Title

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EFFECTIVENESS OF ROPE BRIDGE ARBOREAL OVERPASSES AND FAUNAL UNDERPASSES IN PROVIDING CONNECTIVITY FOR RAINFOREST FAUNA

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Abstract: Rope bridge overpasses and faunal underpasses were effective in restoring rainforest habitat connectivity for many tropical rainforest species that suffer high levels of road mortality or that avoid large clearings, such as those for roads, and, therefore, suffer barrier effects.

Faunal underpasses furnished with logs and rocks to provide cover were constructed in 2001 at a hotspot for tree-kangaroo mortality. The narrow road and 120-m-wide strip of abandoned pasture divided two blocks of rainforest severing an important highland wildlife corridor through an agricultural landscape. No rainforest small mammals were recorded crossing the gap in six months of trapping prior to the road upgrade. During the upgrade, corridors of rainforest trees were planted through the pasture to connect with underpass entrances. Underpass use was monitored weekly using sand tracking beds complemented by infrared-triggered digital cameras. Weekly road kill data were collected for 12 months prior to construction and continues on two 0.5-km road transects in the vicinity of the underpasses and two transects along a highway dividing similar rainforest habitat 5km to the north. In 2004, bird and small mammal use of the planted corridors was investigated.

Many terrestrial rainforest species use the underpasses, including medium-sized and smaller mammals and terrestrial birds, together with two confirmed passages of the rare target species, Lumholtz's tree-kangaroo. Road mortality near the underpasses has remained low, whereas road kill rates are much greater along the narrow rainforest highway without underpasses. Community composition of rainforest birds within the corridors is approaching that of edge rainforest nearby, demonstrating effectiveness at this early stage of growth. However, although rainforest small mammals reside in the corridors, feral and pasture species still dominate, emphasizing the need for longer growth periods to encourage greater use by rainforest specialist mammals of the connectivity afforded by corridors and underpasses.

Several rope bridges erected 7m above narrow roads and designed for use by rare arboreal rainforest mammals have also proven effective and are regularly used by the obligate arboreal Lemuroid ringtail possum, which will not cross roads on the surface or via underpasses. Several other possums that rarely venture to ground level are also regular crossers. Structures also provide safe crossing routes for arboreal species that otherwise suffer road mortality. Monitoring using active infrared-triggered cameras, scat and hair collection, and spotlighting has shown all target rainforest ringtails and other possums using rope tunnel and cheaper rope ladder designs. Similar designs have since been installed elsewhere in Australia over four-lane highways. Subsequent rainforest studies will investigate use of longer rope bridges above a wide highway using mark-recapture and radio-tracking to determine home range and provide population information prior to construction, followed by systematic monitoring of the rope bridges.

Introduction

Fauna of the tropical rainforest understorey and ground layer are adapted to a structurally complex habitat with a cool, moist, and relatively equable microclimate and low light, whereas road clearings comprise an extreme contrast because they are structurally barren, suffer extremes of temperature, humidity and wind turbulence, and have very high daytime light levels (Siegenthaler and Turton 2000, Pohlman et al. 2005). Microclimate changes also permeate the edge of the forest and result in changes in species composition and structure of vegetation, altering faunal habitat at the edge (Siegenthaler et al. 2000, Goosem and Turton 2003, Goosem et al. 2005, Pohlman et al. 2005). Road clearings are, therefore, likely to form either partially permeable (Goosem 2001) or complete barriers (Goosem 2000) to the movements of specialized tropical rainforest fauna, an effect which may be exacerbated by traffic movement, headlights, pollution, and noise emanating from the road clearing. The degree of contrast between the road clearing and rainforest habitat means barrier effects are likely to be greater for many species of rainforest wildlife than for fauna of more open habitats (Goosem 1997, 2004). Barrier effects for tropical rainforest fauna are increased by several factors including wider clearings and microtopography, such as cuttings and embankments adjacent to the road that are difficult for terrestrial animals to traverse (Goosem 2000). Rainforest wildlife is also subject to high levels of road mortality (Goosem 1997, 2000). In areas of high traffic, mortality through vehicle-wildlife collisions can increase the road barrier effect, reducing success of road crossing attempts by less inhibited species (Forman et al. 2003). If effective, the inclusion of wildlife underpasses under roads for terrestrial rainforest wildlife could at least partially mitigate against the problems of mortality and fragmentation. Similarly, canopy overpasses could provide passage for species that are obligatorily arboreal.

Although the success of faunal underpasses for a variety of vertebrates including large mammals (Foster and Humphrey 1995, Clevenger and Waltho 2000, Gordon and Anderson 2003), small mammals (Mansergh and Scotts 1989, Mata et al. 2003, Servheen *et al.* 2003, Taylor and Goldingay 2003), reptiles and amphibians (Yanes et al. 1995, Aresco 2003, Mata et al. 2003, Taylor and Goldingay 2003) has been demonstrated for many roads through open habitats and temperate forests over the past decade, their effectiveness for tropical rainforest fauna has only recently begun to be examined (Goosem et al. 2001, Goosem 2003). Similarly, monitoring of structures provided for movement of arboreal fauna is relatively new (Becker 2003, Weston et al. 2005) and unique within rainforest ecosystems.

In the tropical rainforests of northeast Queensland, Australia, several highways traverse the mountain ranges from the rapidly expanding urban centers on the coast to connect with the mainly rural areas of the tablelands, dividing large blocks of rainforest in the process. Upgrade designs for one highway will straighten and widen the two-lane winding road to four lanes to cater for traffic volume increases from 6,500 to 10,000 vehicles per day. Iterative collaboration between the Queensland Department of Main Roads (QDMR) and researchers from the Rainforest Cooperative Research Center (Rainforest CRC) has ensured that the design of this upgrade incorporates all recent research into mitigation of impacts of tropical rainforest roads, including the two collaborative connectivity projects discussed in this paper. The first project concerns effectiveness of faunal underpasses for terrestrial rainforest species, and the second examines effectiveness of rope bridges in providing connectivity for arboreal rainforest fauna.

All study areas were situated within the rainforests of the Wet Tropics World Heritage Area, northeast Queensland, Australia (fig. 1).

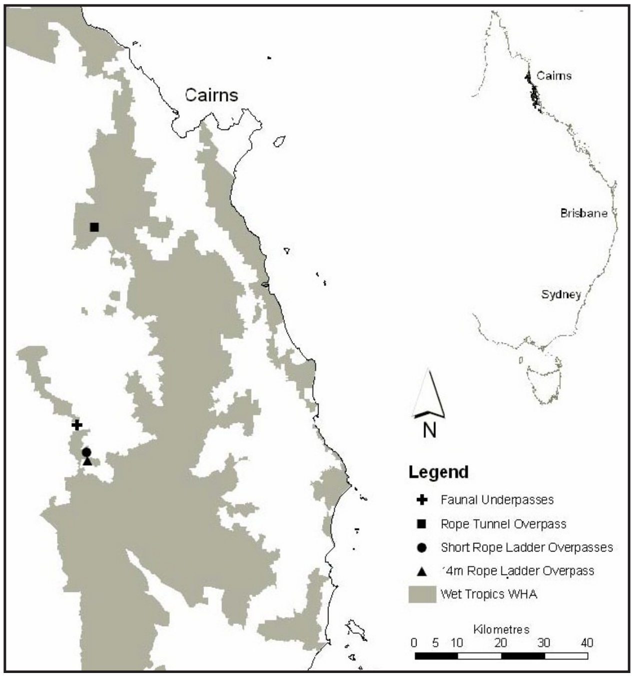

Figure 1. Location of study sites within the rainforests of northeast Queensland, Australia.

Faunal Underpasses

Study area

In 2001, QDMR upgraded a winding section of a one-lane, high-altitude (~1,100m) road to eliminate hairpin bends and provide two wide lanes. The former narrow road and adjacent abandoned pasture divided two important areas of highland rainforest (Goosem et al. 2001, Goosem 2003). Rainforest in this area is habitat for a suite of species with threatened or rare conservation status, including the endangered Southern Cassowary, *Casuarius casuarius johnsoni*, and the rare Lumholtz's Tree-kangaroo, *Dendrolagus lumholtzi*. The area was a hotspot for road mortality of tree-kangaroos (Kanowski et al. 2001, Izumi 2001).

Underpass design and siting: The road upgrade design incorporated four underpasses 3.4m high and 3.7m wide, constructed as galvanized steel arches with a concrete base (fig. 2). The height of the cassowary (1.5-2m) and the requirement to allow animals a direct line of sight to attractive rainforest habitat at either end of the underpasses were the reasons for choice of underpass size. Three underpasses were specifically for faunal use and were subsequently monitored using sand track beds complemented by infrared-triggered digital photography. Underpass design and siting were established in collaboration with QDMR, researchers from the Rainforest CRC, the Centre for Tropical Restoration in the Queensland Environmental Protection Agency, and community groups including the Tree Kangaroo and Mammal Group, Trees for the Evelyn and Atherton Tablelands and Wildlife Rescue.

The three faunal underpasses incorporate "furniture" (fig. 2), including escape poles erected vertically using stirrups in the concrete base. The base was then covered with a ground cover of soil, leaf and branch litter, and rocks and logs to simulate conditions on the forest floor, to reduce the open spaces that rainforest species tend to avoid, and to provide cover for smaller rainforest animals from predators such as dogs, cats and owls (Goosem 2003). A narrow pathway was retained through the centre of the underpass to allow easy movement of larger species. A thick rope was swung from hooks in the ceiling of the underpass through the tunnel and tied to trees near either exit for possible use by obligate arboreal species. Escape poles and ropes provide havens for arboreal species needing to escape from predators (Kanowski and Tucker 2002).

Figure 2. Faunal underpass showing furniture, including escape pole (vertical tree branch), sand bed, attractive habitat at exit, soil, litter, rocks and logs to simulate rainforest floor conditions.

Underpasses were sited as close to remnant rainforest vegetation as possible and rainforest trees were planted between these remnants, incorporating food plants to attract the target species. These "revegetated corridors" completed rainforest habitat connectivity between the main rainforest blocks, the disturbed remnant rainforest patches, and the underpasses. "Corridors" were designed to funnel animals towards underpass entrances and varied in width from about 10m at the underpass entrance to about 50m near rainforest remnants. Trees were planted at 3-m spacings. Erosion control revegetation works on the cut-and-fill embankments incorporated low plants that were less attractive forage and cover for rainforest animals.

Target species

The furniture of the underpasses and associated revegetated corridors were designed to encourage multi-species' use by provision of cover and escape routes from predators and by simulation of rainforest floor habitat. However, two species of conservation significance were carefully considered. The first was the rare Lumholtz's Tree-kangaroo (fig. 3) because of the threat posed to the species by road kill and the known hotspot of mortality at the underpass sites. Adult individuals weigh up to about 8kg, and juveniles disperse through cleared habitat between rainforest fragments. The second was the endangered Southern Cassowary (fig. 3) because road kill is recognized as a threatening process for the species which is estimated to have a total population of less than 1,000 animals remaining. Cassowary presence in the area was confirmed during pre-construction fauna surveys. The large flightless birds reach 1.5–2m in height. Both species are also subject to dog attack, which is considered to be a threatening process. Cassowaries can move easily and quickly through the tunnel using the clear central pathway, whereas tree-kangaroos can escape from dogs using the escape poles.

Pre-construction data collection

Road kill monitoring: For twelve months prior to construction, two 0.5-km road transects were surveyed weekly for road kill by walking on either side of the road. Traffic volume on the road was approximately 600 vehicles/day. Vertebrates were identified to species *in situ* or laboratory.

Figure 3. Lumholtz's Tree-kangaroo (left) and Southern Cassowary (right).
(Photos by Jonathon Munro, Doug Clague)

Small mammal habitat use: Between July and November 2000, small mammals were trapped monthly over three or four consecutive nights in two replicate sites of each of four habitats: abandoned pasture; pasture overrun by the woody weed, *Lantana camara*; rainforest on the edge of the north and south main rainforest areas; and interior rainforest more than 100m from the edge. At each site traps in a grid comprising 20 Elliot aluminum boxes placed at 5-m intervals and two 45 x 20 x 15-cm cages were baited with a mixture of rolled oats, vanilla essence, peanut butter, and honey. Animals were identified to species, weighed, sexed, marked with metal ear tags, and released at point of capture.

Post-construction monitoring methodology

Road kill monitoring: After construction was completed, weekly monitoring by walking continued on adjusted 0.5-km road kill transects. Two similar 0.5-km transects were established along a narrow rainforest highway carrying similar traffic volume (800 vehicles/day) and passing through similar rainforest habitat in the same north-south corridor, but 5km to the north.

Sand-tracking and camera trapping: Underpass use was monitored weekly by recording animal tracks in a 1-m-wide strip of fine sand 5cm deep placed across the centre of each of the three underpasses from one side to the other. Tracks were identified to species where possible or species group in the case of rodents and other groups having similar tracks. Each discrete track was recorded as one use by a taxon, and only one track per week for each species was used in data analysis of species composition. Track monitoring was complemented by occasional use of infrared-triggered digital cameras (Faunatech 110) to confirm identifications.

Corridor use by small mammals: In 2004, after three years growth, corridor trees were between 3m and 6m in height. However, rainforest understorey and ground layers had not yet established, leaving a relatively bare soil surface. Between May and August 2004, small mammals were trapped in three replicates of three habitat types using grids of 22 traps at interior and edge rainforest similar to the pre-construction trapping scheme. Each of the three corridors was divided into two sub-sites – one at the northern entry to the underpasses and one to the south. Grids of ten Elliot traps and one wire cage trap were established in each of the six sub-sites.

Corridor use by birds: Birds were point-censused at each of the nine sites in September 2004. Each site was visited once in the morning between 6am and 9am and once on a different day in the afternoon between 3pm and 6pm. Data were collected from the centre of the small mammal trapping grid over a 20-min period with all birds seen or heard within a 20-m radius being recorded. Birds were assigned to habitat guilds (rainforest, mixed habitat, grassland species and raptors) according to Crome et al. (1994) with data pooled over observation periods.

Data analysis: Road kill data were compared between years and highways for vertebrate groups and habitat guilds using chi-squared tests of homogeneity with Monte Carlo estimation (Lange 1997). Similar tests compared habitats for species composition of birds and small mammals. Kruskal-Wallis nonparametric analysis of variance examined abundance of small mammal species with comparisons performed using Mann-Whitney U-tests. Abundances of rainforest and non-rainforest bird groups were compared between habitats using analysis of variance. Underpass use data from June 2002 to November 2004 was divided into five six-month sampling periods according to wet (Dec-May) and dry (Jun-Nov) seasons and temporal variations compared using homogeneity tests. Relationships between presence of feral and native species were examined by correlation.

Rope Tunnel Arboreal Overpass

Study area

In 1995, a canopy bridge was erected 7m above a narrow (7m clearing) unsealed road carrying very low traffic (mean 4.2 vehicles/day) through highland rainforest 30km southwest of Cairns (fig. 1). The site chosen had no natural canopy connections across the road for 120m in one direction and 50m in the other (Weston 2000). The bridge was constructed in the style of a 50-cm wide x 50-cm deep rope tunnel made of 10-mm silver rope held taut with plastic spacers and attached to wooden poles erected amongst the trees on the road edge The total span of the overpass is 14m (fig. 4a). The tunnel design was used to offer protection from aerial predators. Several short ropes lead from the ends of the tunnel to trees near the support poles. This structure was erected as a collaborative effort by the Queensland Parks and Wildlife Service with assistance from the Far North Queensland Electricity Board using funding from the Wet Tropics Management Authority, but its effectiveness was not monitored until early 2000. In 2000, a single strand of rope was also erected nearby for a short period.

Figure 4a. Rope tunnel arboreal overpass.

Figure 4b. Rope ladder arboreal overpass over two-lane sealed tourist road.

Target species

The main target species for both the rope tunnel and ladder overpasses were the rainforest ringtail possums (fig. 5), including the Lemuroid ringtail possum (*Hemibelideus lemuroides*), the Herbert River ringtail possum (*Pseudochirulus herbertensis*), and the Green ringtail possum (*Pseudochirops archeri*). All three species have an adult weight of between 0.8-1.5kg and have a conservation status of rare (Queensland Nature Conservation (Wildlife) Regulation, 1994). The Lemuroid ringtail possum is highly vulnerable in fragmented forests, as it is an obligate arboreal species, never descending to ground level (Wilson 2000). The Herbert River ringtail possum also very rarely descends to the ground. Roads, therefore, constitute a severe barrier to movements of both of these species, with canopy connections over the road as the only means of movement across the road. Effective arboreal overpasses could provide a solution to the road barrier. Other less obligate arboreal species that could benefit from effective overpasses include several that suffer high levels of road kill, such as the Coppery brushtail possum (*Trichosurus vulpecula johstoni*) and the Striped Possum (*Dactylopsila virgata*), as well as a group of little-known species including the Long-tailed pygmy possum (*Cercartetus caudatus*) and an arboreal rodent (*Pogonomys mollipilosus*).

Figure 5. Target possum species for rope tunnel and ladder overpasses: left – Green ringtail, centre – Herbert River ringtail, right – Lemuroid ringtail. (Photos by WTMA, Mike Trenerry)

Monitoring methodology

Scat collection and hair analysis: A 1-m-wide net of fine mesh designed to intercept scats dropped by arboreal animals was installed under the rope tunnel overpass for several days each month from January to October 2000 and permanently from August to October 2001. Scat source was identified from gross morphology and presence of grooming hairs by an expert in trace analysis. Sections of self-adhesive double-side tape were fixed around the rope to collect hair, which was then identified by the expert using external morphology and microscopic transverse sections.

Remote photography: A passive infrared-triggered camera (Foresite Buckshot 35A or Foresite Bucshot RTV) with red filter to mask the camera flash was periodically installed inside the entrance to the rope tunnel between January and October 2000.

Direct observation by spotlighting: Between July 2000 and February 2002, 40 hours of spotlighting (30W, red filter) were undertaken over 10 randomly selected nights in both wet and dry seasons where any animal using the structure was recorded. Spotlighting observations of animals using natural canopy connections or the edge of the forest were also obtained by walking along both sides of the road.

<u>Rope Ladder Arboreal Overpasses</u>

Study area

Two 10-m-long arboreal overpasses of a less elaborate design than the tunnel were erected over a narrow forestry track in 2000. One emulated the dimensions of the top surface of the tunnel, i.e., 50cm wide. A second was half the width of the existing bridge, i.e., 25cm wide, and resembled a rope ladder. In 2001, this rope ladder was lengthened and erected 7.5m above a sealed two-lane tourist road that carries about 150 vehicles/day through highland rainforest (fig. 4b). All rope ladder overpasses were constructed of "silver" rope and were attached to robust trees, the first two about five meters above ground level with a span of seven or five meters between trees, respectively, in an area where canopy connections provided an alternative route for movement of arboreal species. The distance between trees for the rope ladder overpass above the tourist road was 14m, and the nearest natural canopy connections were more than 200m distant in either direction. A heavy rope held the bridge taut and led into the forest from the support trees.

Monitoring methodology

Remote photography and 40- (forestry track) or 70-hr (sealed tourist road) spotlighting observations were undertaken. For the rope ladder over the sealed road, nets could not be used, so scat collection used funnels of wire mesh funneled into a PVC pipe collector, placed in Sep 2001 and removed in Oct or Dec 2001. Hair samples were obtained between August and November 2001 using a curtain consisting of a wire frame of 55cm diameter draped with double-sided tape and attached centrally to the bridge with tie wire so that animals using the overpass had to pass through or over it, thus brushing against the tape (Weston 2003). Animals moving across the sealed road overpass were captured on video opportunistically.

Results

Faunal underpass project

Road Mortality
Table 1 summarizes mammal, bird, reptile, and amphibian mortality of species native to rainforest, mixed, or grassland habitats on the upgraded road in the 12 months before construction and the two years post construction. Numbers in each vertebrate group killed on the narrow rainforest highway 5km to the north for the two years post upgrade are also included. Vertebrate road mortality was always much greater on the rainforest highway than on the upgraded road (174, 270 vs 56, 43, respectively, for the two years post-construction).

Prior to construction, feral and grassland species were the most common amphibian casualties on the narrow road with rainforest species almost absent. Grassland amphibian casualties declined post upgrade. Feral and grassland species also dominated the amphibian statistics on the rainforest highway to the north, although rainforest species were more abundant there than on the upgraded road. In contrast, reptiles, birds, and mammals from rainforest habitats dominated the statistics for those groups on the rainforest highway. However, rainforest species from these groups were uncommon on the upgraded road. The exception occurred during the first year after upgrade when rainforest birds became a more common casualty on the upgraded road. However rainforest bird mortality declined thereafter. Feral predators (dogs/cats) never featured in the statistics.

Composition of vertebrate groups in the mortality statistics changed over the three sampling periods along the upgraded road (X^2=41.467, df=6, P=0.000) due to a significant decrease in the proportion of amphibians and the concomitant increase in the proportion of birds in the first year post upgrade, followed by an increase in the numbers of mammals in the second year. Habitat preferences of road victims also changed due to the decrease in grassland species (particularly amphibians) and the increase in rainforest species (particularly birds), in the first year post upgrade and the increase in feral species (particularly mammals) in the second year (X^2=38.959, df=6, P=0.000). Proportionally, more rainforest species and fewer grassland and feral species were killed on the rainforest highway to the north than on the upgraded road (X^2=37.955, df=9, P=0.000).

Table 1. Road mortality monitoring for 12 months prior to road upgrade and two 12-month periods after road upgrade at upgraded road and highway 5km to north.

Group	**Upgraded road**			**Rainforest Highway**	
	Pre-upgrade	**1 year post-upgrade**	**2 years post-upgrade**	**1 year post-upgrade**	**2 years post-upgrade**
Amphibia	**62**	**28**	**17**	**87**	**123**
Rainforest	1	1	-	13	7
Mixed	2	-	-	2	-
Grassland	23	4	1	25	56
Feral	20	23	16	31	60
Unidentified	16	-	-	16	-
Reptiles	**1**	**1**	**2**	**22**	**26**
Rainforest	1	1	1	17	19
Mixed	-	-	-	1	4
Grassland	-	-	1	-	1
Feral	-	-	-	1	-
Unidentified	-	-	-	3	2
Birds	**5**	**21**	**12**	**42**	**78**
Rainforest	2	17	6	39	61
Mixed	1	3	4	2	17
Grassland	1	1	-	1	-
Feral	-	-	2	-	-
Unidentified	1	-	-	1	-
Mammals	**2**	**6**	**12**	**23**	**43**
Rainforest	2	5	3	6	26
Mixed	-	1	1	3	2
Grassland	-	-	-	-	-
Feral	-	-	7	1	1
Unidentified	-	-	1	13	14
Total	70	56	43	174	270

Habitat Use by Small Mammals

Ten mammal species were captured during the trapping periods prior to road upgrade (2000) and after three years of revegetated corridor growth (2004). Three rainforest species dominated in the forest interior (94.1%, 96.7%) and edge forest (91.1%, 85.7%) during both trapping periods (fig. 5). Two rainforest species (87.3%) also dominated in the lantana habitat prior to road construction. The dense canopy afforded by this woody weed provided habitat for these less specialised rainforest species, although a few grassland individuals were also recorded there. In contrast, before the road was constructed the abandoned pasture habitat was dominated by three grassland (44.7%) and one feral (31.9%) species (fig. 5) with a few rainforest individuals found in small clumps of lantana scattered through the grass. During the 2000 trapping phase no tagged rainforest individuals crossed the road and abandoned pasture. After three years of tree growth in the revegetated corridors, the habitat was dominated by one feral species (the house mouse, *Mus musculus* – 48.6% of individuals), which was undergoing a population explosion in the area (fig. 5). However, a rainforest species that prefers the rainforest edge was also very common (36.9% of individuals), and only 9.9 percent of individuals were from three grassland species, demonstrating that the canopy in the corridor had greatly reduced the dominance of species preferring this habitat type. Species composition in the revegetated corridors was significantly different from that found in the forest edge (X^2=45.615, df=8, P=0.000) and interior (X^2=80.536, df=9, P=0.000), whilst species composition in edge and interior were similar. Abundances of non-rainforest individuals were significantly greater in the revegetated corridors than in the rainforest edge (Mann-Whitney U test P=0.001) and interior (P=0.000), whereas abundances of rainforest individuals were not significantly different between habitats. None of the captured small mammals was recorded as having crossed the road.

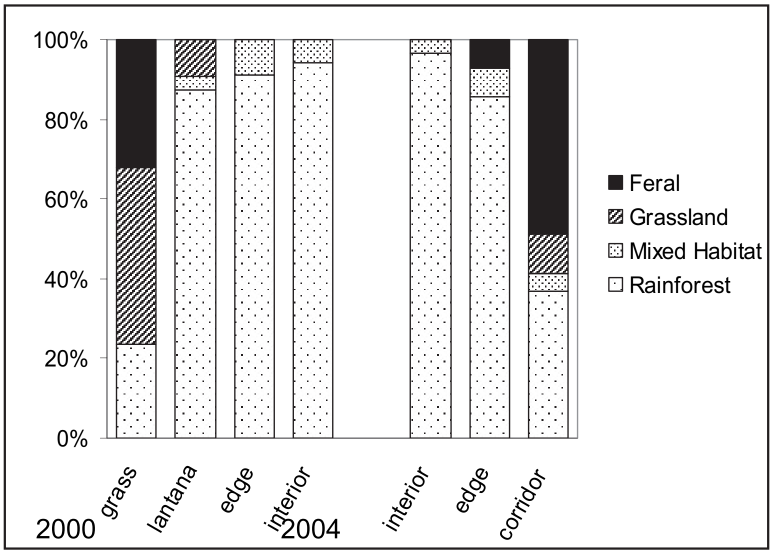

Figure 5. Use of habitats by rainforest, mixed habitat, grassland, and feral small mammals prior to road upgrade (2000) and after three years of growth of planted wildlife corridor (2004).

Corridor Use by Birds

Thirty-nine species were recorded using the planted corridors, edge, and interior rainforest, the majority of which were birds of rainforest habitats (27) with mixed habitat (9), raptors (2) and grassland species (1) less prominent. The rainforest edge was richest in species (29), with the rainforest interior (26) and revegetated corridors (25) having slightly reduced species richness. There was no significant difference in species composition between the three habitats (X^2-test), with all habitats dominated by rainforest species (fig.6). The revegetated corridors recorded the greatest proportion of mixed habitat species (36%) and lowest proportion of rainforest dependent species (52%), compared with 28 percent and 66 percent, respectively, at the rainforest edge and 19 and 81 percent, respectively, in the forest interior. However, this trend of greater guild diversity in the revegetated corridors was not significant. There were no significant differences in abundance of rainforest or non-rainforest birds across the three habitats (ANOVA P>0.15)

Use of Underpasses

Data obtained from sand-traps showed a variety of faunal groups using the underpasses (fig. 7). Two of the common species are rainforest dependent. The majority of the other groups comprised rainforest and mixed habitat species that could not be separated by tracks alone.

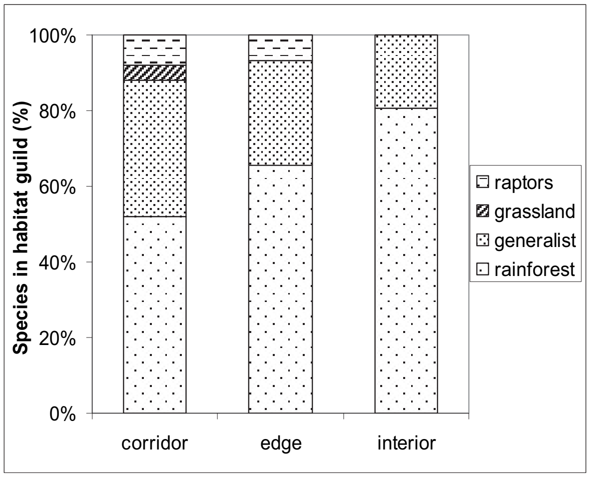

Figure 6. Use of habitats by rainforest, mixed habitat, grassland birds, and raptors after 3 years of growth of corridor trees (2004).

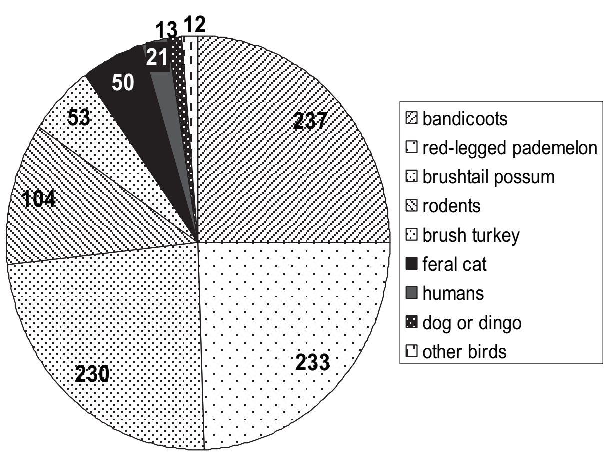

Figure 7. Sand-trapping records of use of underpasses by common faunal groups.
Note: Red-legged pademelon and brush turkey are rainforest species. The majority of recorded bandicoot, brushtail possum, rodents and other birds would be from rainforest with occasional individuals of mixed habitat species or possible grassland rodents

However, based on the proportion of rainforest species captured or observed during fauna surveys and the species identified during camera trapping (fig. 8), the majority of these are likely to be rainforest species. Even in the rodent group, for which trapping captures would suggest feral species predominated, the size of tracks suggested that these could only be rainforest or grassland species, as tracks of the feral house mouse tracks are too small to be recorded in the sand. Seasonal variations in use of underpasses were observed (X^2=31.755, df=20, P=0.046) and may demonstrate seasonal peaks in dispersal or breeding. Non-native species' use was relatively low (mean 13 tracks per 6 months) compared with native species' use (mean 164 tracks per 6 months). Feral predator (cat, dog/dingo) use varied with season (X^2=14.273, df=4, P=0.006), but no correlation was recorded with use of underpasses by native species overall or any of the common native species groups (P>0.25). Native and non-native species, including predators, regularly use the underpasses and also use the underpasses concurrently, either on different days, or at different times. Tracks of both have been recorded in all but three weeks over the three years. Only once has there been any sign of predation near an underpass.

Figure 8. Infrared-triggered digital camera photographs of underpass use. Left – pademelon, center – brushtail possum, right – brown bandicoot.

Target Species
The underpasses have been used on at least two occasions by the target Lumholtz's tree-kangaroo. One complete crossing was verified by following footprints from one entrance to the other. The species is often observed in trees near underpass entrances. The Southern Cassowary has yet to use an underpass, having become exceedingly rare in the area. However, on one occasion a bird was observed attempting to climb through fencing recently erected at an underpass entrance to deter cattle from resting in the tunnel.

Rope tunnel and ladder arboreal overpasses
Table 2 shows species recorded using the various crossing structures. After five years of habituation prior to monitoring, the rope tunnel was used by all target species. Use of the single rope strand over the 7-m road clearing was inconclusive without any direct or photographic evidence. Natural canopy connections above the narrow track were preferred over the 5- to 7-m spans of the narrow and wide rope ladders. However, where no canopy connections occurred nearby, the narrow rope ladder over the sealed tourist road was used by the majority of species. Fig. 9 shows a selection of animals using either rope tunnel or ladder style overpasses.

Table 2. Species identified as using the rope tunnel and ladder overpasses.

Species	Rope Tunnel 7m clearing	Rope single strand near tunnel 7m clearing	Wide rope ladder, canopy connections 7m span*	Narrow rope ladder, canopy connections 5m span*	Narrow rope ladder Sealed road 14m span
Lemuroid ringtail Possum	scat, photo, spotlighting	Scat	Scat	Scat	Spotlighting, scat
Herbert R ringtail possum	scat, photo, spotlighting	Scat	Scat, photo	Scat	spotlighting
Green ringtail possum	Photo		Scat	Scat	
Coppery brushtail possum		Scat, hair		Scat	Photo, hair, spotlighting,
Striped possum	Photo				spotlighting
Long-tailed pygmy possum				Scat**	
Lumholtz's Tree-kangaroo			Scat	Scat, hair**	Hair*
Fawn-footed melomys	scat, photo		Scat	Scat	

*As canopy connections were present, scats may have fallen from above the overpasses.
**These scat and hair samples were not from the centre of the overpass, so the species may not have crossed.

Target Species
All target rainforest ringtail possums have been observed using at least one of the structures (table 2). Additionally, species including brushtail and striped possums that are common in road mortality statistics have also been observed to use at least one of the structures. Use of the rope ladder overpass over the sealed tourist road is now common, with approximately one animal per hour now observed crossing. Multiple individuals of Lemuroid and Herbert River ringtail possums are also known to be prepared to use the same rope ladder overpass, verified by different coat patterns in Herbert River ringtail possums and individuals from different size/age classes of Lemuroid ringtail possums.

Figure 9. Ringtail possums using arboreal overpasses: left and right – Lemuroid and Herbert River ringtail possums on 14-m-span rope ladder over a sealed tourist road; center – Green ringtail possum in a rope tunnel over 7-m-wide unsealed road clearing.

Discussion

These studies have demonstrated the effectiveness of several structures for provision of connectivity above or below roads for rainforest fauna. Road mortality has remained low near the underpasses and many species are using both underpasses and overpasses. However, it must be recognized that natural connections rather than artificial structures are always preferred by rainforest species (Weston 2003), so avoidance of rainforest habitat should be considered the best option when considering road upgrading or new road construction (Goosem 2004). Where avoidance of rainforest is impossible, these mitigation methods have proven to be successful for many rainforest species including specialized rainforest species that avoid the open, disturbed spaces of road clearings.

Faunal underpasses

Use of underpasses and rainforest corridors
Not all terrestrial wildlife species found in these forests have been shown to use the underpasses. There are several potential explanations. The lack of sufficient time for habituation to the structures or the establishment of suitable rainforest habitat in the corridors is one explanation. Small mammal trapping in the corridors demonstrated that several mammal species require further tree growth and establishment of understorey and ground layer before colonization of the corridors is likely to occur and competition eliminates the feral and grassland species. Several years of habituation may be required prior to use of crossing structures (Clevenger and Waltho 2003) with long monitoring periods required to capture sufficient data and variability to provide satisfactory sampling of changing conditions (Hardy et al. 2003). The faunal

underpasses have now been monitored weekly for four years, with one generalist rainforest species commencing use of the structures within a week of their completion and two other groups appearing within four to six weeks. Abundance of individual tracks has increased in that time, together with increasing species richness. However, in the past year, the number of mammal species known to have used the underpass has remained relatively static (J. Munro pers. obs.), although the numbers of bird species observed flying through the tunnels continues to increase. It is proposed to continue underpass monitoring for at least another year and to again examine corridor community composition after a further period of growth.

Alternatively, failure to detect several terrestrial mammal species may be a function of rarity or our inability to distinguish them from others. Fauna surveys and trapping confirm that each of the missing species is very rare in the area and, therefore, may not have used the underpasses due to their low abundance. Also, distinguishing small species from more common mammals is difficult using sand tracking, and the complementary photography may be insufficient to capture rare species. It is planned to increase the use of photographic methods at the underpasses during the next 12 months. Fine-scale tracking methods, such as marble dust (Mata et al. 2003) or soot boards (Hardy et al. 2003), may also be trialed.

A third possibility is that the corridors are not wide enough (Laurance and Laurance 1999) and may consist entirely of edge habitat which fragmentation-sensitive species will not colonise. Restoration corridors already planted in the region, however, suggest that this is not the case for the majority of rainforest species (Simmons and Tucker 2002). Nevertheless, the species most vulnerable to fragmentation, such as the rare arboreal possums, seemingly remain fragmented with no records of attempted road or underpass crossings. For these species with strict habitat specialisations, it has been suggested that corridors should be floristically diverse and at least 30-40m in width (Laurance and Laurance, 1999). This would require further corridor plantings to close canopy gaps, particularly near underpass entrances, and also extend the width of the corridors (Bushnell 2004). For arboreal species, a rope bridge overpass may also be installed once trees attain sufficient height.

A fourth alternative is that the cover provided within the crossing structures may be insufficient to encourage habitat specialists to venture under the road, and the structures may not be used in their current form. Factors such as traffic noise and headlight disturbance of nocturnal species at underpass entrances may also restrict use of the structures. Traffic noise levels are known to be very high at the underpass entrances when large trucks pass by (Goosem et al. 2004). Encouraging greater growth of corridor plants near entrances may reduce such disturbance.

Many authors have demonstrated that wildlife can be selective in their choice of crossing type (Mata et al. 2003, Clevenger and Waltho 2003) and suggest that a variety of underpass designs are complementary for multi-species use. Some species, particularly large mammals, prefer open structures, such as ecoducts, and high, wide, short underpasses, while others prefer more constricted crossing structures and favor underpasses (Clevenger and Waltho 2005). In this study, the initial proposal was to include a range of small underpasses together with a larger structure because Australian rainforest fauna is generally small in size. However, in consideration of one target species, the 1.5- to 2-m-tall Cassowary, it was decided to design and construct larger structures that could be used by this endangered species. To encourage multi-species use and yet maintain the project within financial constraints, we simulated the forest floor within the underpasses as far as possible, and provided a range of cover and escape options for smaller species and those subject to predator harassment. The strategy appears to have been successful, as mammals and birds encompassing a range of sizes and levels of shyness have used the underpasses. However, the possibility remains that species yet to use the underpasses simply have not been provided with their preferred conditions within the crossing structures. This is certainly the case for the arboreal possums, which have not been observed within or near the underpasses. When it was decided to build large underpasses, consideration was given to installing smaller pipes within the underpasses for small species, if it was found that they do not use underpasses once the rainforest corridor understorey and ground layers have become established. This would be similar to the “vole tube” described by Foresman (2003).

Target Species

Lumholtz’s tree-kangaroo, one of the target species for the study, has been observed to use the underpasses twice and is often seen in trees near the entrances. The area which was previously a hotspot for tree-kangaroo mortality has also recorded one instance of road kill of the species, although this did not take place near the underpasses or the mortality transects. Insufficient time has elapsed to determine whether this reduction in road kill rate is significant. One cassowary (of very few remaining in the area) has been observed trying to reach an underpass but was deterred by fencing erected to repel cattle from resting there. This fencing can be removed now that cattle have been removed from the area.

Predators vs. Prey

An interesting aspect of this study was the finding that the occasional presence of feral predators did not appear to influence use by native species (Hunt et al. 1987, Little 2003). There was no correlation between use by any or all native species and the presence of cats or dogs/dingos. The inclusion of various strategies for escape from predators including rocks and logs for cover and poles for escape from dogs may have contributed to this result. Feral predators are considered most likely to pose a problem (Little 2003), as native prey have not co-evolved with these species and could be more susceptible to predation at passages because of failure to detect and avoid signs of predators. This was shown not to be the case. Native predators also have used the underpasses, including an owl roosting on the rope and snakes sunning themselves in the underpass entrances, and feral cats have twice sheltered from rain, but in no instance has underpass use been prevented. There has also been no evidence that the passages comprise traps for prey (Hunt et al. 1987) with only one observation of predation occurring near the underpasses.

Rope bridge arboreal overpasses

Canopy connectivity for obligate arboreal species was provided by the 14-m rope ladder style overpass in an area that did not have other canopy connections. This structure was used by different individuals of the same species and by multiple species, seven mammals in all. The majority of individuals observed using the initial tunnel design actually crossed along the top surface of the structure, prompting simplification of the design to a rope ladder for further trials. More than five months elapsed after construction of the rope ladder overpass over the tourist road before any possum species were photographed on the structure, and another six weeks passed before a target animal was spotlighted crossing the road via the structure (Weston 2003). Although this period of habituation was required, crossing events then became common. Crossing rates have risen to a current level of around one every hour.

Although a single thick rope structure was trialed, results were inconclusive, and the stability afforded by the rope ladder design, together with added safety, suggests that this easily affordable design is preferable. Safety aspects for wider highways suggest attachment to poles with concrete footings rather than attachment to trees. However, durability of the structures themselves is excellent. After 10 years, the original rope tunnel design made of silver rope with a high UV rating is showing little sign of decay, even without any maintenance.

Arboreal overpasses have been installed elsewhere in Australia, based on the designs shown to be successful in rainforest habitats. These are generally much longer structures than those we have monitored to date. The tree density of the forests which these new installations link is much more open than rainforest systems, so resident possums and gliders are expected to be less dependent on canopy cover and thus may be more prepared to move across the clearing using the arboreal overpasses. Little monitoring of these longer structures has been undertaken to date. However, a 70m-long tunnel-design overpass (fig. 10) has been monitored irregularly with digital infrared photography, and brushtail possums appear to be regular users (D. Bax pers. comm.). A glider has also been photographed. Rope ladder-style structures have been erected in Brisbane, Queensland, across a road dividing an urban habitat corridor (fig. 11). Monitoring will commence soon.

Figure 10. 70m-long tunnel-style overpass erected in open forest habitat near Newcastle, NSW. Brushtail possum using the interior of the structure. (Photos by David Bax)

Figure 11. 60m-long rope ladder-style arboreal overpass erected in open forest habitat in Brisbane, Queensland. (Photos by Pauline Fitzgibbon)

Our current research focus is on whether arboreal rainforest fauna will also use longer rope overpasses to cross highways. Ringtail possums are being radio-tracked to determine home ranges and, in particular, road frontage of home range, to ensure that rope overpasses are accessible to the home ranges of several individuals. Animals using adjacent habitat will be tracked and any movements across the road determined. Translocations to determine whether animals will return to home ranges via the overpasses may also be attempted after sufficient time for habituation to the crossing structures. Overpasses will again be monitored by photography, spotlighting, and scat and hair sampling.

Conclusions

Use of underpasses or overpasses is not necessarily proof that the structure of faunal populations has been sufficiently re-connected to maintain populations on either side of a road. Population studies are crucial in determining whether sub-populations of a metapopulation connected by crossing structures are of sufficient size and/or receiving sufficient recolonising individuals from other sub-populations to maintain themselves. However, such studies require a long-term financial commitment to provide in-depth information regarding survivorship, recruitment, and dispersal of juveniles, physical condition, short-term and long-term reproductive rates, sex ratios, and genetic exchange (Hardy et al. 2003). Information demonstrating isolation of populations resulting in reduced breeding opportunities, skewed sex ratios, decreased fitness and reduced probability of population survival takes many years to collect and is generally outside the levels of financial support supplied by road management agencies in Australia. However, evaluation of usage and road mortality by a relatively cheap monitoring system can provide a good indication of effectiveness, particularly if monitoring continues in the long term. Such studies provide answers to the most basic question posed by Hardy et al. (2003): Do crossing structures reduce mortality and allow animals to move safely across roads? If long-term monitoring demonstrates frequent use by a variety of wildlife and low mortality rates, the wildlife passages should at least be helping locally to preserve those species by connecting habitats and thereby restoring home ranges, genetic exchange, and the potential for recolonisation after catastrophes. These studies have demonstrated this for common rainforest terrestrial species and also for rare arboreal species. Longer-term monitoring is required to determine whether species which have not been recorded using the artificial crossing structures are actually displaying some sort of innate avoidance behavior and whether their exclusion will result in some form of long-term flow-on effect in ecosystem function.

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Nigel Weston is a research road ecologist within the Rainforest CRC sustainable linear infrastructure project at JCU, Cairns, whose master of science study investigated the mitigatory potential of rope tunnel and ladder overpasses for arboreal rainforest fauna. He is currently engaged in extending this work to encompass larger highways with Dr. Robyn Wilson undertaking distribution studies.

Sally Bushnell is a master's student of natural resource management at JCU, Townsville. Her master's project in the Rainforest CRC examined the effectiveness of faunal underpasses and associated revegetated corridors in mitigating road mortality and providing connectivity for rainforest fauna.

References

Aresco, M. 2003. Highway mortality of turtles and other herpetofauna at Lake Jackson, Florida, USA, and the efficacy of a temporary fence/culvert system to reduce roadkills. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp 433-449. North Carolina State University, USA.

Becker, H. and B. Iuell. 2003. Habitat fragmentation due to infrastructure: A European review on habitat fragmentation, wildlife and traffic. – a handbook for identifying conflicts and designing solutions. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp1-14. North Carolina State University, USA.

Bushnell, S. 2005. The effectiveness of revegetation corridors and faunal underpasses: mitigating the effects of a road through fragmented highland rainforest. M.Appl.Sci, thesis, James Cook University, Townsville.

Clevenger, A.P. and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. In *2003 Proceedings of the International Conference on Ecology and Transportation*, eds. C.L. Irwin, P. Garrett. and K.P. McDermott, pp293-302. North Carolina State University, USA.

Clevenger, A.P. and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movements of large mammals. *Biological Conservation* 121:453-464.

Crome, F., J. Isaacs and L. Moore. 1994. The utility to birds and mammals of remnant riparian vegetation and associated windbreaks in the tropical Queensland uplands. *Pacific Conservation Biology* 1:328-343.

Foresman, K. 2003. Small mammal use of modified culverts on the Lolo South project of western Montana. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp 342-343. North Carolina State University, USA.

Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine and T.C. Winter. 2003. *Road ecology: science and solutions*. Island Press, Washington, DC. 481pp.

Foster, M.L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida panther and other wildlife. *Wildlife Society Bulletin* 23: 95-100.

Goosem, M. W. (1997). Internal fragmentation: the effects of roads, highways and powerline clearings on movements and mortality of rainforest vertebrates. In *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities*. Edited by W.F. Laurance and R.O. Bierregaard Jr. pp 241-255. University of Chicago Press, Chicago.

Goosem, M.W. (2000). Impacts of roads and powerline clearings on rainforest vertebrates with emphasis on ground-dwelling small mammals. PhD thesis. James Cook Uni. 313 pp.

Goosem, M. 2001. Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. *Wildlife Research* 28, 351-364.

Goosem, M. 2003. Effectiveness of East Evelyn faunal underpasses. In *Proceedings of the National Environment Conference*, 2003, edited by R. Brown and C. Hanahan. pp 200-205.

Goosem, M. 2004. Linear infrastructure in tropical rainforests: mitigating impacts on fauna of roads and powerline clearings. In *Conservation of Australia's forest fauna*, edited by D. Lunney, pp 418-434. Royal Zoological Society of NSW, Mosman, NSW.

Goosem, M., C. Harriss, G. Chester and N. Tucker. 2004. Kuranda Range: applying research to planning and design review. Report to the Queensland Department of Main Roads. Rainforest CRC, Cairns.

Goosem, M., N. Maver and S. Turton. 2005. Success of ecological rehabilitation in reducing edge effects on rainforest microclimate and vegetation along a powerline clearing. *Austral Ecology* submitted.

Goosem, M., Y. Izumi and S. Turton. 2001. Efforts to restore habitat connectivity for an upland tropical rainforest fauna: A trial of underpasses below roads. *Ecological Management and Restoration 2*, 196-202.

Gordon, K. and S. Anderson. 2003. Mule deer use of underpasses in western and southeastern Wyoming. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp309-318. North Carolina State University, USA.

Hardy, A., A. Clevenger, M. Huijser and G. Neale, 2003. An overview of methods for evaluating the effectiveness of wildlife crossing structures. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp 319-330. North Carolina State University, USA.

Hunt, A., J. Dickens and R.J. Whelan. 1987. Movement of mammals through tunnels under railway lines. *Australian Zoologist* 24:89-93.

Izumi, Y. 2001. Impacts of roads and fragmentation on fauna on the Atherton and Evelyn Tablelands, North Queensland. M.Appl.Sci. thesis, James Cook University, Cairns. 146pp.

Kanowski, J., L. Felderhof, G. Newell, T. Parker, C. Schmidt, B. Stirn, R. Wilson and J.W. Winter. 2001. Community survey of the distribution of Lumholtz's tree-kangaroo on the Atherton Tablelands, north-east Queensland. *Pacific Conservation Biology* 7:79-86.

Kanowski, J. and N.I.J. Tucker 2002. Trial of shelter poles to aid the dispersal of tree-kangaroos on the Atherton Tablelands, north Queensland. *Ecological Management and Restoration* 3:137-138.

Lange, K. 1997. Mathematical and Statistical Methods for Genetic Analysis. Springer-Verlag, New York.

Laurance, S.G. and W.F. Laurance. 1999. Tropical wildlife corridors: use of linear forest remnants by arboreal mammals. *Biological Conservation* 91:231-239.

Little, S. 2003. The influence of predator-prey relationships on wildlife passage evaluation. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp 277-292. North Carolina State University, USA.

Mansergh, I. and D. Scotts. 1989. Habitat and social organization of the mountain pygmy possum restored by tunnel. *Journal of Wildlife Management* 53:701-701.

Mata, C., I. Hervas, J. Herranz, F. Suarez, J.E. Malo and J. Cachon. 2003. Effectiveness of wildlife crossing structures and adapted culverts in a highway in northwest Spain. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp 265-276. North Carolina State University, USA.

Pohlman, C., S. Turton and M. Goosem. 2005. Edge effects of linear canopy openings on tropical rainforest understorey microclimate. *Biotropica* submitted.

Siegenthaler, S., B. Jackes, S. Turton and M. Goosem. 2000. Edge effects of roads and powerline clearings on rainforest vegetation. In *Impacts of roads and powerlines on the Wet Tropics World Heritage Area II*, edited by M.W. Goosem and S.M. Turton, pp 46-64. Rainforest CRC, Cairns.

Siegenthaler, S. and S. Turton. 2000. Edge effects of roads and powerline clearings on microclimate. In *Impacts of roads and powerlines on the Wet Tropics World Heritage Area II*, edited by M.W. Goosem and S.M. Turton, pp 20-43. Rainforest CRC, Cairns.

Servheen, C., R. Shoemaker and L. Lawrence. 2003. A sampling of wildlife use in relation to structure variables for bridges and culverts under I-90 between Alberton and St. Regis, Montana. In *2003 Proceedings of the International Conference on Ecology and Transportation*, edited by C.L. Irwin, P. Garrett. and K.P. McDermott, pp 331-341. North Carolina State University, USA.

Simmons, T. and N.I.J. Tucker. 2002. The rat's tale – use of small mammals as bioindicators in a restored forest linkage in far north Queensland. In: *Ecology 2002: Handbook of the 2nd Joint Meeting of the Ecological Society of Australia and the New Zealand Ecological Society*, edited by J. Landsberg, p141. Cairns, Australia.

Taylor, B. and R. Goldingay. 2003. Cutting the carnage: wildlife use of road culverts in northeast New South Wales. *Wildlife Research* 30:

Weston, N. 2000. Bridging the rainforest gap. *Wildlife Australia* 37:16-19.

Weston, N. G. 2003. The provision of canopy bridges for arboreal mammals: a technique for reducing the adverse effects of linear barriers, with case studies from the Wet Tropics region of north-east Queensland. M.Sc. thesis, James Cook University, Cairns. 180pp.

Weston, N., M. Goosem, H. Marsh and R. Russell. 2005. A review of new technologies aimed at reducing roadkill and restoring habitat connectivity, especially for arboreal mammals. *Landscape and Urban Planning* submitted.

Wilson, R. 2000. The impact of anthropogenic disturbance on four species of arboreal, folivorous possums in the rainforests of North-east Queensland, Australia. PhD thesis, James Cook University, Cairns. 313pp.

Yanes, M. J.M. Velasco and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71:217-222.