *Morelia spilota*			1
Total	**13**	**2**	**3**

Figure Captions

Figure 1. Site map showing approximate locations of land-bridge and underpasses at Compton Road, southern Brisbane.

Figure 2. The land-bridge over Compton Road, southern Brisbane, also showing exclusion fencing (photograph D.N. Jones, taken April 2005)

Figure 3. Interior of underpass A showing internal structure, raised shelf and 'furniture' (photograph D.N. Jones, taken April 2005).

Figure 4. Total tracks of all species detected in both underpasses per 24-hour survey, for weeks from start of study. Intensive phase (26 weeks) where week 1= week starting 9 August 2005 to week 26 = week starting 6 February 2006; monthly phase (13 months) from June 2002 (week 48) to June 2007 (week 100).

Figure 5. Weekly total scats collected from all zones of the land-bridge over 26 weeks of intensive phase, August 2005 – February 2006, for weeks from start of study. Week 1= week starting 9 August 2005, week 26 = week starting 6 February 2006.