The provision of canopy bridges to reduce the effects of linear barriers on arboreal mammals in the Wet Tropics of northeastern Queensland.

Thesis submitted by

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NIGEL GRAEME WESTON

ABSTRACT

In 1995, Queensland Environmental Protection Agency personnel designed and built an inexpensive aerial connection (canopy bridge) across a rainforest road near Cairns in northeast Queensland. This was done in response to studies showing that habitat fragmentation caused by roads was isolating animal populations and impeding genetic interchange. Tree-dwelling species appeared to be particularly susceptible and it was reported that canopy connections were probably crucial for some rare species in the Wet Tropics. The canopy bridge was subsequently promoted by the Main Roads Department, among others, as a means of encouraging safe fauna movement across road corridors in the region. As the effectiveness of these had not yet been determined, it was recommended that canopy bridge trials be undertaken.

A review of the existing scientific literature and secondary sources revealed that the first bridge for arboreal mammals was built in 1963 in Longview, Washington State, United States, to promote the safe crossing of a busy highway by squirrels. Since then, crossing structures have been erected in at least ten countries. These range from simple ropeways to more elaborate structures. As of this writing, at least four canopy bridges are being trialed or considered for use in Australia.

The trials I conducted at the existing bridge near Cairns, using methods such as spotlighting, analyses of hair and faecal pellet samples and remote photography, demonstrated that at least five arboreal and scansorial mammal species were using it to cross the rainforest road. When it became clear that arboreal species were indeed using

the existing bridge as a crossing route, additional studies were initiated. These were designed to test whether design and position influenced usage of the bridges by arboreal mammals. Two simplified bridges were erected along an abandoned snig track near Millaa Millaa on the Atherton Tablelands. This decision was based on several factors including prior knowledge of arboreal mammal assemblages within the area and the presence of suitable vegetation. Another consideration was the narrow configuration of the track resulting in overlapping tree canopies that were unlikely to impede the movement of arboreal mammal species. The animals generally preferred to use the natural crossings with only two verified crossing events recorded.

One of the simplified bridges used over the snig track was subsequently removed, lengthened and installed along an old highway between Millaa Millaa and Ravenshoe on the Atherton Tablelands. The most important consideration in this instance was the configuration of the road corridor – it was of a sufficient width and length to represent a likely impediment or heightened risk for the movement of arboreal mammals. Although it took five months for a verified crossing event to occur, these events increased in frequency the longer the trial continued until they became commonplace. In total, 52 completed crossing events involving at least four arboreal mammal species were recorded over an 80-hour period. Thirty-five involved rainforest ringtails, 16 involved brushtails, one a striped possum and another an unidentified small mammal. This equates to a crude possum-crossing rate of one every 1.5 hours. However, the rate increases to approximately one possum-crossing every hour when the time between the bridge being installed and the first crossing event (presumably a period of familiarisation) is discounted and to just under three crossings per hour over the final twelve hours of direct observation at the site. It remains unclear how many individual animals made the crossing, although repeat sightings of the same individual were likely.

A constraint of this study was that replication was impossible due to financial and bureaucratic constraints. However, a pilot study such as this was needed to provide insight before a more large-scale highly replicated study could be attempted. The study showed that arboreal and scansorial mammals would use canopy bridges to cross roads in the Wet Tropics region, especially where no canopy connectivity remains. It could therefore be argued that the conservation of some arboreal species would benefit from canopy bridges becoming a standard feature of road design. Canopy bridges could also become tourist attractions and raise community awareness about the dual problem of roadkill and habitat fragmentation. In this way, canopy bridges have the potential to pay an important role in the presentation and transmission of World Heritage values in the Wet Tropics.

Keywords: canopy bridge, arboreal mammals, roads, Wet Tropics.

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Chapter 1: General introduction

CHAPTER 1: GENERAL INTRODUCTION

INTRODUCTION

Road corridors have considerable potential both as conduits of gene flow and as reservoirs of biodiversity in highly fragmented landscapes (Hobbs 1997; Major et al. 1999). This prompted Schullery (1987) to refer to the roadside as 'the longest meadow'. However, roads themselves have substantial adverse impacts on biodiversity, as do the vehicles that travel on them (Adam 1995). These adverse impacts include habitat loss and mortality caused by collisions with vehicles. Perhaps the most significant impact of roads is fragmentation of habitats (both terrestrial and aquatic) and wildlife populations (Saunders et al. 1987; Saunders & Hobbs 1991; Moritz & Kikkawa 1993; Trombulak & Frissell 2000).

When linear barriers such as roads inhibit faunal movements, subdivided populations may become increasingly prone to the loss of genetic variability and local extinction (Fahrig & Merriam 1985; Moritz et al. 1993; Simberloff 1993; Gerlach & Musolf 2000). Species most at risk are those with poor dispersal abilities, sedentary habits and specialised needs and those endemic to an area (Andrews 1990). Tree-dwelling mammals, particularly those that do not show a tendency towards moving across the ground, are considered especially vulnerable (Winter 1984, 1991; Andrews 1990; Laurance 1990, 1995, 1997; Valladares-Padua et al. 1995; Winter & Goudberg 1995a; WTMA 1997; Malcolm 1998; Wilson 2000).

The vulnerability of animals is of increasing concern to both wildlife managers and managers of road systems in Australia and around the world. In particular, authorities in the Wet Tropics region of northeast Queensland realise that the adverse effects of road corridors potentially threatens to degrade many of the outstanding natural universal values for which much of the area was inscribed on the World Heritage List. However, these effects can be ameliorated to some extent through innovative measures that incorporate new technologies to protect and manage wildlife.

THEORETICAL AND APPLIED RELEVANCE OF THE RESEARCH

Many studies have described attempts to assist terrestrial fauna to cross linear barriers such as roads (Mansergh & Scotts 1989; Clarke et al. 1998; Clevenger & Waltho 2000; Jones 2000; see also Leighton 1988). Most have involved the construction of underpasses and, to a lesser extent, overpasses (so-called 'green bridges'). Canopy bridges have been recommended for arboreal mammals (i.e., Scott 1988; Lyon & Horwich 1996) but few have been built and even fewer have had their efficacy documented. In 1997, the Queensland Department of Main Roads (QDMR) recommended trials to determine if canopy bridges are effective in reducing road kills and habitat fragmentation in the Wet Tropics region.

The Wet Tropics region extends some 450 km between Townsville and Cooktown on the northeast coast of Queensland (see **Figure 1.1**). It is an extraordinary strip of scenic country with high rainfall and pristine wilderness areas (Trott 1996). The topography rises from sea level to undulating plateaus at 800-900 m with isolated peaks, including Mt Bartle Frere, at 1622 m the highest mountain in Queensland (Trott 1996). Much of this region (about 894,000 ha) was inscribed on the World Heritage List of Natural Properties on 9 December 1988 in recognition of its outstanding universal values (WTMA 1992):

- as an outstanding example representing the major stages in the earth's evolutionary history;
- as an outstanding example representing ongoing geological processes, biological evolution and man's interaction with his natural environment;
- containing superlative natural phenomena, formations or features; and
- containing the most important and significant natural habitats where threatened species of animals or plants of outstanding universal value live.

The rainforests of the Wet Tropics region support nine genera of arboreal marsupials (i.e., *Cercartetus*, *Dactylopsila*, *Dendrolagus*, *Hemibelideus*, *Petaurus*, *Pseudochirops*, *Pseudochirulus*, *Pseudocheirus*, *Trichosurus*). Consequently, the area is home to the largest concentration of arboreal marsupials in Australia and this diversity was one of the reasons for World Heritage listing (Goosem 2000d). Additionally, several genera of semi-arboreal or scansorial marsupials and rodents (e.g., *Antechinus, Dasyurus, Melomys, Pogonomys, Uromys*) occur in rainforests in the area.

The habitat of these species appears to be secure because most of what remains is now within the WTWHA (see Strahan 1995). However, this assemblage contains species of special scientific or conservation importance that are susceptible to being killed on roads (e.g., Lumholtz's tree kangaroo, *Dendrolagus lumholtzi*, Goosem 2000a; Schmidt et al. 2000) as well as those that are reluctant to cross cleared gaps between rainforest fragments (e.g., the lemuroid ringtail possum, *Hemibelideus lemuroides*, Wilson 2000). Given that there are at least 1,427 km of roads and highways crisscrossing the WTWHA (Goosem 1997), these effects may threaten the long-term survival of some arboreal species (Schmidt et al. 2000). This is compounded by other threatening processes such as the impacts of tourism, land clearing on private land and global warming (Wilson 2000).

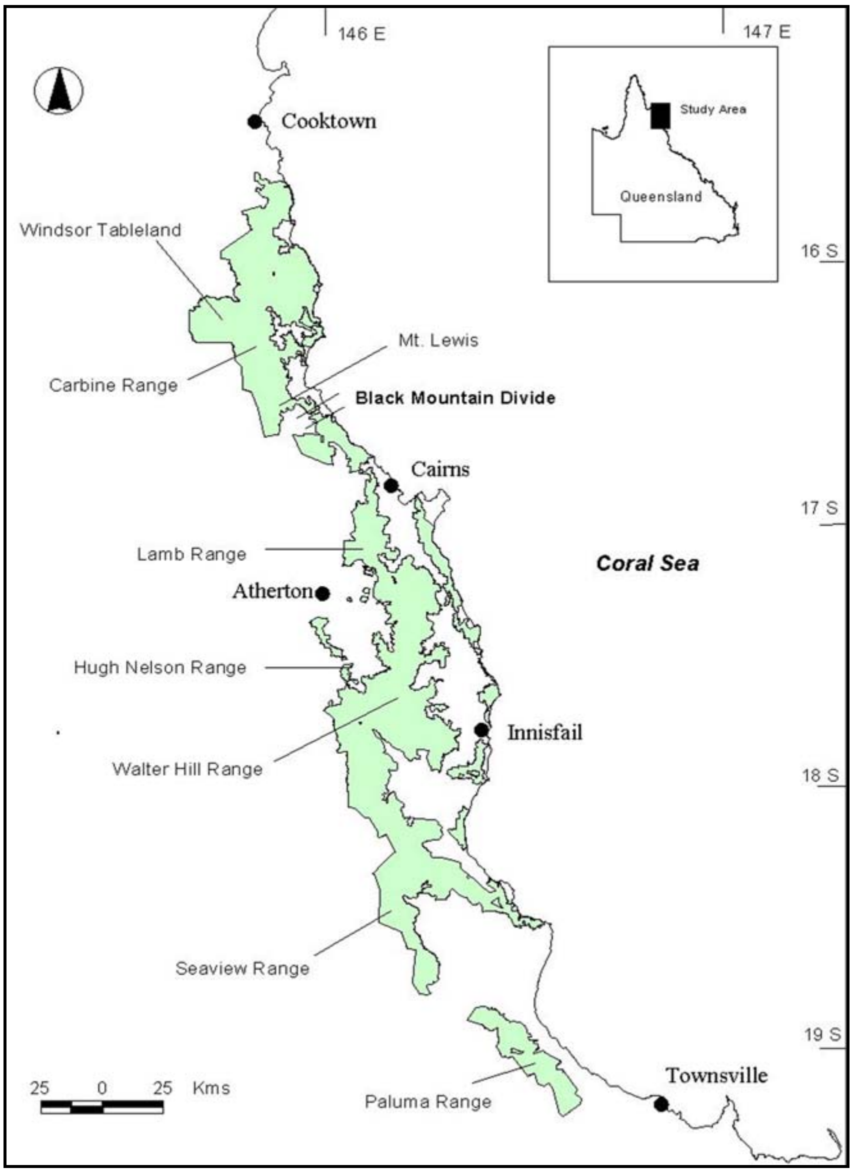

Figure 1.1 Wet Tropics region, northeast Queensland, with the World Heritage Area shaded (Source: Rainforest CRC)

This study commenced in 1998 as part of a Rainforest CRC project, *Impacts of Roads & Powerlines on the Wet Tropics World Heritage Area*, co-funded by the Wet Tropics Management Authority (WTMA). It was prompted by the QDMR (1997a) recommendation that canopy bridge trials be undertaken (see also Moore & Moore 1998; QDMR & WTMA 1998; QDMR 2000). I began the study while working for a consulting firm in Cairns who specialised in the environmental aspects of road planning, design, construction, maintenance and operation. As it is a thesis in Tropical Urban & Regional Planning, I not only provide information on the use of canopy bridges by arboreal mammals but also address the implications in terms of cost, road user safety and presentation in a region where there is a wide range of values held by different sections of the community in relation to snig tracks, roads and highways.

AIMS OF RESEARCH

This research aims to investigate the use of inexpensive aerial bridges (i.e., canopy bridges) by arboreal mammals and their potential for reducing the adverse effects of linear barriers such as roads (e.g., roadkill, habitat fragmentation).

Research questions

The study seeks to answer the following questions:

- Are canopy bridges used by arboreal fauna to cross linear barriers such as roads?
- If so, which species use canopy bridges and how do they use them?
- Does canopy bridge design affect usage by arboreal fauna?

The study was conducted in rainforests of the Atherton Uplands (after Williams & Pearson 1997), northeast Queensland, wholly within or adjacent to the Wet Tropics of Queensland World Heritage Area (WTWHA). This sub-region is a major centre of endemism for rainforest fauna in the Wet Tropics (Nix 1991; Williams 1997) and supports a rich arboreal mammal assemblage (Kanowski 1999; Wilson 2000).

THESIS OUTLINE

The organisation of this thesis is as follows:

The current chapter introduces the problem and presents an outline of the research conducted for this thesis.

In Chapter Two, I review what is known about the ecological effects of roads and discuss what actions are required to ameliorate these effects. I conclude by reviewing research into the use of new technologies aimed at restoring habitat connectivity, both in Australia and overseas. Special attention is given to studies directed at reducing roadkill and habitat fragmentation for arboreal mammals.

In Chapter Three, I provide a definition of biodiversity and outline the legal obligations of stakeholders to conserve it. I discuss the present situation in relation to biodiversity conservation in Australia, particularly in the context of roads in the Wet Tropics. I also detail the adverse effects of roads on arboreal mammals in this area as well as the implications for managers of road systems and wildlife in the Wet Tropics region of the findings presented in the previous chapter, i.e., that simple, inexpensive overpass structures enhance the movement of arboreal mammals across roads.

In Chapter Four, I describe the various materials and methods employed to monitor the use of canopy bridges by arboreal mammals at three separate sites in the Wet Tropics region. These comprise an existing rope tunnel built in 1995 across an old logging track, two rope bridges of simpler design - effectively rope ladders swung horizontally across an abandoned snig track - and a longer bridge spanning a sealed, dual carriageway. I provide an overview of the general study area and include information on site selection and arboreal species assemblages, as well as the biophysical and land use contexts of the sites themselves.

In Chapter Five, I document the results of investigations into the use of canopy bridges by arboreal mammals in the Wet Tropics region. These results are arranged according to the three separate study sites mentioned above.

In Chapter Six, I discuss the results of the research conducted for this thesis. I summarise what has been done in Australia and around the world with respect to canopy bridges and report that trials undertaken in the Wet Tropics conclusively demonstrate that arboreal and scansorial mammals will readily use them to cross roads, especially where canopy connectivity is not maintained. I explore the implications of these findings, not only in terms of wildlife management but also with reference to cost, road user safety and presentation of the WTWHA to visitors. The thesis concludes with an outline of my ideas for further research that would increase our understanding of the use of canopy bridges by arboreal mammals, particularly in the Wet Tropics region of northeastern Queensland.

Chapter 2: Review

Abstract. This chapter reviews the current state of knowledge about the ecological effects of roads, such as roadkill and habitat fragmentation, and discusses what actions are required to ameliorate these effects. It reviews research into the use of new technologies aimed at restoring habitat connectivity, both in Australia and overseas, and finds that wildlife-crossing structures have steadily gained acceptance as mitigation measures so that today there are five broad types in use. However, most mitigation measures target animals that move along the ground, despite studies suggesting that the barrier effect of roads is exacerbated for arboreal species. Thus, special attention is given to mitigation measures directed at reducing roadkill and habitat fragmentation for arboreal mammals. It is found that the first simple, inexpensive overpass structure was constructed in 1963 in Longview, a small town in Washington State in the United States, to allow safe passage for squirrels. Canopy bridges, ranging from simple rope bridges (ropeways) to elaborate tunnel-like structures, have since been erected for a variety of arboreal mammals in at least ten countries, including Australia. There is evidence that these bridges may enhance the movement of arboreal mammals during construction and continued operation of roads and other linear barriers.

CHAPTER 2: REVIEW

INTRODUCTION

There is an extensive literature about the ecological effects of roads and traffic (see reviews by Andrews 1990; Bennett 1991; Spellerberg 1998; see also special section – ecological effects of roads – *in* Conservation Biology, February 2000). With more than 800,000 km of public roads throughout Australia (Bates 1997), road reserves encompass a large and significant amount of land, some of which provides excellent representations of vegetation and ecosystems that have otherwise been locally cleared or degraded (Adam 1995; Napier 1997). Both Hobbs (1997) and Major et al. (1999) found that roadside strips have considerable potential both as conduits of gene flow and as reservoirs of biodiversity in highly fragmented landscapes. This led Farmar-Bowers (1997) to suggest that roadsides are Australia's richest biodiversity reserve. However, roads themselves have substantial impacts on biodiversity, as do the vehicles that travel on them (Adam 1995).

I discuss the ecological effects of roads in the first part of this chapter. This is followed by a discussion about the actions needed to ameliorate these effects. Finally, I review research into the use of new technologies aimed at linking historically related habitat or natural regions and ensuring movement between such regions, both in Australia and overseas. Special attention is given to studies directed at reducing both roadkill and habitat fragmentation for arboreal species.

ROAD EFFECTS

Roadsides are likely to be especially important in intensely farmed and urban regions where other suitable habitat is scarce (Bellamy et al. 2000; see also Fortin & Arnold 1997; Meunier et al. 2000). Schullery (1987) called the roadside ‘the longest meadow’ and Edna Walling famously referred to it as ‘the Front Garden of the Nation’ in her classic book, *Country Roads: The Australian Roadside* (Walling 1952). Walling, one of Australia's most influential landscape designers, was among the first to appreciate the value of remnant roadside vegetation. She outlined several very good reasons for retaining ‘scrub’ along roads, including the provision of ‘imperative conditions of shelter and nesting for birds, and honey producing flowers for bees – two invaluable friends of the farmer’ (Walling 1966, p. 93).

Even in natural areas, it has been discovered that roadsides can benefit species which use them variously as a refuge, a movement corridor, a foraging area and as habitat in which to reside (e.g., Taylor et al. 1985; Lewis 1991; Dennis 1997; Utah Division of Wildlife Resources & Department of Transportation 1998; Meunier et al. 1999). However, behaviour that regularly brings species of animals into contact with roads also makes them vulnerable to threats such as poisoning and disease transmission (e.g., Burnett 1994) and, of course, passing traffic. In this way, roadsides can be described as ‘ecological traps’ (after Andrews 1990).

Roadkill

One of the main reasons conservation biologists are concerned about the adverse impacts of roadsides is because they expose animals to the hazards of traffic (Mann & Plummer

1993). There is no doubt that enormous numbers of animals are killed on roads. A conservative estimate of 5.5 million individuals was made for annual rates of frogs and reptiles killed on sealed roads in Australia (Ehmann & Cogger 1985). Bennett (1991) searched a 0.5 km transect along a road in western Victoria and recorded 419 carcasses of five species of frogs in a single night. Frogs also figured prominently in the roadkill statistics collected by Goosem (2000a), who estimated that 5,000 vertebrates (mainly amphibians) per kilometre were killed each year on a rainforested highway near Cairns, in the WTWHA. Given that the WTWHA contains 101 km of state-controlled roads (roads that form part of the state's road network) (S. Goosem 2001), the above estimate suggests that more than half a million vertebrates are killed on highways within the WTWHA each year. The road toll for the wider region is likely to be much higher when state-controlled roads outside of the WTWHA, other major roads, minor roads and snig tracks are taken into account. In the United States, vehicular traffic has been estimated to kill a million vertebrates a day (Tarburton 1972, Lalo 1987).

Few data are available on the effect of roadkill on wildlife populations. In general, it appears that for most animals, particularly smaller species (e.g., invertebrates), roadkill does not exert a significant pressure on their population or conservation status (Bennett 1991; Yen & Butcher 1997). However, Fahrig et al. (1995) found that traffic mortality has a significant effect on the local density of frogs in particular and that recent increases in traffic volumes worldwide are probably contributing to declines in frog populations, especially in developed areas. Reynolds (1998) reported that levels of road-induced mortality could be high enough to induce local population extinction. This is probably not surprising, given the large numbers of frogs that figure in roadkill statistics.

There is also increasing evidence that roadkill has a significant impact on populations of larger species, particularly mammals, that are regularly and repeatedly brought into contact with roads. For example, Clarke et al. (1998) found that road traffic is the largest single cause of death for badgers, *Meles meles*, in Britain and that a correlation exists between declining badger populations and areas where road and traffic densities are high. The WWF-UK (1998) claimed that c.47,000 badgers are killed on British roads each year. In the Netherlands, cars have been implicated in the extirpation of local badger populations (Reynolds 1998), whilst Huijser and Bergers (2000) suggested that roads and traffic might affect the survival probability of local populations of hedgehogs, *Erinaceus europaeus*. Similarly, the results of a study on a section of motorway in western France by Lode (2000) emphasised that traffic considerably affected populations of vertebrates, especially mammals (43.2% of road-killed animals). In Tasmania, local populations of native mammals (e.g., eastern quoll, *Dasyurus viverrinus*) are known to have become extinct due to road mortality (Tasmania Parks and Wildlife Service 1998; Jones 2000).

The problem of roadkill appears to be greatest for mammal species with restricted or declining distributions. It is the major source of mortality for most of the large threatened species in Florida and accounts for over 50% of known deaths of the endangered Florida panther, *Felis concolor* (Harris & Gallagher 1989). In Brazil, roadkill threatens populations of the black lion tamarin, *Leontopithecus chrysopygus*, one of the world's most endangered species of primates (Valladares-Padua et al. 1995). In Australia, roadkill is a significant source of mortality for small and declining populations of the eastern barred bandicoot, *Perameles gunnii* (Brown 1989, cited in Bennett 1991), and Proserpine rock-wallaby, *Petrogale persephone* (Nolan & Johnson 2001). The last known eastern quoll in Victoria was killed by a car in the Melbourne suburb of Kew (D. Hespe, 1999 pers. comm.) and the last known individual in New South Wales (and by implication, the Australian mainland) suffered a similar fate in the Sydney suburb of Vaucluse (Reardon 1999). In the Wet Tropics region, Goosem (2000a) found that road mortality may be a threatening process for rare mammal species such as Lumholtz's tree-kangaroo, *Dendrolagus lumholtzi* (see also Schmidt et al. 2000).

Road-effect zone

Although the most obvious impact of roads on wildlife is the mortality caused by collisions with vehicles, adverse effects extend beyond the pavement. Harvard landscape ecologist Richard Forman (quoted in Aschwanden 2001) developed a concept that he termed the 'road-effect zone' - the total area over which a road exerts its influence. It begins with the destruction and alteration of habitat associated with road construction and consequent reductions in wildlife population size. For example, the United States Council on Environmental Quality (1974, cited in Goosem 1997) estimated that each kilometre of interstate highway could require the alienation of up to 13.5 ha of habitat. In the Wet Tropics region, Goosem (1997) reported that 608 ha of habitat in 1,427 km of roads and highways have been alienated within the WTWHA (based on the area cleared).

The construction, use and maintenance of roads has also been demonstrated to:

- alter the way water, air and nutrients move across the landscape (Turton & Freiburger 1997);
- intensify the toxic contamination among roadside populations (Jeffries & French 1972, cited in Lode 2000);

- provide opportunities for colonisation by weeds and serve as a conduit for the movements of pest fauna (such as pigs and cane toads) and diseases and pathogens (such as *Phytophthora*) (Burnett 1994; Cooperative Research Centre for Tropical Rainforest Ecology and Management 1997); and
- permit the ingress of hunters, poachers and trappers (Wilkie & Morelli 1998; Wilkie et al. 2000).

Noise and artificial lighting have also been shown to affect some wildlife (Reijnen & Foppen 1994; Reijnen et al. 1995). Perhaps most importantly, roads are believed to be one of the main obstacles to the movement of land animals.

Barrier effect

As described by Yanes et al. (1995, see also Fahrig & Merriam 1985; Gilpin & Soule 1986), linear infrastructure like roads can generate a 'barrier effect', which involves the blockage or restriction of movement by certain species and/or populations across them. There are several ensuing negative consequences: reduction of genetic diversity due to the increase in inbreeding, increased risk of local extinction due to population dynamics and catastrophic effects, and a decrease in the ability to recolonise etc. This barrier effect was quantified for the first time by Gerlach & Musolf (2000) who studied the barrier effects of various roadways on the genetic subdivision of bank vole, *Clethrinomys glareolus*, populations in southern Germany and Switzerland. They demonstrated that fragmentation of landscape by highways has an important effect on gene flow and the genetic substructuring of populations.

Contrary to popular opinion, linear barriers need not be impenetrable structures. As noted by Reynolds (1998), wildlife mortality from vehicle collisions can contribute to the barrier effect of roads. Other studies examining roads of different widths, surfaces and traffic volumes have found that the major factor inhibiting road crossing appears to be the physical presence of the road, rather than the disturbance factor of vehicular traffic (e.g., Mader 1984; Mansergh & Scotts 1989; Burnett 1992; Goosem 1997). Even roads with minimal traffic and narrow clearing widths can strongly inhibit wildlife crossings. In the most frequently cited example, Mader (1984) found that forest mice, *Apodemus flavicollis*, in Germany did not cross roads with widths from 3 m to 6 m, and if individuals were translocated very few returned.

One method of determining whether roads exert a barrier effect is to use data from roadkills. If an animal has attempted to cross the road, it can be concluded that the road is not perceived as a complete barrier (although it may function as one if crossing success rates are low). Species not found as roadkill may be using alternative crossing routes; may be fast or intelligent traffic avoiders; or may simply avoid crossing. This last group could be cause for particular conservation concern (Goosem 1997).

Arboreal species at risk

In Goosem's (2000a) study of a rainforested highway in the WTWHA, more than 4000 vertebrates of over 100 species were recorded as road kills on a 2 km stretch. However, several species known to occur in the study area were under-represented in or absent from these statistics. These included species of special conservation or evolutionary interest, including arboreal marsupials such as possums and tree-kangaroos. Goosem

(1997, 2000a) hypothesised that the arboreal species were either using the few canopy connections as crossing points or avoiding the road altogether.

Goosem's findings, and those of other researchers (e.g., Winter 1984, 1991; Laurance 1990, 1995, 1997; Valladares-Padua et al. 1995; Winter & Goudberg 1995a; Malcolm 1998; Wilson 2000) suggest that the barrier effect is exacerbated for arboreal species. These studies also suggest that the inhibitory effects of roads can differ considerably between species. The Australian Museum Business Services (AMBS) (2001), in a review of the effects of roads on arboreal marsupials, found that roads do not generally constitute a physical barrier to gliders unless the roads are wider than 60 m (such as dual carriageway highways) and lack suitable roadside habitat (large emergent trees). Presumably, this is because all Australian gliders are known to cover distances of 60 m or more, with the exception of the tiny feathertail glider, *Acrobates pygmaeus*, which can glide 30 m (Lindenmayer 2002). The AMBS (2001) also found that roads do not constitute a barrier to species that move along the ground when crossing open spaces (e.g., common ringtail possum, *Pseudocheirus peregrinus*, and common brushtail possum, *Trichosurus vulpecula*). However, these species run the risk of being struck by passing vehicles and the danger of predation is also greatly increased (Baker & Degabrielle 1987 and Banks 1999, cited in AMBS 2001). Indeed, possums are among the most common patients treated at NRMA Wildlife Clinics at Taronga and Western Plains Zoo. These clinics treat about 1,500 animals each year, about a quarter of which are road injured (*The Open Road*, September/October 2000).

It is reasonable to assume that the barrier effect of roads is strongest for arboreal species that neither glide nor move at ground level ('canopy-dwellers', after Malcolm 1998).

Within the Wet Tropics region, there are four endemic ringtail possum species that fit this description. They are known collectively as the rainforest ringtails and comprise the green ringtail, *Pseudochirops archeri*, the Herbert River ringtail, *Pseudochirulus herbertensis*, its close relative the Daintree River ringtail, *Pseudochirulus cinereus*, and the lemuroid ringtail, *Hemibelideus lemuroides* (detailed species accounts are presented in **Chapter Four**). All can be termed canopy-dwellers, with the lemuroid ringtail considered to be the most canopy-loving of the four species (Winter & Goudberg 1995a).

REDUCING ROAD IMPACTS

The realisation that road impacts can ultimately result in a loss of biodiversity has motivated conservation biologists to investigate the actions that are needed to ameliorate these effects (Rosenberg et al. 1997). The problem of roadkill, in particular, has aroused concern and attempts have been made to reduce the toll for certain species (Bennett 1991). Management techniques that have been trialed in the United States include fences to prevent access to the highway; one-way gates to direct deer out of the road reserve; warning signs of a variety of levels of sophistication (including a lighted animated deer); highway lighting; and roadside reflectors which direct light from passing vehicles to the side of the road, thereby ‘freezing’ animals. Highway fencing is the most successful measure, and roadside reflectors have had some success; but lighting and signs were not effective (Bennett 1991).

Similar techniques have been trialed in Australia, again with varying degrees of success. Fencing has most commonly been used to exclude macropods from roads (QDMR 2000). Specifically designed koala-proof fencing has also been used to discourage koalas from entering road reserves. In Queensland, the State Government recently tested warning reflectors to deter macropods along a 6 km stretch of road on the Landsborough Highway, between Barcaldine and Longreach (*The Sunday Mail* 18/3/01). Such reflectors have already been installed in areas where the endangered Proserpine rock-wallaby has been killed and, along with the removal of guinea grass from road edges, appear to have succeeded in decreasing the number of animals killed by vehicles (*The Courier Mail* 24/8/01). In contrast, studies in Victoria to assess the usefulness of reflectors in an attempt to reduce roadkill of the endangered eastern barred bandicoot indicated that reflectors made little difference (Sheridan 1991, cited in QDMR 2000).

Jones (2000) reported a study involving the implementation of several different measures on a tourist road in Tasmania where resident wildlife populations had locally declined and gone extinct. The measures, directed at drivers (slowing traffic speed, increasing driver awareness) and wildlife (deterring wildlife from crossing where there is oncoming traffic and encouraging escape off the road), were successful in reducing the roadkill rate to a level that natural population increase could sustain. However, all of the measures were installed simultaneously so their relative effectiveness could not be disaggregated. It is also important to note that the recovery relied on recruitment from nearby local populations (see discussion on ‘metapopulation’ theory, below).

While the above measures may help reduce the toll for certain species, they do little to ameliorate the barrier effect of roads. In fact, they may exacerbate it in some instances (e.g., highway fences). Consequently, management techniques that maintain or improve ecological connectivity and increase dispersal are especially important (Laurance 1995, 1997; Laurance & Gascon 1997; Thwaites 1998).

LINKING LANDSCAPES

Although the notion of ecological connectivity has a long history, it did not appear in modern form until 1970, when Richard Levins, an ecologist at the Harvard School of Public Health, created the first mathematical model of what he called a 'metapopulation' - a set of linked local populations of a species, each in its own separate patch of habitat (Mann & Plummer 1995). In Levins' formulation, the population of any given patch rises and falls over time; there is always a small chance that the population on any given patch can vanish but the empty habitats can be repopulated if the metapopulation has sufficient connectivity (Mann & Plummer 1995; see also Fahrig & Merriam 1985; Gilpen & Soule 1986; Rosenberg et al. 1997). This was evidently the case in the Jones (2000) study, involving the implementation of several different measures on a tourist road in Tasmania.

However, critics (e.g., Bonner 1994; Hess 1996) are sceptical about applying such mathematical models to real life. The results, they say, depend too much on the assumptions made in constructing the models. The biggest concern is that the calculations do not take into account problems such as the spread of disease, fire and genetic dilution, which could undermine the good that corridors achieve. Despite these concerns, metapopulation theory has become the justification for wildlife corridors and other management techniques that increase movement among populations (Hess 1996). Beier and Noss (1998, p. 1250) concluded that: '…all else being equal, and in the absence of complete information, it is safe to assume that a connected landscape is preferable to a fragmented landscape'.

TECHNOLOGICAL SOLUTIONS

Much has been written about 'wildlife corridors', which usually involve 'planning, planting and preserving strips of vegetation to assist animals to move across a landscape that would otherwise be hostile to them' (Hobbs 1997, p. 58). In some cases, ecologically engineered wildlife passageways have been constructed as a special type of wildlife corridor (Reynolds 1998). Both examples deal with attempts to link historically related natural regions and ensure movement between such regions, thereby increasing connectivity to a level that assures regional survival of populations or metapopulations (after Merriam & Saunders 1993).

Reynolds (1998) reported that functionally, wildlife crossing structures or passageways are anticipated to provide a corridor that:

- enables migration and dispersal to continue;
- links severed elements of an animal's home-range; and
- reduces mortality due to road collisions.

Species likely to benefit from passageways are those that:

- suffer high mortality due to road collisions;
- show strong migratory behaviour;
- require large areas, both at the individual and population level; and
- are constrained in their dispersal by linear infrastructure.

Some structures designed to manage the connectivity of wildlife across roads have become standard management tools, especially in aquatic habitats where culverts and fish ladders are designed to minimise disruption of stream flow and bed morphology and allow fish passage in streams affected by urban growth (Glavin & Osborne 1997; see also QDMR 1997b). Stream connectivity is enforced legislatively in Queensland, where it is an offence under s. 112 of the *Fisheries Act 1994* to build waterway barrier works. It has taken considerably longer for the crossing requirements of land animals to be acknowledged. Despite this (or perhaps because of it), Gerlach and Musolf (2000) argued that to ensure migration, and therefore gene flow, certain structures such as underpasses and overpasses are necessary to reduce barrier effects, and their effectiveness must be evaluated. Likewise, Trombulak and Frissell (2000) argued that assumptions about the capability of site- and species-specific mitigation and remediation measures to reduce the ecological consequences of existing and proposed roads need examination.

Wildlife crossing structures

The concept of wildlife crossing structures for land animals is not new - tunnels under roads were used as early as 1958 in the United Kingdom to reduce roadkill of badgers (Noss n.d.). In Europe, wildlife crossing structures have steadily gained acceptance as mitigation measures (Lugo and Gucinski 2000) so that today there are five broad types in use (Reynolds 1998) (**Table 2.1**).

Table 2.1: Wildlife crossing structures (from Reynolds 1998)

Crossing type	Description
Amphibian tunnel	Perhaps the most commonly installed wildlife crossing structure in Europe. Target species are frogs, toads, newts and salamanders, with tunnels being installed at points where annual migration routes to and from breeding ponds are severed by linear infrastructure such as roads or railways. The most effective tunnels are rectangular, with diameters of 100 cm for tunnel lengths of <20 m, and up to 150 cm for tunnel lengths >50 m. Placement is critical and fencing or guide walls are required to lead animals to the tunnel entrance.
Ecopipe	In Europe, pipes of c.30-40 cm diameter are commonly used to provide wildlife crossing structures for small to medium-sized mammals. Although often explicitly installed for badgers, other species such as foxes, rabbits, hedgehogs, martens (beech and/or pine) and stoats have been recorded using them. Mice and voles appear to make little or no use of pipes. Well-drained pipe floors consisting of sand or earth appear to be preferred. In the United Kingdom pipes of 60 cm diameter to 90 cm diameter are used as otter passageways for road crossing lengths of up to 20 m and 50 m respectively.
Ecoculvert	Comprise conventional pre-fabricated concrete culverts to which raised ledges are added, thereby combining the drainage function with that of a crossing structure for terrestrial animals. The floor of the ledges usually comprises soil or sand. The following species have been recorded using such structures: hedgehogs, rabbits, badgers, foxes, stoats, polecats, stone martens, water voles, muskrats, brown rats, wood mice, voles and shrews, including water shrews, and amphibians (frogs, toads and newts). In the Wet Tropics region, it has been found that small road culverts are used by some rainforest mammals as underpasses (Goosem & Turton 1999; Goosem, 2000a), while other rainforest fauna, including the endangered southern cassowary, have been observed to use highway culverts as road crossing routes (Moore & Moore 1999).

Crossing type	Description
Wildlife underpass	Consists of earth-floored tunnels specifically constructed to permit the movement of wildlife beneath roads or railways. Such structures are typically associated with guiding fences and screening vegetation and are used by a wide variety of species, including rabbits, weasels, wild boars, badgers, foxes, deer, black bears, wolves and mountain lions. In Banff National Park, Canada, underpasses have been used for cross-highway travel by at least seven large mammal species (Clevenger & Waltho 2000, but see Leighton 1988). Depending on target species, the structures range in diameter from 3 to 30 m wide with a minimum height of 2.5 m. Four large (3.4 m high and 3.7 m wide) underpasses are currently being trialed at East Evelyn, in the Wet Tropics region (Goosem et al. 2001). They were fitted with internal furnishings (escape poles, ropes, soil and litter) and were sited to allow maximum opportunities for movements of larger fauna such as tree-kangaroos and cassowaries between patches of existing native vegetation (Goosem et al. 2001).
Wildlife overpass	Also known as 'green bridges', 'landscape connectors' or 'ecoducts', these structures comprise vegetated bridges designed and constructed specifically for the use of wildlife, although landholder access tracks are sometimes incorporated. They were initially designed for large game animals such as deer, with probably the first being established over motorways in France in the 1980s. These early bridges were installed to preserve the migratory movements of large mammals and to reduce traffic-related mortality. With greater awareness of the consequences of habitat fragmentation and barrier effects, green bridges are increasingly being used to link animal habitats either side of a road.

To date, the most common approach has been site-specific, i.e., to retrofit crossing structures at locations where roadkill is perceived to be a problem. For example, in 1996 the Florida Department of Transportation created ‘Paynes Prairie Ecopassage’ in an area that had recorded some of the worst roadkill numbers in North America. Comprising a system of underpasses and guide walls, it was designed to divert small and medium-sized wildlife away from traffic lanes to safe passage beneath the highway. O’Neill (2001) claimed that it was the first such system to provide community-wide protection.

However, Andrews (1990) argued that the most successful strategies are developed to meet the needs of specific species (i.e., species-specific). She cited as an example the ‘tunnel of love' constructed for the endangered mountain pygmy-possum, *Burramys parvus*, in southeastern Australia (details in Mansergh & Scotts 1989). Jones’ (2000) study in Tasmania is another good example.

In Queensland, the QDMR is investigating ways to reduce the impact of roads and traffic on those species and populations most affected, such as the endangered southern cassowary, *Casuarius casuarius*, at Mission Beach. This work is based on a detailed project to identify movement corridors and propose risk reduction strategies for fauna, especially cassowaries (see Moore & Moore 1998). According to the QDMR (2000), fauna provisions should meet the needs of all species, not only generalist species that are able to readily adapt to new environments

Crossing structures for arboreal species

Despite the growing acceptance by both wildlife managers and managers of road systems of the need to reduce the barrier effects of roads - the U.S Department of Transport’s

Federal Highway Administration even has a web-site devoted to the subject, entitled *Critter Crossings – Linking Habitats and Reducing Roadkill* and found at http://www.fhwa.dot.gov/environment/wildlifecrossings - most studies have focused on animals which move along the ground. There has been little discussion of overpasses for arboreal fauna (AMBS 2001; see also QDMR 2000) even though this group is considered to be amongst the most susceptible to habitat fragmentation (see discussion, above).

Although the effectiveness of 'green bridges' has been proven for scansorial species such as the California cougar, *Puma concolor* (Harvard University Graduate School of Design 1998), brown bears, *Ursus arctos* (Chadwick 2001), and even koalas, *Phascolarctos cinereus*, (C. Moon, 1999 pers. comm.), these structures facilitate wildlife movement at ground level. For an overpass to allow successful movement of all arboreal species, including canopy-dwellers, an upper canopy is necessary. This requires a substantial amount of ground surface above a tunnelled road to allow tree growth, which is likely to be impractical (QDMR 2000). Consequently, it has been suggested that mitigation of the fragmentation effects caused by linear disturbances for these species can best be achieved by strengthening extant canopy connections, and by establishing new connections across road clearings (Goosem & Marsh 1997; Goosem 2000c).

Inexpensive aerial constructions (canopy bridges) have been recommended for arboreal mammals in Australia (Scott 1988; Goosem 1997; QDMR 1997, 2000; QDMR & WTMA 1999) and overseas (Lyon & Horwich 1996). In 1990, Andrews wrote that no canopy bridges had been documented, with the exception of bamboo poles connecting orchard trees in China, to facilitate the movement of a predatory citrus ant. However, the current study has found that canopy bridges have been used in Australia and at least 10 other countries. These range from simple rope bridges (or ropeways) to elaborate tunnel-like structures, as documented below.

Ropeways

Ropeways have been used in the United States and England, Scotland and Wales. The first reported ropeway was constructed as long ago as 1963 in Longview, a small town in Washington State in the United States. Called the 'Nutty Narrows Bridge', it was constructed to allow safe passage for squirrels, *Sciurus* sp., over the town's main thoroughfare, Olympia Way (see **Figure 2.1**). The 60-foot (18.3 m) bridge was built from aluminium and lengths of fire hose. Longview City Council (2001) stated that it did not take long before reports were received of squirrels using the bridge. Squirrels were even seen escorting their young and 'teaching them the ropes' (Longview City Council 2001).

Figure 2.1 First ropeway in Longview, United States (Photo: Scary Squirrel World)

It took until the mid-nineties before ropeways were built in Great Britain to reduce road deaths of the threatened red squirrel, *S. vulgaris* (Norwood 1999; see also Wight Squirrel Project Newsletter Nos: 5, 7) (**Figure 2.2**). The first ropeway was erected in June 1996 in Calthorpe Road, Ryde on the Isle of Wight, England. According to the Wight Squirrel Project (H. Butler, 2002 pers. comm.), the woods in the vicinity are small and fragmented and four or five road deaths a year could impact on the population. Feed hoppers attracted the squirrels to the crossing point and they were quick to use the ropeway. A second rope was erected at Yarmouth in 1998 and a third in Easthill Road, Ryde (**Figure 2.3**). All three ropeways were used frequently, although no quantitative data were obtained (H. Butler, 2001 pers. comm.).

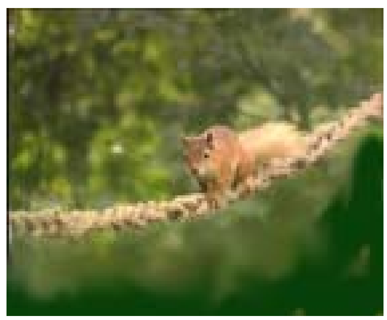

Figure 2.2 Red squirrel using a ropeway on the Isle of Wight, England (Photo: Wight Squirrel Project)

Ropeways have also been used in Wales to help conserve red squirrels (Forestry Commission News Release No: 1900) and a series of ropeways were erected in Erchite Forest, near Foyers, on the south shore of Loch Ness in north Scotland in 1999 (Forestry Commission News Release Nos: 1869, 1900). Forest District Manager Malcolm Wield said at the time:

> ‘The concept of these rope bridges has worked successfully in England and we agreed that it should be tried here too. We know that, given the choice, red squirrels prefer staying in the tree canopy rather than coming to the ground. The rope-bridges take advantage of this behaviour and so should prove to be a safer and more successful option than coming to the ground. We’re confident that the bridges will help sustain

the population of the red squirrel, by reducing deaths caused by road traffic. Sometimes the simplest ideas prove to be the best ones.'

Forestry Commission News Release No: 1900

In early 2000, plans to erect a network of ropeways across the country's trunk road network were announced by the Scottish Environment Minister (*The Herald (Scotland)*, 1/2/00). The bridge scheme, which was to use ropes 4 inches thick to ensure squirrels have enough room to pass each other, was taken up in the Executive Guidelines, published in January 2000. As well as ropeways, the plan to make the entire 3,400 km trunk road network more animal-friendly included underpasses for otters (*The Herald (Scotland)*, 1/2/00).

Figure 2.3 Ropeway erected above Easthill Road, Ryde, on the Isle of Wight

Ropeways in Great Britain are typically erected above class B (minor) roads at a height of >20 ft (6.1 m) and supported by strong trees on either side (see **Figure 2.3**). In West

Sussex, a ropeway was strung between two telegraph poles at a height of 18 ft (5.9 m) to link habitat for another threatened species, the common dormouse, *Muscardinus avellanarius.* This ropeway, which cost £5,000 (AU$12,900), was one of the environmental measures being carried out by the developer of Bolnore Village to reduce the fragmentation effects of the new Haywards Heath relief road (*The Argus (Mid Sussex)*, 8/3/02). Dr Tony Whitbread, head of conservation at the Sussex Wildlife Trust, was quoted as saying:

> Dormice live in trees. They really like having aerial walkways and don't like walking on the ground if they can help it. If you stick a path through a large woodland you could divide the population in half and so it becomes untenable. That is why people are fairly careful not to make any complete breaks.
>
> *The Argus (Mid Sussex)*, 8/3/02

The ropeways on the Isle of Wight were removed in 2002, partly because all insurance ceased at the end of April of that year. According to the Wight Squirrel Project Newsletter No: 7 (December 2002), inspection of the Ryde sites revealed that the branches had grown and now 'bridged the gap' and that the ropes were no longer necessary anyway. One of the ropes was also attached to a tree that had contracted Dutch Elm Disease and was due for felling. Also, the squirrels had recently moved their crossing route. The newsletter stated that, if in the future there was a suitable site for a rope, Wight Nature Fund had agreed to help. In the meantime, Wight Squirrel Project is reported to be working on a squirrel friendly 'tube' (or rope tunnel) to span roads that are too wide for a ropeway. Presumably, this approach was triggered by the exchange of information between Helen Adams of the Wight Squirrel Project and myself, based on the prototype rope tunnel designed by Rupert Russell (see below).

In Australia, ropeways were trialed in the vicinity of the Pacific Highway in northeastern NSW to prevent koala road deaths but it is understood that liability concerns prevented their adoption (C. Moon, 1999 pers. comm.). In September 2002, the Tasmanian Department of Primary Industries, Water & Environment built two ropeways across a busy road in the Hobart region (Channel Highway, adjacent to the Kingston Beach Golf Course, see **Figure 2.4**) to allow safe passage for arboreal marsupials, primarily common ringtail possums. The officer in charge, Zoe Tanner (2002 pers. comm.), reported that each ropeway was made from a single line of 12 mm double braid rope and an additional three ropeways were constructed alongside the road to provide access to the crossing bridges. These were installed at least 6 m above the road surface and tied to trees and electricity poles. No information is yet available on their use. In the Wet Tropics region, Wilson (2000) constructed vine linkages over a forestry road and examined their use by arboreal marsupials but her results were inconclusive.

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Figure 2.4 Channel Highway ropeway, Kingston, Tasmania (Photo: Zoe Tanner)

Pole bridges

A variation of the ropeway has been used to connect habitat and reduce roadkill of the critically endangered black-lion tamarin at a farm in Sao Paulo, Brazil (Valladares-Padua et al. 1995; also C. Padua, 2003 pers. comm.). Instead of a rope, round wooden poles were stretched above the road at a height of 6 m (see **Figure 2.5**). Ropes then connected each end with the adjacent forest (C. Padua, 2003 pers. comm.).

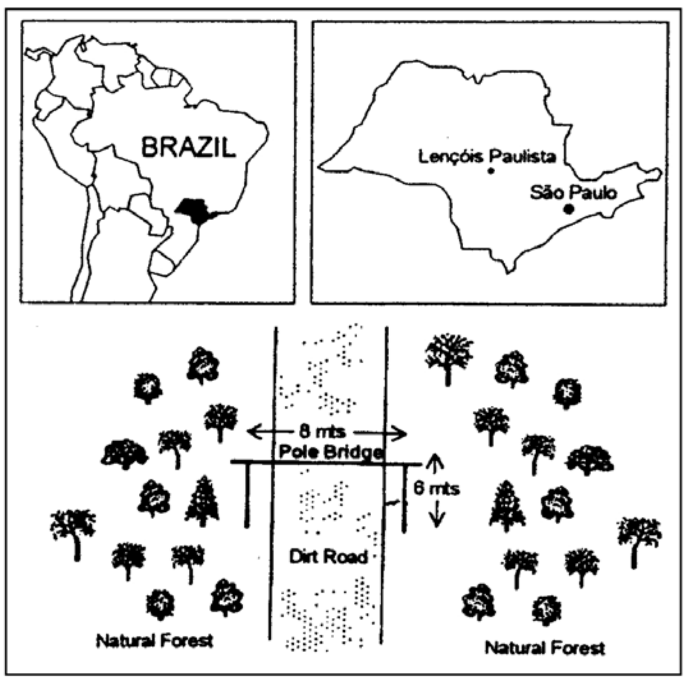

Figure 2.5 A simplified illustration of the pole bridge at the Rio Claro farm of Duratex S.A., Lencois Paulista, Sao Paulo, Brazil (Source: Valladares-Padua et al. 1995).

The bridge was installed at a locale where the animals were crossing and Valladares-Padua et al. (1995) reported that black lion tamarins and capuchins, *Cebus apella,* began crossing the bridge as soon as it was assembled. From its installation, in the middle of August 1991, to the end of 1994, two groups of black lion tamarins and a large group of capuchins were recorded (incidentally) using the bridge on at least 40 occasions. Valladares-Padua et al. (1995) reported that these primate groups used the bridge constantly, probably daily. According to Valladares-Padua et al. (1995, p14):

> This simple alternative has undoubtedly reduced quite considerably the possibilities of these animals being run over, and in the case of the lion tamarins, contributing to the protection of one of the most endangered species in the world.

Monkey bridges

Rope bridges of 'monkey bridges' have been used in at least five countries around the world. An example is the Kenyan 'colobridge', the first of which was constructed in 1996 over the Diani Beach Road to reduce road deaths of the Angolan colobus monkey (see **Figures 2.6, 2.7**). According to the Colobus Trust (P. Kahumbu & F. Ndiege, 2001 pers. comm.), a standard colobridge measures c.30 m and consists of a rope ladder swung horizontally across the road. Poles on either side usually support it although strong trees are sometimes used. Platforms are also installed at each end to provide feeding/resting places. They cost US$300 (AU$490) each and take two days to erect.

The Colobus Trust has now erected 19 colobridges along the Diani Beach Road with the generous funding from many individual donors (Born Free Foundation 2003). They have proven popular with the colobus – one was used within 30 minutes of its completion (Born Free Foundation 2002) and other species such as vervets, *Cercopithecus aethiops*, sykes monkeys, *C. albogularis*, and even baboons, *Papio cyanocephalus*, have also used them (P. Kahumbu, 2001 pers. comm.). Two indicators are used as a basis for selecting locations (P. Kahumbu, 2001 pers. comm.):

1. The place with the highest road kills.

2. The place where the colobus are mostly seen crossing.

Figure 2.6 Colobidge across the Diani Beach Road, Diani, Kenya (Photo: Colobus Trust)

Figure 2.7 An Angolan colobus monkey using a colobridge in Kenya (Photo: Colobus Trust)

It was reported in the 2001 Newsletter of Wakuluzu, Friends of the Colobus Trust, that the bridges have 'undoubtedly helped to decrease road traffic accidents' which have dropped in one location by 'an amazing 50%' (*Colobus Update*, December 2001). The Colobus Trust subsequently assisted with the construction of a colobridge over a busy road through the range of the highly endangered Zanzibar red colobus, *Procolobus kirkii*, in Tanzania. One bridge has been constructed and has been successfully used (Born Free Foundation 2003).

Monkey bridges have also been used in Belize for the endangered black howler monkey, *Alouatta caraya*, (P. Beier, 1999 pers. comm.) and in Punta Laguna, Mexico, where environmental artist Lynne Hull worked with Mayans living in a Yucatan forest to design one for spider monkeys, *Ateles* sp. (greenmuseum.org 2003). The Mayans cut the lightest but strongest tree branches with shapes Hull admired, and then used nylon cord to tie the branches together, suspending them like a hammock (see **Figure 2.8**). This bridge, built in 1998, was not used and Hull speculated that the reason for this was that 'the monkeys might not trust the structure' (greenmuseum.org 2003).

Figure 2.8 Monkey bridge in Punta Laguna, Mexico (Photo: Lynne Hull)

CNN (1998) reported that authorities in Taiwan had built an elaborate monkey bridge in a bid to save Taiwanese macaques, *Macaca cyclopis,* threatened by highway traffic. Made of rope and on a shoestring budget, the bridge stretches across the New Cross Central Taiwan Highway near the small town of Nantow, 250 kilometers south of Taipei. Up to 40 Taiwanese macaques were killed or injured on the road each year and wildlife officers from Yu-shan National Park Headquarters came up with the idea of the bridge because they feared the highway carnage would threaten the existence of the species. The monkeys quickly took to the bridge - running, playing and just lounging along it (see **Figure 2.9**). Director of the park, Lee Wu-hsiung, said at the time that ‘it is the first and only monkeys’ bridge in Taiwan’ (CNN 1998). It spans the road about 10 m above the ground and exclusion netting directs the monkeys to it (see **Figure 2.10**).

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Figure 2.9 A Taiwanese macaque relaxes on a monkey bridge near Nantow, Taiwan (Photo: APTV)

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Figure 2.10 Monkey bridge across the New Cross Central Taiwan Highway, near Nantow, Taiwan (Photo: APTV)

Rope tunnels

Rupert Russell of the Queensland Environmental Protection Agency (QEPA) designed and built a single rope tunnel across a forestry road in the Wet Tropics region in 1995 to encourage the movements of rainforest ringtail possums (see **Figure 2.11**). He used a tunnel design to provide protection from aerial predators (R. Russell, 1998 pers. comm.). The structure spans 14 m, is located 7.3 m above the road surface, and is supported by telegraph poles on either side. Ropes leading to the tunnel extend a short way through the trees. Prior to the current study, anecdotal evidence indicated that the Herbert River ringtail possum used the rope tunnel, although no systematic observations had been undertaken at the site (R. Russell, 1998 pers. comm.).

Figure 2.11 Rope tunnel across a forestry road in the Wet Tropics, Australia

An even more elaborate tunnel-like structure was trialed near Sydney between January and November 2000 (AMBS 2001). The structure consisted of a 23 m long wire cable strung between poles either side of the Wakehurst Parkway, a busy two-lane road in Allambie Heights. Suspended around the centre of the wire cable was an 11 m long aluminium alloy perforated tube, designed for the protection of the animals using the structure as well as the vehicles travelling underneath. The trial, which represents the only documented study of canopy bridges to date, provided inconclusive evidence on possum movement and use because there was no way to distinguish between individuals. However, it did reveal that one or several common ringtail possums utilised the overpass on several occasions. The trial results also suggested that arboreal species used the bridge as a refuge during a wildfire although, importantly, no significant reduction in the incidence of road mortality within the study area was recorded.

Other structures

As of this writing, canopy bridges are being trialed or considered for use:

- on the Goulbourn Valley Highway, near Shepparton in central Victoria, targeting squirrel gliders, *Petaurus norfolcensis* (R. van der Ree, 2002 pers. comm.);
- on the Calder Highway, near Macedon in the Melbourne region, for arboreal species including koalas (R. Abson, 2002 pers. comm.);
- at Hallidays Point, near Forster on the mid north coast of NSW, for arboreal and scansorial species including the brush-tailed phascogale, *Phascogale tapoatafa* (B. Campbell, 2002 pers. comm.); and
- in Brisbane, at Moggill Koala Hospital, where QDMR are testing pole bridges for possible incorporation into road schemes in Redlands Shire. The use of associated exclusion fencing is also being investigated (W. Twist, 2003 pers. comm.).

Trials of ‘glider poles’ were also undertaken by AMBS (2001) at Termeil in southeastern NSW. The overpass was a simple structure made using a timber pole to which a cap and a cross member or ‘perch’ was attached near the top. The pole was about 12 m in height and positioned within the road corridor to provide a ‘stepping stone’ for gliding marsupials between areas of vegetation on either side of the road. Unfortunately, no glider traffic was recorded.

At this point, it should be noted that wildlife carers commonly use canopy bridges to keep recuperating animals off the ground. Smith (1995) suggests that home owners should make their gardens safer for possums, or any other native fauna that may be visiting or sharing them, by providing high aerial pathways between isolated trees by means of a thick rope or piece of timber (see **Figure 2.12**). Margit Cianelli, who runs a care and release centre for native animals on the Atherton Tablelands, adopted this approach by running a thick rope from her house deck to a large pink evodia, *Melicope elleryana* on the forest edge. The ropeway was suspended 3 m above the ground and the distance covered was about 10 m. A Lumholtz’s tree-kangaroo used the rope a couple of times, a Herbert River ringtail did so for about a month and a green ringtail used it continuously for about five years (M. Cianelli, 2001 pers. comm.). Captive tree-kangaroos will readily use ropes and they often move along them upside down, in a sloth-like fashion (K. Coombes, 2001 pers. comm.).

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Figure 2.12 A sugar glider, photographed in Smith (1995), takes advantage of a route to an isolated tree. Intriguingly, the generic name for this species, *Petaurus*, translates to 'rope dancer' (Lindenmayer 2002).

SUMMARY

Roads have many deleterious effects on wildlife. Direct effects, such as mortality, are obvious. In contrast, many indirect effects of roads are cumulative and involve subtle ecological changes that are not as obvious but may be more harmful. Concern about the linear barrier effects of roads has motivated conservation biologists to discuss the actions that are needed to ameliorate these effects. Several measures that attempt to link historically related natural regions and ensure movement between such regions have been trialed. Most have been directed at facilitating the movement of ground-dwelling animals, with little discussion of overpasses for arboreal fauna. However, simple, inexpensive overpass structures have been in use since 1963 and there is evidence that they may enhance the movement of a variety of arboreal mammals during construction and continued operation of roads and other linear barriers.

Chapter 3: Implications of the use of canopy bridges by arboreal mammals for managers of road systems and wildlife in the Wet Tropics region

Abstract. This chapter provides a definition of biodiversity and finds that its conservation is an obligation for stakeholder groups at all levels. Despite institutional arrangements designed to prevent biodiversity loss, wildlife continues to be lost in Australia and many threatening processes, such as land clearing and fragmentation of ecosystems, still pose major problems. This is found to be the case in the Wet Tropics region, which is considered a significant area for the preservation of rare or uncommon Australian mammals. Whilst effort is made to conserve the biodiversity of this region, including critical habitats and rare or threatened species, road corridors are found to have the potential to fragment and impact adversely on these values. In the Wet Tropics, as elsewhere, arboreal mammals comprise a group of animals seriously affected by roads. The species most drastically affected by habitat fragmentation caused by roads are the endemic rainforest ringtail possums, especially the lemuroid ringtail, while for Lumholtz's tree-kangaroo, roadkill is considered a threatening process. All are gazetted as 'rare' species under State nature conservation legislation. The findings that simple, inexpensive overpass structures may enhance the movement of arboreal mammals across roads thus have implications for managers of roads and wildlife in this region.

CHAPTER 3: IMPLICATIONS OF THE USE OF CANOPY BRIDGES BY ARBOREAL MAMMALS FOR MANAGERS OF ROAD SYSTEMS AND WILDLIFE IN THE WET TROPICS REGION

INTRODUCTION

The Wet Tropics World Heritage Area and surrounding region has an extraordinary degree of biological diversity or 'biodiversity' (S. Goosem 2000d). The vegetation of this area is predominantly rainforest, but there is a range of sclerophyll forest and woodland types, mangroves and swamp communities (S. Goosem 2001). Although covering just one-thousandth of the land surface of the Australian continent, these vegetation communities contain more than 3,850 vascular plant species (Davis et al. 1995; also G. Werren, 2003 pers. comm) and support more than one-third of Australia's mammal species (Trott 1996). As already mentioned, this area is considered to be particularly significant for its diversity of arboreal marsupials. However, many of these species are particularly vulnerable to forest fragmentation caused by linear barriers such as roads (e.g., Winter 1984, 1991; Winter & Goudberg 1995a; Laurance 1995, 1997; Goosem 1997, 2000a; Wilson 2000).

This chapter provides a definition of biodiversity and outlines the legal obligations of stakeholder groups to conserve it. It discusses the present situation in relation to biodiversity conservation in Australia, particularly in the context of roads in the Wet Tropics, and details the adverse effects of roads on arboreal mammals in this area. It concludes with an assessment of the implications for managers of road systems and wildlife in the Wet Tropics region of the findings presented in the previous chapter, i.e., that simple, inexpensive overpass structures enhance the movement of arboreal mammals across roads.

BIODIVERSITY CONSERVATION

Biodiversity is described as 'the variety among and within living things and the ecological systems where they live' (ANZECC 1996). When using this definition, biodiversity is usually considered at three levels (Adam 1995; ANZECC 1996):

- genetic variation within species;
- variation between species (i.e., the number of species); and
- the diversity of habitats and/or ecosystems.

However, Farmer-Bowers (1997) suggested that it might be more helpful to think of biodiversity as 'native flora and fauna in sufficient quantities to ensure the natural variations in communities are maintained'.

Beattie (1995) identified beauty, utility and profit as three overlapping reasons for the conservation of biodiversity. Other values might include spiritual enrichment (possibly a subset of beauty) and the intrinsic right of species to exist (see Purdie 1995). In short, biodiversity contributes to the continued existence of a healthy planet, our own well-being and economies (Burbidge & Wallace 1995). Accordingly, the conservation of biodiversity is now legally mandated in many places throughout the world, including Australia. This is especially relevant in the context of the current study because the Wet

Tropics is considered to be a biodiversity ‘hotspot’ of global importance (see Davis et al. 1995).

Legal obligations of managers of road systems and wildlife with respect to biodiversity conservation

The United Nations played an important role in placing environmental issues on the international, national and local agenda (Duncan 1993). Indeed, the first global environmental summit in 1972 highlighted evidence of the rapid depletion of biodiversity, among other things. Since then, according to Duncan (1993), government regulation of the environment has become something of an international growth industry.

Australia became one of the first of 140 countries to commit to the identification, protection and conservation and presentation of World Heritage properties when it adopted the Convention Concerning the Protection of the World Cultural and Natural Heritage (the World Heritage Convention) in 1974. The World Heritage values of the WTWHA are documented in the original nomination and a recent update prepared for the Wet Tropics Management Authority (WTMA). As reported in **Chapter One**, the large concentration of arboreal marsupials in the rainforests of northeastern Queensland was one of the reasons for World Heritage listing.

The International Convention on Biological Diversity, which deals at a global level with biodiversity conservation, its sustainable use and the fair and equitable sharing of the benefits arising from this use, was ratified by Australia in 1993. This followed the 1992 signing of the Intergovernmental Agreement on the Environment by the Australian Commonwealth, the States and the two Internal Territories and the Australian Local

Government Association. The conservation of biodiversity was a fundamental consideration in the Intergovernmental Agreement, which was designed to provide a mechanism by which to facilitate:

- a cooperative national approach to the environment;
- a better definition of the roles of the respective governments;
- a reduction in the number of disputes between the Commonwealth and the States and Territories on environmental issues;
- greater certainty of government and business decision making; and
- better environment protection.

Then, in 1996, the Commonwealth Government released its National Strategy for the Conservation of Australia's Biological Diversity. This Strategy aimed to 'bridge the gap between current activities and those measures necessary to ensure the effective identification, conservation and ecologically sustainable use of Australia's biological diversity' (ANZECC 1996, p. ii). It was reviewed in 2001 by ANZECC, who found that Commonwealth initiatives including Natural Heritage Trust programs and Regional Forest Agreements, as well as many initiatives in individual jurisdictions have all assisted in progress towards achieving the aim of the Strategy (ANZECC 2001). Other Australian instruments, such as the National Strategy for Ecologically Sustainable Development and the National Forestry Policy Statement, also stress the importance of conserving biodiversity.

Perhaps the most significant Commonwealth initiative has been the introduction of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). As its title suggests, one of the objects of this Act is to promote biodiversity conservation. At its commencement on 16 July 2000, the Act repealed the following relevant Commonwealth legislation:

- *Endangered Species Protection Act 1992*;
- *World Heritage Properties Conservation Act 1983*;
- *National Parks and Wildlife Conservation Act 1975*; and
- *Environmental Protection (Impact of Proposals) Act 1974*.

The EPBC Act is the biggest reform of Commonwealth environment laws since the first environment statutes were enacted in the early 1970s. Of particular relevance to managers of roads and wildlife in the Wet Tropics region are the specific requirements for activities that have a significant impact on nationally threatened species and ecological communities and protected areas (including World Heritage properties and values). Accordingly, the Commonwealth Environment Minister has already considered several road construction and maintenance proposals in the region (e.g., Kuranda Range, Mission Beach) under the new assessment and approval regime.

Of particular relevance to the current study, the Queensland Government enacted special legislation for protection and management of the WTWHA in 1993 (*Wet Tropics World Heritage Protection and Management Act 1993* (Qld)) and the Commonwealth followed a year later (*Wet Tropics of Queensland World Heritage Area Conservation Act 1994* (Cwlth)). These Acts establish responsibilities for the protection, conservation, presentation, rehabilitation and transmission to future generations of the WTWHA, within the meaning of the World Heritage Convention. The *Wet Tropics Management*

Plan, released after much controversy in 1998, was prepared to help Australia meet these international obligations and its provisions are legally enforceable under the Queensland legislation. The Plan is also about maximizing the benefits of the Area for the local and wider community, while minimizing threats to the Area's integrity (WTMA 1997). It is also about enabling groups and individuals throughout the Wet Tropics region to contribute to the management of the Area.

Management of the WTWHA is on three levels (Environment Australia n.d.):

1. A State/Commonwealth Ministerial Council coordinates policies and funding.
2. WTMA is responsible for general planning, and is advised by Community Consultative and Scientific Advisory Committees.
3. Several Queensland government departments manage the day-to-day aspects of the Wet Tropics.

Key Queensland government departments responsible for roads in the WTWHA include QDMR and the QEPA. QDMR control state-owned roads while the QEPA have specific statutory responsibilities for the sound environmental management of protected areas (e.g., national parks and forest reserves) and other conservation and environmental responsibilities. These departments must ensure that management of roads and tracks within the Area is consistent with provisions of the *Wet Tropics Management Plan 1998* and policies for its implementation. The most important consideration is the likely impact of a proposed activity on the Area's integrity. According to Schedule 3 of the Plan, 'integrity' of the area, or of land in the area, means the extent to which the World Heritage values of the area or land-

a) are in their natural ecological, physical and aesthetic condition; and

b) are capable of sustaining themselves in the long term.

The practical implications of this with respect to the current study are explored further in **Chapter Six**.

There is other Queensland legislation containing statutory provisions relevant to managers of roads and wildlife in the region, both within and outside of the WTWHA. These include but are not limited to:

- *State Development and Public Works Organisation Act 1971*
- *Nature Conservation Act 1992*;
- *Environmental Protection Act 1994*;
- *Land Act 1994*; and
- *Vegetation Management Act 1999*.

The *Integrated Planning Act 1997* is also relevant inasmuch as its objective of 'ecological sustainability' is supported by stated obligations such as (Chadwick 2000):

- taking account of long and short term environmental effects of development at local, regional, State and wider levels;
- applying the precautionary principle; and
- avoiding if practicable, or otherwise lessening, the adverse environmental effects of development.

Additionally, places supporting biodiversity or resilience are recognised as 'valuable features' under this Act, which means that they are one of the core matters that must be addressed by local governments in a planning scheme (Kingham 1999).

Local governments, as the other key authority responsible for roads in the Wet Tropics region, are also bound by a National Local Government Biodiversity Strategy, which was endorsed by unanimous vote at the National General Assembly of Local Government in November 1998. This document represents an agreed local government position at the national level on the management of biodiversity, recognising that (Campbell & Kitching 1999):

- conservation and sustainable use of our natural resources will only be achieved through local area planning and management, along with community education and participation;
- there is a willingness by local government across Australia to play a lead role in dealing with our most pressing and complex conservation issue – the loss of biodiversity; and
- a clear and cooperative partnership arrangement is required between the three spheres of government.

The three spheres of government were also part of a joint initiative with key community interest groups that developed a comprehensive Regional Plan for Far North Queensland to guide decision making related to growth, development and management of the region over the next 20 years or so (FNQ RPAC 2000). The FNQ Regional Plan is a non-statutory policy document that provides essential advice to the regional community and to public decision-makers when undertaking their planning, budgetary, infrastructure provision and resource management responsibilities (FNQ RPAC 2000). The importance of biodiversity conservation to the region is recognised by the third Regional Goal, to 'protect and enhance the biological diversity and ecological integrity of terrestrial, freshwater, coastal, estuarine and marine environments' (FNQ RPAC 2000, p. 53). Of particular relevance to the current study, the arboreal rainforest marsupials (possums & tree kangaroos) are recognised as regional conservation priorities (FNQ RPAC 2000).

It is clear that the conservation of biodiversity, both generally and specifically in the Wet Tropics, is therefore an obligation for stakeholder groups at all levels (Farmar-Bowers 1997). This was supported by Bates (1997) who found, in a review of responsibilities in relation to construction, use and maintenance activities within road reserves, that:

> Road authorities (state and local government) and service providers such as energy, water supply and sewerage authorities, as the statutory bodies in whom management and control of roads and infrastructure laid in road reserves is vested, undoubtedly have a legal responsibility as well as powers in respect of the environmental effects of their activities. They must comply…with the statutory directions contained in a wide range of environmental legislation
>
> Bates (1997, p 3).

As a consequence, environmental management has become a high corporate priority for road authorities across the country. In Queensland, the QDMR has produced several documents that provide direction for the department to become an environmentally responsible corporation. These include:

- Department of Main Roads Strategic Plan;

- Road Network Strategy; and
- Roads Implementation Plan.

QDMR has also developed an Environmental Policy that commits the department to the:

> …protection of the environment by observing the Government's policy of ecologically sustainable development.
>
> Main Roads will contribute to sustainable development in the provision of transport infrastructure through constant improvement in environmental performance…and by fulfilling the requirements of State and National strategies and laws
>
> QDMR (1998, p. 2).

The Policy represents the departmental commitment to 'best practice' environmental management and gives a clear statement of intent for QDMR with respect to environmental planning, assessment and management.

The QDMR Environmental Management Strategy was developed as a basis for self-regulation of activities that might impact on the environment. Featuring a Corporate Environmental Management System, based on the interim Australian standard AS/ISO 14000, this Strategy identified four key outcome areas for QDMR in achieving sustainable transport, namely:

1. Biodiversity and Ecological Systems
2. Amenity and Quality of Life
3. Resource Conservation
4. Global Environment

The Strategy also emphasised the department's commitment to continual improvement in the pursuit of 'best practice' roads delivery and environmental management and committed it to using the most effective strategies to avoid or minimise the risk of harmful effects on the environment in the course of its operations. This is reflected in QDMR's *Road Project Environmental Management Processes Manual* (1997b) and resulted in the development of a series of best practice environmental management manuals, including one for the planning, design, construction, maintenance and operation of roads in the Wet Tropics.

The present situation

Despite the institutional arrangements referred to above, Australia continues to lose its wildlife and many threatening processes, such as land clearing and fragmentation of ecosystems, still pose major problems (Krockenberger et al. 1997; Australian State of the Environment Committee 2001; Williams et al. 2001; National Land & Water Resources Audit 2002). The EPBC Act lists 108 species of plants and animals in the 'extinct' category (i.e., there is no reasonable doubt that the last member of the species has died). This represents a minimum count of species lost since European settlement; there may well have been others. Of the remaining 1600 species of terrestrial vertebrates, Recher and Lim (1990) estimated that 300 are still threatened with extinction. About a third of these are found in Queensland (i.e., 93 species of terrestrial vertebrate prescribed as either 'vulnerable' or 'endangered' under the Queensland *Nature Conservation Act 1992*), and one tenth are found in the Wet Tropics region. In fact, the Wet Tropics region provides the only habitat for more than 400 species of plants and 76 species of animals that are 'rare', 'vulnerable' or 'endangered' under the Queensland *Nature Conservation Act 1992*

(Goosem 2000d). Many of these species are confined to the region – along with Cape York, the Wet Tropics has the highest level of mammal endemism in the country (National Land and Water Resources Audit 2002). Not surprisingly, it is considered a significant area for the preservation of rare or uncommon Australian mammals (Delahunt et al. 1991) (**Table 3.1**).

Table 3.1: Rare and threatened[1] terrestrial mammals of the Wet Tropics[2]

Scientific name	Common name	Conservation status
Bettongia tropica	**Northern bettong**	**Endangered**
Dasyurus maculatus gracilis	**Spotted-tailed quoll (northern subsp.)**	**Endangered**
Petaurus gracilis	**Mahogany glider**	**Endangered**
Hipposideros cervinus	Fawn leaf-nosed bat	Vulnerable
Hipposideros semoni	Greater wart-nosed horseshoe-bat	Vulnerable
Macroderma gigas	Ghost bat	Vulnerable
Murina florium	**Flute-nosed bat**	**Vulnerable**
Petaurus australis reginae	**Yellow-bellied glider (northern subsp.)**	**Vulnerable**
Taphozous australis	Coastal sheathtail-bat	Vulnerable
Antechinus godmani	**Atherton antechinus**	**Rare**
Dendrolagus bennettianus	**Bennett's tree-kangaroo**	**Rare**
Dendrolagus lumholtzi	**Lumholtz's tree-kangaroo**	**Rare**
Hemibelideus lemuroides	**Lemuroid ringtail possum**	**Rare**
Hipposideros diadema	Diadem horseshoe-bat	Rare
Kerivoula papuensis	Golden-tipped bat	Rare
Pseudochirulus cinereus	**Daintree River ringtail possum**	**Rare**
Pseudochirulus herbertensis	**Herbert River ringtail possum**	**Rare**
Pseudochirops archeri	**Green ringtail possum**	**Rare**
Rhinolophus philippinensis	Large-eared horseshoe-bat	Rare
Saccolaimus saccolaimus	Naked-rumped sheathtail-bat	Rare
Sminthopsis leucopus	White-footed dunnart	Rare

[1]According to *Nature Conservation (Wildlife) Regulation 1994* (Including amendments to SL No. 215 of 2001); [2]Species listed in **bold** type endemic to the Wet Tropics region (after Nix & Switzer 1991)

According to Lunney (1991), the degree to which Australia's remaining forest fauna is conserved should become a primary performance indicator for the nation to be assessed as a civilized society. Historically, the conservation of wildlife in Australia has relied on (Short & Smith 1994):

- protection from hunting and trade;
- reservation of land as national parks and nature reserves; and
- faunal surveys to map distribution and abundance.

These approaches are now considered insufficient to stabilise the decline of threatened species or to promote their recovery (Lunney 1991; Braithwaite et al. 1993; Short & Smith 1994; Cork & Catling 1997; see also Hale & Lamb 1997). Burbidge (1995) reported that two main approaches are now being taken to the management of threatened species. One is to treat a species on its own, according to a recovery plan that documents the threats to it and to prescribe actions to counteract these. The other approach is to concentrate on ameliorating the threatening processes *per se*.

It is recognised that these efforts must target the entire regional landscape, not just isolated reserves or habitat remnants (Laurance 1995, 1997; Aschwanden 2001) and initiatives that maintain or improve ecosystem connectivity are considered to be especially important (Laurance 1995, 1997; Laurance & Gascon 1997; Thwaites 1998). As discussed in **Chapter 2**, management or modification of the landscape that surrounds habitat remnants is one way of facilitating movement between such remnant patches and structures designed to manage the connectivity of wildlife across roads are becoming standard management tools.

ROADS AND THE WET TROPICS

In **Chapter 2**, I reported that there are 1,427 km of snig tracks, roads and highways crisscrossing the WTWHA (from Goosem 1997). Wilson (2000) considered this a conservative estimate, as it did not include roads less than 7 m wide (forestry track including shoulders). Taking the numerous logging and snig tracks into account, she estimated that there are 3,427 km of roads in the WTWHA (**Table 3.2**).

Table 3.2 Length of roads in rainforest within the Wet Tropics (Source: Wilson 2000)[1]

Data source	*AUSLIG*	*WTMA*
Above 300 m altitude	915 km	2590 km
Above 300 m altitude	715 km	2127 km
Above 300 m altitude	568 km	1890 km
Total length	1397 km	3427 km

[1]Estimates of the length of roads varied between the two sources due to the different scales (AUSLIG 1:250,000: WTMA 1:50,000) at which the information was digitized. The fine resolution of the WTMA data includes the numerous logging and snig tracks.

These roads are used for transport, recreation and education purposes, land holder access and access to public utilities (QDMR 1998). Parts of the regional road network link urban centres, residential areas and major highway systems throughout the Wet Tropics region. As reported by the QDMR (1997a), the importance of the agricultural and tourism industries to the economy of the Wet Tropics region, their dependence on transportation, together with the geographical remoteness of the region from the rest of Australia mean that international, interstate and intra-regional transport linkages are an important component of the region's economy.

Over 700,000 visitors to the region arrive by vehicle (QDMR 1997a) and tourism in the WTWHA is estimated to generate over AU$750 million each year (Driml 1997). The tourism value of roads has two aspects (QDMR 1997a):

1. Transport of tourists and passengers throughout the region.

2. As scenic routes that present the region's unique landscapes.

As already mentioned, there is a World Heritage obligation to present the significant natural values upon which much of the regional economy depends.

However, roads have a detrimental effect on the conservation values of the Wet Tropics region (QDMR 1998). Whilst effort is made to conserve the biodiversity of the region, including critical habitats and rare or threatened species, road corridors have the potential to fragment and impact adversely on these values (QDMR 1998). In the Wet Tropics, as elsewhere, arboreal mammals comprise a group of animals seriously affected by roads.

Effects on arboreal mammals

Most of the arboreal mammals restricted to the Wet Tropics are officially listed as rare or threatened due to their restricted geographical distribution. This means that governments are required to have regard to the management requirements needed to conserve these species. The 'rare' species include the rainforest ringtail possums and the tree-kangaroos: Lumholtz's tree-kangaroo, *Dendrolagus lumholtzi*, and Bennett's tree-kangaroo, *D. bennettianus*. The mahogany glider, *Petaurus gracilis*, is listed under both State and Commonwealth legislation as 'endangered', as is the semi-arboreal spotted-tailed quoll (northern race), *Dasyurus maculatus gracilis*. Roads in the Wet Tropics adversely affect all of these species, particularly those that are rainforest-dependent (the mahogany glider is found in coastal lowland woodland [Jackson & Claridge 1999]).

Winter (1984) coined the term 'quaternary disjunctions' for linear barriers caused by clearing, such as roads. He pointed out that the decision as to whether a quaternary disjunction exists at a particular location is subjective and/or arbitrary and will remain so until such time that genetic interchange across potential disjunctions is measured (e.g., Gerlach & Musolf's (2000) study of the barrier effects of various roadways on gene flow and the genetic substructuring of bank vole populations in southern Germany and Switzerland). It is possible however, to estimate the relative ability of species to cross a disjunction, on the basis of their mobility, use of habitat, and altitudinal zonation. By any measure and as discussed below, the arboreal mammal species most drastically affected by habitat fragmentation caused by roads in the Wet Tropics is the lemuroid ringtail possum (Pahl et al. 1988; Laurance 1990, 1997; Winter 1991; Wilson 2000).

Lemuroid ringtail at risk

The lemuroid ringtail possum (see also detailed species account given in **Chapter Four**) occurs only in montane rainforest above about 480 m on the Atherton Tablelands, and above 900 m on the Mt Carbine Tablelands (Flannery 1994). It has a very restricted distribution of only 300,000 ha in these two isolated areas (Flannery 1994). Given that most of this area is now within the WTWHA (see **Figure 3.1**) and because the lemuroid ringtail is still relatively common in the small area where it is found (particularly above about 800 m) some authors have concluded that its conservation status is secure (e.g., Flannery 1994; Winter & Goudberg 1995a). However, considerable fragmentation of rainforests has occurred within these areas (particularly the southern Atherton Tableland), leaving only scattered forest patches ranging from about 1 to 600 ha (Laurance 1990).

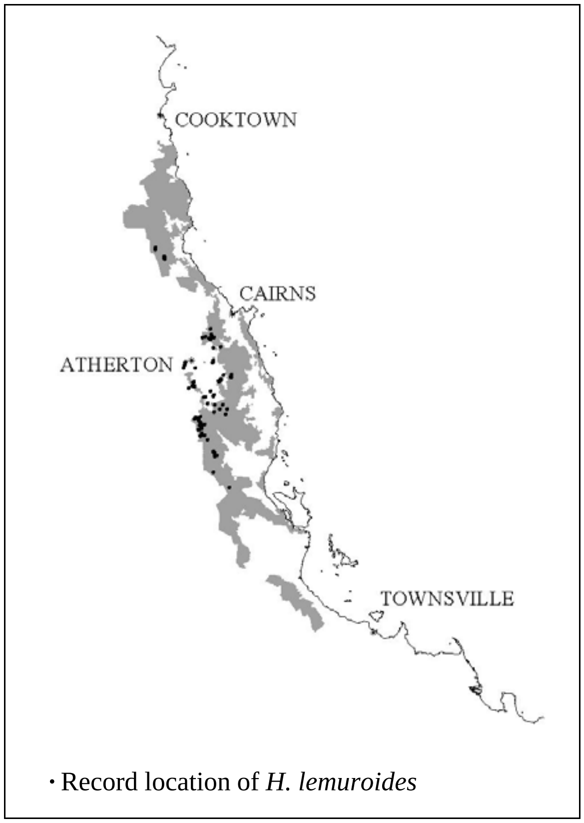

Figure 3.1 Recorded locations of the lemuroid ringtail possum in the Wet Tropics region (WTWHA shaded). Scale 1:6 million approx. (Map by Emily Bolitho, based on data compilation and systematic surveys; see Williams et al. 2003)

Laurance (1990, 1995; see also Malcolm 1998) found that the local rarity (or abundance) of arboreal folivores can be a misleading indicator of extinction proneness, and that some locally abundant species are highly vulnerable in fragmented forests. He cited the lemuroid ringtail as an example, finding that it declined by >97 percent in abundance in forest fragments and disappeared rapidly - from a small (1.4 ha) fragment in only three to nine years and from larger (43-75 ha) fragments in 35-60 years. Kennedy (1990) agreed, contending that the lemuroid ringtail must be considered as potentially vulnerable, given its restricted rainforest range and its susceptibility to disturbance. The potential adverse effects of climate change in the region heighten the species' vulnerability (S. Williams, 2002, pers. comm.). This is discussed further in **Chapter Six**.

It is not known why lemuroid ringtails are so susceptible, although potential contributing factors include (Winter 1984; Laurance 1990; R. Russell 2003 pers. comm.):

- their relatively limited high-altitude habitat;
- their high degree of specialisation on leaves of primary forest trees; and
- the obligatory requirement for tree cavities as den sites.

In relation to the last point, Herbert River ringtails occasionally build their own nests or rest in large epiphytic ferns if dens are in short supply (Russell 1980; also R. Russell, 2003 pers. comm.). Presumably, the closely related Daintree River ringtails do the same. The green ringtail, meanwhile, relies on its cryptic colours, simply hunching its body into a ball to sleep on a branch by day (Russell 1980; Winter & Goudberg 1995b; Menkhorst & Knight 2001). The lemuroid ringtail also differs from the other rainforest ringtails in that it almost never ventures to the ground (Laurance 1990; Wilson 2000).

As discussed by Gamlin & de Rohan (1996), canopy-dwellers need to move around within the precarious world of the treetops. All face barriers in their daily movements, irrespective of the scale on which they operate. For a large mammal, such barriers may be gaping chasms between tree crowns in the canopy, created by the phenomenon of 'crown-shyness'. Moving across natural gaps at great height is a challenge met in several ways. Some animals can simply stretch across the void while for others, there is the option of leaping. Lemuroid ringtails are leapers - they launch themselves into the air and land, sometimes on a small branch but more often sprawled across a mass of fine twigs and leaves on the outskirts of the next tree crown. The lemuroid ringtail can cover distances of 2-3 m in this way (Flannery 1994 and pers. obs.). There is strong convergence between canopy mammal faunas on different continents (Emmons 1995) and lemuroid ringtails have many ecological equivalents in Old World rainforests; the specific name *lemuroides* refers to an alleged similarity to the lemurs of Madagascar (Kerle 2001). Their behaviour supports this name as well as shared physical characters (e.g., short snout and forward facing eyes). The other rainforest ringtails do not leap and generally move across branches on all fours, gripping tightly and using their grasping, prehensile tails for balance.

The most distinctive features of the rainforest are its closed canopy and structural composition that sharply define it from neighbouring habitats. Consequently, animals that occur there are often reluctant to venture beyond the shelter of the closed canopy (Winter 1991). The lemuroid ringtail is one such animal and is not likely to come to the ground to cross any gaps that it cannot bridge by leaping (Wilson 2000). The strong aversion for descending to ground level shown by this species means that the presence of a road that lacks any canopy connection may be a complete barrier to movement (Wilson 2000).

Pahl et al. (1988) and Laurance (1990, 1995) found that the Herbert River ringtail possum appears less vulnerable to rainforest fragmentation than the lemuroid ringtail although fragmentation can still lead to local extinctions. The results of Wilson's (2000) study were consistent with these findings; the Herbert River ringtail will cross wide internal gaps within the forest but such gaps are a barrier to the movement of the lemuroid ringtail. Nevertheless, Herbert River ringtails prefer to use canopy connections where available. Paradoxically, provision of canopy connectivity for Herbert River ringtails is actually more difficult than for lemuroids because they require more solid canopy connections and are less agile when it comes to vines and thin branches (Goosem 2000b). The behaviour noted by Mike Trenerry (quoted in Goosem 2000b, p. 111) whereby '…Herberts will use their own weight to create links across the canopy by weighing down the ends of the branches' was also observed during the current study. Even when crossing open spaces, Herbert River ringtails prefer to be above the ground as Wilson (2000) discovered when she observed a Herbert River ringtail using barbed wire as a means of moving in a powerline clearing. Similarly, Augee (1996, cited in AMBS 2000) found that, although common ringtail possums come to the ground when necessary, they prefer to move through the lower vegetation strata.

The green ringtail possum, meanwhile, appears to be the least-affected of the rainforest ringtails to fragmentation (Laurance 1990, 1995; Wilson 2000). One was seen crossing a road at ground level during the current study (Tinaroo Falls Dam Road, 5/5/00) and Goosem (2000b) reported that many researchers have observed roadkills of this species, highlighting the fact that they will descend to the ground to cross roads. Wilson (2000) recorded numerous crossings of this species and a wide powerline corridor had no obvious effects on the movements of this species in her study. Nevertheless, like the other ringtails, they probably prefer to be above the ground.

In August 2000, I wrote to a local community conservation group, the Tree Kangaroo and Mammal Group, requesting anecdotes from members about possums crossing artificial structures. Just one affirmative response was received, from Ms Amanda Freeman, who saw a striped possum using a phone cable near Lake Eacham. The cable consisted of two twisted strands of about 2 cm diameter each running between poles c.25 m apart. It ran parallel with, and a couple of metres away from, the forest edge (A. Freeman, 2000 pers. comm.). Then, in March 2001, a green ringtail was rescued from a powerline on the outskirts of Atherton in March 2001 (M. Cianelli, 2001 pers. comm.). This record is notable as it represents the first known example of a rainforest ringtail using a powerline as a crossing route. Of course, this could simply be an artifact of the rarity of powerlines in their preferred habitat!

Although Laurance (1990, 1995) found that Lumholtz's tree-kangaroo exhibited negative but intermediate responses to fragmentation, its major problem with roads appears to be the cars that travel on them. Because it readily comes to the ground to cross between trees and forest patches, individuals of this species are often found as road kills. In a community survey undertaken by the Tree Kangaroo and Mammal Group, 250 records were obtained of road-killed tree kangaroos on the Atherton Tablelands over the last decade (Schmidt et al. 2000). This led Schmidt et al. (2000) to conclude that roadkill was an important cause of mortality for this species. Goosem (2000a) proposed that it might be a threatening process.

The implications of the above are clear:

- lemuroid ringtails need assistance to cross canopy gaps that they cannot bridge by leaping;

- other possum species, while they will come to the ground, prefer to move through the trees; and
- roadkill adds to the pressures upon rare and threatened native mammal populations.

The last point is also relevant in terms of presentation of the World Heritage values of the WTWHA, one of the core responsibilities of WTMA (see discussion in **Chapter Six**). According to Newell (1999a), the carnage of native fauna on the roads throughout Australia is something that overseas visitors often find immediately striking and appalling. Certainly in Tasmania visitors are often distressed at the high number of roadkilled animals they see (Tasmania Parks and Wildlife Service 1998). According to local conservation groups (B. Beavis, 2002 pers. comm.) and tour operators (R. Tagawa, 2002 pers. comm.), residents and visitors to the Wet Tropics region express similar sentiments (see also Newell 1999a).

Because it is a generalist and moves easily on the ground, one mammal very frequently roadkilled in both Tasmania and the Wet Tropics is the brushtail possum (e.g., Goosem 2000b; QDMR 2000). In urban Launceston, Tasmania, annual road mortality of the resident brushtail population (Tasmanian subspecies, *T. v. fuliginosus*) exceeds local birth rate (Statham & Statham 1997, cited in Jones 2000). Two subspecies are thought to occur in the Wet Tropics, the coppery brushtail, *T. v. johnstoni*, which occurs in upland rainforest and the nominate race, *T. v. vulpecula*, which occurs in more open forest. Although roadkill is not currently considered to be a significant cause of mortality for either subspecies (Goosem 2000b), complaints by residents and tourists alike suggest that the road carnage detracts from their World Heritage experience. It might interest managing authorities to learn that in Greece, the Automobile Club of Greece and the Scout movement have both agreed to help the National Office of Hellenic Tourism to remove dead animals from the nation's roads (*The Sunday Age*, 10/10/99).

Use of natural connections

According to Gamlin and de Rohan (1996; see also Rose 1978), routes connecting trees are rare and those that exist become well worn. They suggest that animals memorise the best footpaths, remembering convenient gangways and underpasses, shortcuts and launchpads. This certainly appears to be the case in the Wet Tropics, where arboreal runways – especially links formed between canopy gaps – are used by all species of possums (Goosem & Turton 1999; Wilson 2000). Scent marking of these runways occurs frequently (Goudberg 1990, cited in Wilson 2000). Further, all species of possums in Wet Tropics rainforests, including the rainforest ringtails and the brushtail, have been observed utilising natural connections to cross roads in the region (Goosem 2000b).

Conversely, tree-kangaroos most commonly move between trees at ground level (Newell 1999a). Only one of the 33 respondents to a questionnaire designed to collate experience and knowledge with respect to arboreal species and their road crossing habits reported seeing tree-kangaroos cross a road via a canopy connection (Goosem 2000b). Nonetheless, a Lumholtz's tree-kangaroo was observed sleeping in a canopy connection over the road during the day while another was observed hopping on large branches in the canopy from one tree to another (Goosem 2000b). Tree-kangaroos also use exposed branches or vines in their natural environment. In one recent report, a Lumholtz's tree-kangaroo was seen moving upside down along a vine spanning a 5 m wide rainforest stream (K. Coomber, 2001 pers. comm.). There has also been an unconfirmed report that tree-kangaroos have used ropes fitted in the large underpasses currently being trialed at East Evelyn (M. Goosem, 2003 pers. comm.).

Investigation into artificial connections

In a paper on conservation issues in northeastern Queensland, Winter (1991) asked whether overpasses made a difference to the ability of rainforest mammals to cross roads. As reported in **Chapter Two**, Rupert Russell designed and built his bridge in 1995. Then, in 1997, QDMR released its *Best Practice Manual for the Planning, Design, Construction, Maintenance and Operation of Roads in the Wet Tropics*. The mission for the implementation of the manual was ‘to provide safe, equitable and economic roads within the wet tropics region while presenting, conserving and rehabilitating the area’s unique natural and cultural values to the greatest extent practicable’ (QDMR 1997a, p. O-1). The manual’s overall goal was ‘to improve the performance and management of road corridors within the Wet Tropics region by using current information and the latest technology in such a way that takes into account the costs and benefits to the environment, community and economy’ (QDMR 1997a, p. O-1).

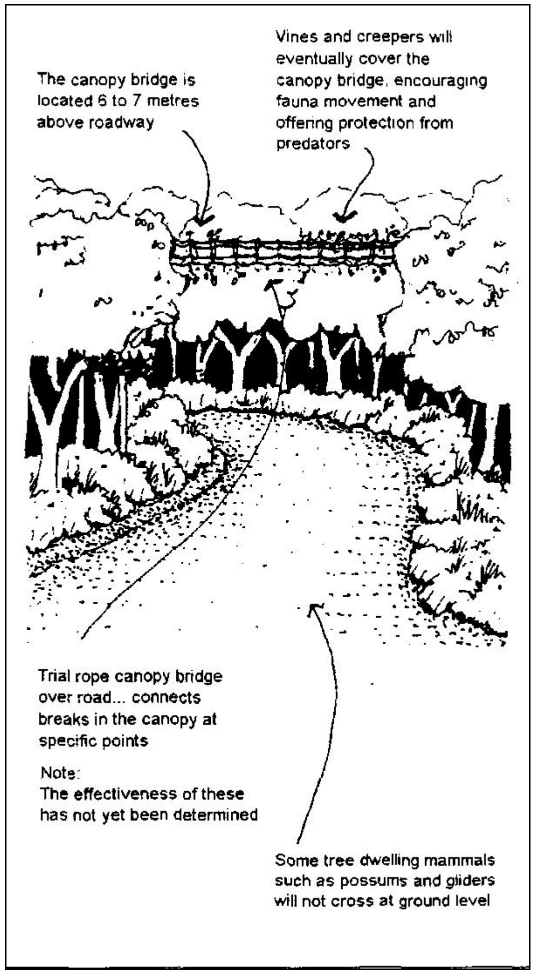

Figure 3.2 Canopy bridge (Source: QDMR 1997a, p. E-33)

The development of the Best Practice Manual was overseen by a steering committee including staff of the Rainforest CRC and QDMR, QEPA, WTMA, the then Department of Natural Resources, Alliance for Sustainable Tourism, and local government. The Manual was intended for use by all those involved in the planning for, design of, operation and maintenance of roads in the Wet Tropics region. Its purpose was ‘to assist in the implementation of best practice in the development and ongoing operation of roads within the region, taking into account the World Heritage and other natural, cultural and conservation values of the region, with particular emphasis on those values that are unique and that the Queensland community is obligated to preserve in a global and Australian context' (QDMR 1997a, p. O-2).

Of particular relevance to the current study, the QDMR Best Practice Manual carried a simplified illustration of the existing B Road bridge, along with the recommendation that the potential use of canopy bridges be investigated (see **Figure 3.2**). The results of these investigations constitute the bulk of the remainder of this thesis. The results of these investigations are documented in the remainder of this thesis.

SUMMARY

Managers of road systems and wildlife in the Wet Tropics region (e.g., QDMR, QEPA, local government, WTMA) have obligations to manage the environmental effects of their activities, particularly in the WTWHA. These obligations are given force by the many laws, policies and strategies by which these authorities are bound or to which they are committed. It is obvious that the special faunas of the region have special needs, especially in relation to the adverse impacts of roads. It has been shown that simple, inexpensive overpass structures may enhance the movement of possums and other arboreal wildlife across roads and that, theoretically, the species that would most benefit by the installation of these structures in Australia are restricted to the Wet Tropics region (e.g., lemuroid ringtail possum). Responding to calls to investigate and, if justified, implement practical measures to reduce roadkill and habitat fragmentation, QDMR recommended research into canopy bridges. The next two chapters detail the results of these investigations and the materials and methods employed.

Chapter 4: Use of canopy bridges by arboreal mammals in the Wet Tropics region – materials & methods

Abstract. Responding to calls to investigate and, if justified, implement practical measures to reduce roadkill and habitat fragmentation, QDMR recommended research into canopy bridges. This chapter describes the various materials and methods employed to monitor the use of canopy bridges by arboreal mammals at three separate sites in the Wet Tropics region. These comprise an existing rope tunnel built in 1995 across an old logging track near Cairns, two rope bridges of simpler design near Millaa Millaa - effectively rope ladders swung horizontally across an abandoned snig track - and a longer bridge spanning a sealed, dual carriageway between Millaa Millaa and Ravenshoe. All three sites were located in rainforests of the Atherton Uplands and methods employed at each of the sites included scat collection, remote photography, direct observation (spotlighting) and hair sampling. This chapter also provides an overview of the general study area and includes information on site selection and arboreal species assemblages, as well as the biophysical and land use contexts of the sites themselves.

CHAPTER 4: USE OF CANOPY BRIDGES BY ARBOREAL MAMMALS IN THE WET TROPICS REGION – MATERIALS & METHODS

INTRODUCTION

This chapter describes the materials and methods I employed to monitor the use of canopy bridges by arboreal mammals in the Wet Tropics region. It provides an overview of the study area and includes information on site selection and arboreal species assemblages, as well as the biophysical and land-use contexts of the sites themselves.

OVERVIEW OF STUDY AREA

As reported in **Chapter One**, the study was conducted in rainforests of the Atherton Uplands, northeast Queensland, wholly within or adjacent to the WTWHA. This region is a major centre of endemism for rainforest fauna (Nix 1991; Williams 1997) and supports a rich arboreal mammal assemblage (Kanowski 1999; Wilson 2000). The region (see **Figure 4.1**) consists of a mid to high plateau ranging from 600-1,200 m AHD. Mean annual rainfall varies from 1,425 mm at Atherton to 2,625 mm at Millaa Millaa with a pronounced summer wet season (Tracey 1982). As a result of past clearing, the majority of the rainforests exist as forest fragments (1 to 600 ha in area) surrounded by a mosaic of cattle pastures or crops interspersed by narrow (usually <50 m wide) ‘corridors’ of regrowth forest along streams (Laurance 1997). Large (>3000 ha) forest tracts survive only on steeper hillsides (Laurance 1997).

SITE SELECTION

B Road

As reported in the previous two chapters, the QEPA's Rupert Russell designed a canopy bridge in the form of a rope tunnel to encourage the movements of the rainforest ringtail possums in 1995. It was constructed with the assistance of WTMA and the then Far North Queensland Electricity Corporation across the Kauri Creek Road (otherwise known as the B Road) in the Danbulla State Forest, about 30 km southwest of Cairns (Site 1 on **Figure 4.1**). This site was chosen because there was no natural corridor for some distance each way, and lemuroid ringtails were seen simultaneously on both sides of the road at this point (R. Russell, 2003 pers. comm.). Although it was suggested that Herbert River ringtails used the bridge, no systematic observations had been undertaken at the site until my study.

Snig track

When it became clear as a result of the work reported here that arboreal species were using the original bridge as a crossing route, I initiated additional studies to test whether the design and position of canopy bridges influenced their use by the rainforest ringtails. Two simplified rope bridges were erected along an abandoned snig track on private property, about 10 km southwest of Millaa Millaa (Site 2 on **Figure 4.1**). This decision was based on several factors including prior knowledge of arboreal mammal assemblages within the area and the presence of suitable vegetation. Another consideration was the narrow configuration of the track resulting in overlapping tree canopies that would be unlikely to impede the movement of arboreal mammal species. This allowed investigation of whether the rainforest ringtails would use artificial structures in preference or in addition to natural crossing routes.

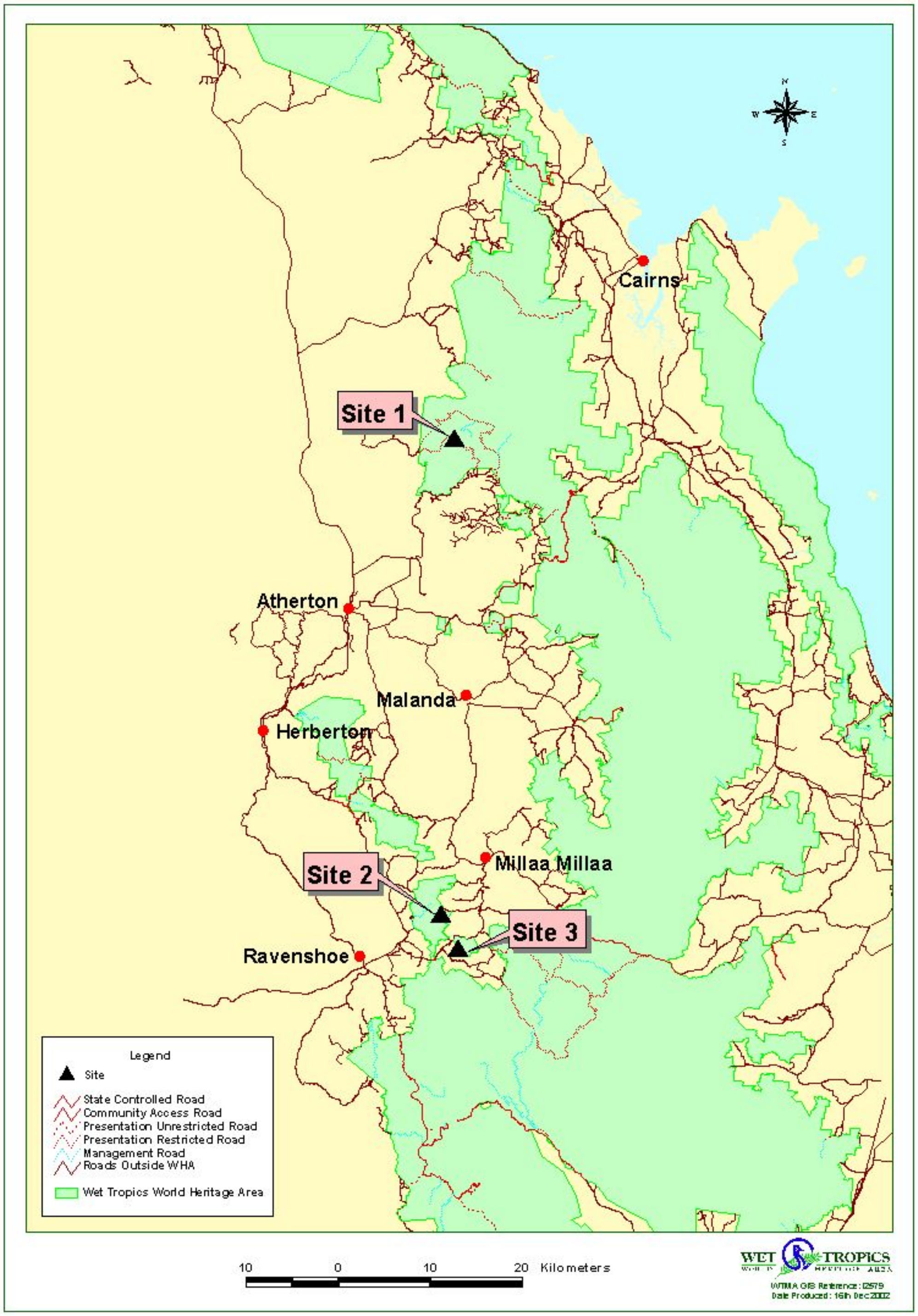

Figure 4.1 Study site locations

Old Palmerston Highway

About halfway through the study, an opportunity arose to install a canopy bridge along the Old Palmerston Highway, about 10 km east of Ravenshoe (Site 3 on **Figure 4.1**). The site was known to support a healthy population of lemuroid ringtails and a den being used by two individuals was destroyed at this location during roadside maintenance in 1997 (R. Wilson, 2001 pers. comm.; see also Wilson 2000). However, the most important consideration was the configuration of the road corridor – it was of a sufficient width and length to represent a likely impediment or heightened risk for the movement of arboreal mammals. It also carried more traffic than was the case at canopy bridge sites already established, which added another dimension to the study and enhanced its relevance to managers dealing with real-world problems and issues. The Herbert River ringtail had been recorded as a roadkill near this site (Goosem 2000b), as had Lumholtz's tree-kangaroo (Schmidt et al. 2000; Izumi 2001).

ARBOREAL SPECIES ASSEMBLAGE

All three sites were in rainforests of the Atherton Uplands (after Williams & Pearson 1997). Arboreal mammal species known or expected to occur at these sites include the green, Herbert River and lemuroid ringtail possums, coppery brushtail possum and Lumholtz's tree-kangaroo as well as the long-tailed pygmy-possum, *Cercartetus caudatus*, striped possum, *Dactylopsila trivirgata*, sugar glider, *Petaurus breviceps*, and prehensile-tailed rat, *Pogonomys mollipilosus*. The three sites are also within the known range of several semi-arboreal and/or scansorial species such as the spotted-tailed quoll, *Dasyurus maculatus*, fawn-footed melomys, *Melmoys cervinipes*, and white-tailed rat, *Uromys caudimaculatus*.

The target species for the current study were the three rainforest ringtails mentioned above and Lumholtz's tree-kangaroo. As discussed in the previous chapter, all four species are listed as 'rare' under the Queensland *Nature Conservation Act 1992*. This is because their range is geographically restricted to the Wet Tropics region. The four species are not listed as threatened species under the EPBC Act as it does not carry a 'rare' designation. Nevertheless, they are an integral part of the World Heritage values of the WTWHA and these values are protected as 'matters of national environmental significance' under the Act. It could also be argued that the status of at least two of the four species should be upgraded as the lemuroid ringtail is considered to be highly vulnerable in fragmented forests and road mortality is a threatening process for Lumholtz's tree-kangaroos. Detailed accounts of the four species (from Menkhorst & Knight 2001) are presented in **Table 4.1**.

Table 4.1: Target species accounts (from Menkhorst & Knight 2001)

Species	Account
 Green ringtail (Photo: Mike Trenerry)	**Green Ringtail Possum *Pseudochirops archeri*** **Head-body length** 300-380 mm; **tail length** 310-370 mm; **weight** 800-1300 g Large, thickset; fur thick, woolly; tail strongly prehensile, completely furred, thick at base tapering to narrow tip which may be white. Upperparts olive-grey grizzled with silver, yellow and black giving a peculiar greenish tinge, face grey; distinctive white patches above and below eyes and behind and below ears. Three dark stripes along back, of variable width and boldness. Underparts creamy white to buff. Eye-shine red. Sparsely distributed in montane tropical rainforest above 300 m between Paluma and Mt Windsor Tableland (w. of Mossman), ne Qld. Nocturnal, arboreal, solitary, eats mostly leaves. Does not build nest or use hollows, but spends daylight hours sitting curled-up on branch. Births occur Aug-Nov and a single young is raised.
 Herbert River ringtail (Photo: Mike Trenerry)	**Herbert River Ringtail Possum *Pseudochirulus herbertensis*** **Head-body length** 300-400 mm; **tail length** 330-480 mm; **weight** 800-1500 g Upperparts uniformly chocolate brown or black. Underparts usually pure white but chin and insides of lower limbs may be pale brown. Dark fur of limbs may be interrupted by bands of white fur. Some males entirely dark brown. Tail narrow, naked underneath for terminal half, usually tipped white. Eye-shine orange. Locally common in montane tropical rainforest above about 350 m from Mt Lee (w. of Ingham) to Lamb Range (w. of Cairns), ne Qld. Nocturnal, arboreal, mostly solitary; moves slowly and carefully through the canopy; eats leaves from wide range of rainforest trees. Most births May-July, 2 young reared.

Species	Account
 Lemuroid ringtail (Photo: Mike Trenerry)	**Lemuroid Ringtail Possum *Hemibelideus lemuroides*** **Head-body length** 320-400 mm; **tail length** 300-370 mm; **weight** 750-1100 g Upperparts, face, entire tail, limbs and feet rich chocolate; underparts greyish brown, sometimes with yellow tinge. Pale eye-rings. Tail bushy for entire length, not tapered. Muzzle short, forehead steep, ears short. Bright white eye-shine. Some individuals entirely creamy white with and orange tinge (most frequent on Carbine Tableland). Common in mature-age rainforest above 450 m between Ingham and Cairns, ne Qld. Isolated population above 1100 m on Carbine Tableland. Social, occurring as pairs or family groups; agile, leaps noisily from one clump of foliage to another. Shelters by day in tree hollow, emerges at night to feed on leaves, flowers, fruits. Birth of a single young occurs Aug-Nov.
THIS IMAGE HAS BEEN REMOVED DUE TO COPYRIGHT RESTRICTIONS Lumholtz's Tree-kangaroo (Photo: Karen Coombes)	**Lumholtz's Tree-kangaroo *Dendrolagus lumholtzi*** **Head-body length** 520-650 mm; **tail length** 660-740 mm; **weight** 6.0-9.5 kg The smallest tree-kangaroo. Dark grey-black upperparts contrast strongly with pale yellowish buff underparts, blackish face contrasts strongly with pale grey-yellow band across forehead, crown, face behind eyes and neck. Black forefeet and hindfeet contrast with buff ankles and wrists. Tail long, cylindrical, blackish above, flecked with rufous in basal half, with yellow-buff underside. Now generally restricted to montane rainforest (> 800 m) in ne. Qld between Kirrama (nw. of Cardwell) and Mt Spurgeon (w. of Mossman), although recent records from coast in n. of range (e.g., S. Mossman River, Port Douglas) (R. Russell, 2003 pers. comm.). Nocturnal, cryptic, territorial. Agile, competent climber; hindlegs can move independently, unlike those of other macropods; leaps from branch to branch or to ground, where it hops like typical kangaroo. Sleeps during day crouched with head tucked between legs in dense foliage or on large branch. Eats leaves of rainforest trees. Births can occur in all months; a single young raised every 2 years.

STUDY SITE DESCRIPTIONS

B Road (Site 1)

This site is at an elevation of 1025 m along the B Road that traverses Danbulla State Forest in the WTWHA (17°06’S, 145°35’E) (Site 1 on **Figure 4.1**). The research was conducted under a Department of Natural Resources Permit to Collect on State Forest 185 and 607 in the Far North District of the North Region (no. 1468). The site is within the Traditional Country of the Tableland Yidinji Tribal groups. Permission to enter country was granted by the custodians of this country, Mr Con Stewart of the Tableland Yidinji group on 12th January 2000, and Ms Syb Bresolin of the Dulguburra Yidinji Clan group who visited the site on 15th December 2001.

The forest is on granite soils and is classified as Simple Notophyll Vine Forest (Type 8, *sensu* Tracey 1982). Mapping by Tracey and Webb (1975) shows it as Type 8/9, i.e., a mix of simple notophyll vine forest and simple microphyll vine-fern forest. According to local botanists Bob Jago and Dr Bruce Wannan, who visited the site on 20/8/00, it is more typical of Type 8 despite being at the upper elevational limit for this forest type. New mapping by Peter Stanton for WTMA shows it as Type G8x, i.e., simple notophyll vine forest on granite with structure significantly altered by disturbance (T. Webb, 2002 pers. comm.). The key diagnostic features of this forest type are (Tracey 1982):

- Canopy surface relatively even, 24-33 m with occasional emergents to c.35 m.
- Girth sizes with exception of emergents are uniform, i.e., ‘pole forest’

- Barks typically have a grey and white lichen cover, and are generally flaky and scaly on the emergents
- Leaves are mostly notophyll; microphylls become more common with increasing altitude
- Plank buttresses, robust woody lianes and deciduous species are rare
- Slender (1-2 cm) and wiry (diameter <1 cm) lianes generally common
- Epiphytes common in the tree crowns but are rare low down on the tree trunks.

See **Appendix 4.1** for a detailed plant species list for this site.

The B Road is part of the Lamb Range network of old logging roads and provides seasonal, two-wheel drive access (i.e., four-wheel drive access in wet weather). Originally constructed to service pastoral estates in the 1920s (L. May, 2002 pers. comm.), it is now a ‘presentation restricted’ road under the *Wet Tropics Management Plan 1998* and permits to traverse are required from the QPWS to ensure safety and minimal habitat disturbance (EPA 2002). Consequently, few vehicles (legally) use the road; with about four or five permits issued daily (C. Morris, 2002 pers. comm.). Goosem (2002) studied the impacts on small mammals of traffic disturbance on the B Road and reported that there was almost no traffic during her trapping sessions (mean = 4.2, s.e. = 1.0, range 0-16 vehicles per day). At the canopy bridge site, the road generally runs in an east-west direction and has a clearing width of 7 m. This consists of a 6 m wide gravel surface plus a 1 m wide drainage ditch on the northern side. Canopy closure is not maintained above the road surface, although natural connections occur approximately 120 m to the east and 50 m to the west of the bridge site.

The bridge itself is essentially a 50 cm wide x 50 cm deep rope tunnel, made with 10 mm silver rope and held taut by plastic spacers (see **Figure 4.2**). The structure spans 14 m, is located 7.3 m above the road surface and is attached to telegraph poles installed on either side (**Figure 4.2**). The poles stand about 3 m back from the road verge so the entry points to the bridge occur within the forest proper. A few short ropes lead from the ends of the tunnel into trees nearest the support poles. Taking roadside vegetation into account, the canopy gap is 5-6 m wide.

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Figure 4.2 Canopy bridge held taut by plastic spacers and attached to telegraph poles at each end (Photo: Liz Poon)

As reported in **Chapter 2**, the tunnel design was used to offer protection from aerial predators (Russell, R. 1998 pers. comm.). The rufous owl, *Ninox rufa queenslandica*, and lesser sooty owl, *Tyto multipunctata*, are known predators of the rainforest ringtails and the co-existing grey goshawk, *Accipiter novaehollandiae*, will also take animals that are exposed during the day (Winter & Trenerry 1995).

An 8 m long 24 mm manila fibre rope was also strung across the road about 5 m north of the existing bridge from 13-21 October 2000 and again between 12 August and 29

December 2001. This was done in an attempt to ascertain whether the rainforest ringtails would use this very simple alternative to the existing canopy bridge.

Snig track (Site 2)

The site is at an elevation of 980 m along an unsealed, abandoned snig track on the lower slopes of Mt Fisher (17°34'S, 145°34'E) (Site 2 on **Figure 4.1**). It is located on freehold land immediately adjacent to the and is within the Traditional Country of the Ma:Mu Tribal group. Mr Thorold Brotherton now owns the property and he gave permission on 13 September 2000 to conduct research at the site.

The forest is on basalt soils and is classified as Complex Notophyll Vine Forest (Type 5a, *sensu* Tracey 1982). Mapping by Tracey & Webb (1975) shows it as Type 8/9, i.e., a mix of Simple Notophyll Vine Forest and Simple Microphyll Vine-fern Forest. According to adjoining landowner and naturalist Doug Clague, it is more typical of Type 5a. This appears to be supported by new mapping by Peter Stanton for WTMA that shows it as Type B5ax, i.e., Complex Notophyll Vine Forest on basalt with structure significantly altered by disturbance (T. Webb, 2002 pers. comm.). The key diagnostic features of this forest type are (Tracey 1982):

- Canopy is uneven, 20-45 m, with many tree layers
- Most trees branched in the upper third of the stem, but many branch half-way, providing a much greater depth of crowns than in nearby simple notophyll vine forests
- Notophylls with some microphylls are most common in the canopy but mesophylls are also prominent in lower layers

- Trunk sizes are uneven and plank buttresses common
- Robust woody lianes and epiphytes are generally conspicuous
- Bark types characteristically rough with dipples and scrolls, scales and flakes and shallow fissures

See **Appendix 4.1** for a detailed plant species list for this site.

Two bridges were erected over the snig track on 12 December 2000. The first bridge was designed as far as practicable to emulate the dimensions of the top surface of the existing structure on the B Road (i.e., 50 cm wide) (**Figure 4.3**). In this sense, it resembled the hammock used in Taiwan for macaque monkeys (see **Chapter Two**). It is referred to henceforth as the ‘wide’ bridge (or DS for ‘double strand’ in **Appendices 5.1, 5.3**). The second bridge was half the width of the existing bridge (i.e., 25 cm wide) and effectively resembled a rope ladder swung horizontally across the track (**Figure 4.3**). It was identical to the colobridges described in **Chapter Two**. It is referred to henceforth as the ‘narrow’ bridge (or SS for ‘single strand’ in **Appendices 5.1, 5.3**). It was removed on 25 March 2001, lengthened and installed at the Old Palmerston Highway site (see below).

Gulf Net Menders, the Cairns-based chandlers who built the original bridge, made both these structures. They were constructed of white nylon rope and measured 10 m in length. Both bridges were attached to strong trees on the track verge about 5 m above ground level. The distance between the trees (Tooram walnut *Bielschmiedia tooram* and tulip sterculia, *Franciscodendron laurifolium*) supporting the wide bridge was 6.9 m. The distance between the trees (sarsparilla, *Alphitonia petrei* and silver ash, *Flindersia bourjotiana*) supporting the narrow bridge was 4.9 m. As already mentioned, the narrow track resulted in considerable contact between branches of trees on opposite sides of the track, allowing easy movement for arboreal mammals choosing to cross it.

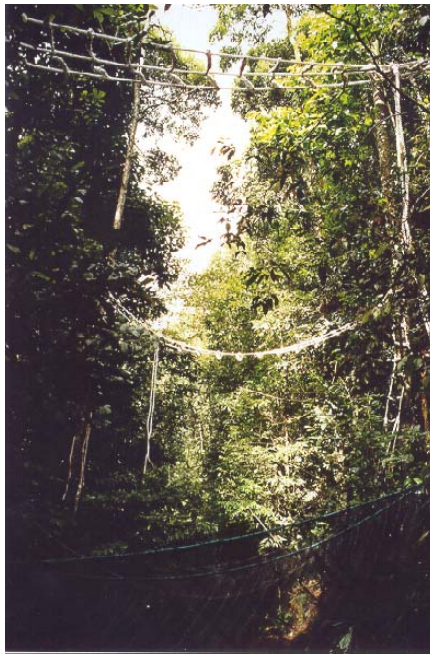

Figure 4.3 Snig track site, showing wide bridge in foreground, narrow bridge at rear and collection nets underneath

Old Palmerston Highway (Site 3)

The site is at an elevation of 963 m along the Old Palmerston Highway between Millaa Millaa and Ravenshoe, immediately adjacent to the Maalan State Forest in the (17°36'S, 145°35'E) (Site 3 on **Figure 4.1**). The highway is a state-controlled road, thus the road reserve is under the management of QDMR. The Department gave permission to conduct research at the site, subject to conditions, on 2 April 2001 (refer **Appendix 4.2**). The site is within the Traditional Country of the Ma:Mu Tribal group. Permission to enter country was granted by the custodians of this country, Mr Victor Maund and Mr James Epong in April 2001. Mr Troy Minniecon visited the site on 27 April 2002.

The forest is on basalt soils and is classified as Simple Notophyll Vine Forest (Type 5a, *sensu* Tracey 1982). New mapping by Peter Stanton for WTMA shows it as Type Ra, i.e., Regrowth Rainforest, although Type B5ax forest, i.e., Complex Notophyll Vine Forest on basalt with structure significantly altered by disturbance, is mapped nearby (T. Webb, 2002, pers. comm.). The key diagnostic features of this forest type are (Tracey 1982):

- Canopy is uneven, 20-45 m, with many tree layers
- Most trees branched in the upper third of the stem, but many branch half-way, providing a much greater depth of crowns than in nearby simple notophyll vine forests
- Notophylls with some microphylls are most common in the canopy but mesophylls are also prominent in lower layers
- Trunk sizes are uneven and plank buttresses common
- Robust woody lianes and epiphytes are generally conspicuous
- Bark types characteristically rough with dipples and scrolls, scales and flakes and shallow fissures

See **Appendix 4.1** for a comprehensive plant species list.

The Old Palmerston Highway is a sealed, dual carriageway that is classed as a district road. Constructed in the mid to late 1920s (M. Harvey, 2002 pers. comm.), it now serves as a scenic route between the townships of Millaa Millaa and Ravenshoe. It has an average annual daily traffic count of 152, 10% of which are commercial vehicles (R. Lithgow, 2002 pers. comm., citing QDMR 2001 survey information).

The narrow bridge used at the snig track site was lengthened from 10 to 15 m by Gulf Net Menders and installed over the highway on 7 April 2001 (**Figure 4.4**). QDMR staff assisted with bridge installation and, importantly, traffic control. The bridge was attached to two strong trees (silver basswood, *Polyscias elegans* and bollywood, *Litsea leefeana*) on the road verge at a height of 7.5 m. A heavy rope held the bridge taut and led from the silver basswood into the nearby forest. The distance between the trees measured 13.5 m. Canopy closure is not maintained above the road surface and natural connections do not occur in the immediate vicinity of the bridge site (i.e., more than 200 m in either direction). The linear disturbance created by the road in the vicinity of the bridge can be seen clearly in **Figure 4.5**.

Figure 4.4 Canopy bridge being installed over the Old Palmerston Highway, April 2001 (Photo: Sue Frankcombe)

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Figure 4.5 Aerial photo showing the Old Palmerston Highway wending its way through the Maalan State Forest (arrow shows approximate location of bridge). Scale 1: 25,000 approx. (Photo: DNR *Geoscape* CD-ROM)

B ROAD: FIELD STUDY

Scat collection

As noted by Triggs (1996), faecal pellets, or ‘scats’, are among the more characteristic signs left by an animal, and they are the ones most likely to be found. They not only indicate which species of animal passed by, and when, but also what it had been eating. Based on their size, scats can also give a guide to an animal’s approximate age, amongst other things. According to some researchers (e.g., Vernes 1999; Westcott 1999), counting scats is a potentially useful method to indirectly census forest-dwelling animals.

A net designed to intercept scats deposited by arboreal mammals was installed under the bridge for several days each month between 13 January and 13 October 2000 and permanently between 12 August and 26 October 2001. The net was made by *Gulf Net Menders* and was essentially a fine nylon mesh hammock (see **Figures 4.3, 5.1**). It was twice the width of the bridge (1 m) and installed about 2 m above the road surface. An additional net was installed beneath the manila rope during its second installation between 12 August and 26 October 2001. The net under the bridge was checked for scats on 15 occasions and the net under the rope on five occasions. Each time that scats were present, their location was recorded according to where they had landed in the net (i.e., north, centre, south). I also searched for other signs (e.g., predator scats, pellets regurgitated by owls and other raptors, whitewash).

Scats collected from the nets and occasionally from the road surface and verge were analysed by Barbara Triggs, an authority on the identification of mammalian traces. Her identification was mostly based on an assessment of the gross morphology of the scat sample although occasionally the identity of the animal could be determined by examining grooming hairs isolated from a scat under a microscope. Most mammals lick their fur, swallowing some of it and passing it in their scats. By breaking up the scats and extracting the hair or hairs present, it is possible to identify the animal (Triggs 1996). This process is presumably more reliable for herbivorous mammals, like the rainforest ringtails and tree-kangaroos.

Remote photography

An infrared game surveillance camera (*Foresite Buckshot 35A*) was periodically installed inside the entrance to the canopy bridge between 13 January and 13 October 2000. The 35 mm autofocus camera was enclosed in a waterproof, airtight housing with a passive infrared detector that senses heat and motion. To further weatherproof the camera, the manufacturers simplified the electronics by pre-setting them to low sensitivity range (an animal would have to come within a metre or so to trigger it) and no delay between picture-taking. Eight AA type batteries powered the camera. I used climbing apparatus to access the camera during installation and retrieval. The camera was also installed above the manila rope for a week from 13-21 October 2000. Film was retrieved and photographs developed periodically during the time the camera was installed. Colour 800 speed print film was used initially but after trialing various film and filter combinations in July 2000, black and white 400 speed print film was found to be most suitable. This choice allowed the use of a red filter to mask the bright white light of the camera's flash and thereby reduce stress caused to animals with night-adapted vision. Bright light temporarily destroys the night-adapted vision of the rainforest ringtails, which then takes half an hour to return (Wilson 2000).

A new infrared camera enclosed within a freestanding housing (*Foresite Buckshot RTV*) was installed on top of the bridge for about a month between 29 December 2001 and 9 February 2002. The low sensitivity and two-minute delay between picture taking (i.e., shortest available) settings were selected. An extension ladder was used to access the camera during installation and retrieval at this location. Film was retrieved and photographs developed on a weekly basis. As above, black and white 400 speed print film was chosen as this allowed the use of a red filter to mask the flash.

Direct observation (spotlighting)

Between 29 July 2000 and 8 February 2002, 40 hours were spent directly observing the bridge over 10 nights. I sat within viewing distance of the structure and illuminated any animal that appeared upon it with a 30 W, 12 V spotlight. A filter was used to mask the beam except in poor weather. The nights were randomly selected to cover both wet- and dry-season conditions. Spotlighting was usually conducted during the first five hours after sunset, but was continued until 5 a.m. on one occasion (30/11/01). Where possible, conventional photographic equipment (*Canon EOS* 35 mm single-lens reflex camera) was used to record crossing events. Spotlighting was also conducted in the vicinity of the bridge to observe the use of natural canopy connections. Incidental observations of arboreal species and potential predators were made by walking along the edge of the forest on both sides of the road with the spotlight.

Spotlighting did not commence until six months into the study because, as Lindenmayer (2002) discussed, it is possible that repeated spotlighting of a given population on a frequent basis could change patterns of behaviour – for example, animals might avoid those parts of their home range subject to frequent survey (in this case, the canopy bridge).

Data logging

A data logger (*Tinytag Plus*) attached to an infrared detector was installed on top of the bridge between 25 November and 29 December 2001 in an attempt to quantify its use by the rainforest ringtails. The logger was enclosed within a weatherproof case, powered by a 12-volt rechargeable battery and topped up by a 12-volt solar array (**Figure 4.6a**). This was mounted on a 25 cm wide timber platform (which was later used as a mount for the *Buckshot RTV* infra-red camera) with the passive detector (which senses moving heat) directed across the bridge (see **Figure 4.6b**; see also **Figure 6.7**).

Figure 4.6a, left, Data logger (*Tinytag Plus*) attached to an infrared detector, enclosed within a weatherproof case and powered by a 12-volt rechargeable battery; b, right, A 3-section extension ladder was used to access the logger to download data to a laptop computer (Photo: Steven Nowakowski)

The detector was then configured to switch the counter in the data logger. The logger was started and data downloaded weekly to a laptop computer using *Gemini Logger Manager* software (GLM Version 2.3). A 3-section extension ladder was used to access the logger (Figure 4.6b). Local security firm *ADT Security* assisted with the construction and installation of this arrangement.

Hair sampling

Hair sampling was used to detect the presence of various species of mammals on the manila rope. This involved fixing 20 sections of self-adhesive double-sided tape around the rope at 40 cm intervals. Fur from animals using the rope adhered to the tape and this hair was later analysed and identified to species level (where possible) by Barbara Triggs.

Her identification was based on an assessment of the gross morphology of the hair sample, as well as an examination of sections of individual hairs under a microscope.

Playback calls

Playing the calls of species known to occur in an area can elicit a calling response from other individuals (Lindenmayer 2002). Kanowski (1999) successfully used call playback in combination with direct observation to survey the distribution of the rufous owl, *Ninox rufa*, in rainforests of the Atherton Uplands. I played the calls of large forest owls through a small portable loud speaker on one occasion (25/10/01) as a way of determining the presence of these potential predators at the bridge site.

SNIG TRACK: FIELD STUDY

Scat collection

Nets of similar dimensions to those already described were installed under the bridges from 12 December 2000. Between 12 December 2000 and 25 March 2001, Doug Clague and/or I checked the nets on 60 occasions and scats collected were sent to Barbara Triggs for analysis. I also searched for other signs (e.g., predator scats, pellets regurgitated by owls and other raptors, whitewash).

Remote photography

Both infrared game surveillance cameras (*Foresite Buckshot 35A* and *Buckshot RTV*) were periodically installed on or near the canopy bridges between 12 December 2000 and

15 December 2001. Film was retrieved and photographs developed periodically during the time the cameras were installed. Colour 400 speed print film was used.

Direct observation (spotlighting)

Between 13 December 2000 (i.e., upon bridge installation) and 28 March 2002, 40 hours were spent directly observing the bridges over 10 nights. Spotlighting was usually conducted during the first five hours after sunset, but was continued until 4.30 a.m. on one occasion (2/3/01). Otherwise, the methodology was the same as for Site 1.

Hair sampling

Hair sampling was used to determine the presence of various species of mammals on the wide bridge. This was done by:

1. attracting them to an open-ended plastic tube that contained double-sided tape and a bait; and
2. placing a specially-designed ‘curtain’ at the entrance to the bridge to capture hairs from animals passing through it.

The traps were installed on the wide bridge on 11 August 2001 and positioned about one metre from each end of the bridge: the tube at the eastern end and the hair curtain at the western end.

The hairtube was a variation of the standard tube employed by zoologists except that both ends were left open on the recommendation of Barbara Triggs (2001 pers. comm.), who advised that ringtail possums were rarely recorded by hairtubing. The tube was made from a section of PVC stormwater pipe (diameter 15 cm) and self-adhesive double-sided tape was fixed to the inside of the tube. Although a mixture of peanut butter, rolled oats and honey was placed inside to attract the animals, using baited hairtubes for folivivores is problematic. As Lindenmayer (2002) points out, it is impossible to bait a trap with foliage that would entice an animal into a trap – fresher leaves can be found in the forest. This may be one reason why ringtails are so rarely detected using this method.

Consequently, the hair curtain was created to provide a more reliable way of testing for the presence of folivorous species, especially the rainforest ringtails and tree-kangaroos. It was basically a circular wire frame (diameter 55 cm) draped with a curtain of double-sided tape and designed to slip easily onto the bridge, whereupon it was fixed in place with tie wire (see **Figure 4.7**). Any mammals using the bridge as a crossing route had no option but to pass through or over it, thus brushing against the tape. This device proved moderately successful, providing samples of fur that were sent to Barbara Triggs for analysis and identification to species level.

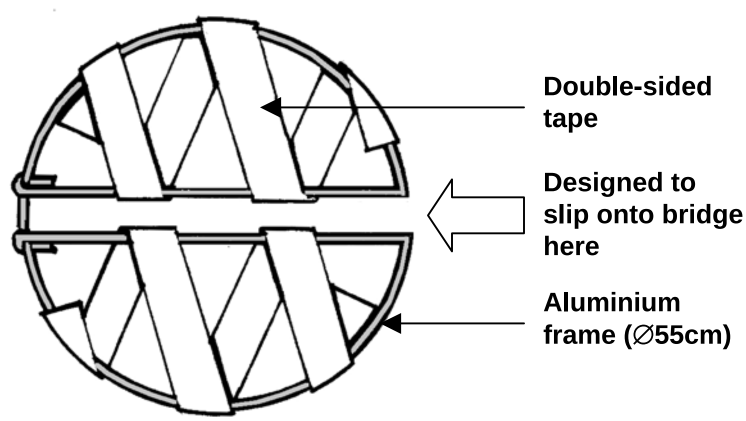


Figure 4.7 Hair curtain used to test for the presence of folivorous species on the wide bridge

OLD PALMERSTON HIGHWAY: FIELD STUDY

Scat collection

As the highway is part of a declared road network and is frequently travelled by large commercial vehicles, the nets employed at the previous two sites could not be used. Consequently, lightweight scat collection devices were designed to intercept scats deposited by arboreal mammals on the bridge. These were basically funnels constructed of wire mesh (7.5 mm x 7.5 mm) and a section of PVC stormwater pipe (5 cm diameter), sealed off at the bottom with fine nylon mesh (**Figure 4.8a**). This design allowed the collection of solid items whilst still allowing rainwater to pass through. Using a modified pruning pole, six funnels were suspended below the bridge on 9 September 2001 (**Figure 4.8b**). Four were removed on 27 October 2001 and the remaining two on 15 December 2001. Scats collected in the funnels were sent to Barbara Triggs for analysis and identification. I also searched for other signs (e.g., predator scats, pellets regurgitated by owls and other raptors, whitewash).

Figure 4.8a, left, Scat trap; b, right, Scat traps in place under Old Palmerston Highway bridge (note hairtube at far end of bridge)

Remote photography

Both infrared game surveillance cameras (*Foresite Buckshot 35A, Buckshot RTV*) were periodically installed at either end of the canopy bridge between 7 April 2001 and 15 December 2001. The *Buckshot RTV* infrared camera was installed in the silver basswood to which the southern end of the bridge was attached from 12-20 April 2001 and the *Buckshot 35A* camera was fastened to the bollywood at the northern end from 9-15 September 2001. Otherwise, the methodology was as per Site 2.

Direct observation (spotlighting)

Between 7 April 2001 (i.e., upon bridge installation) and 2 July 2003, 80 hours were spent directly observing the bridge over 21 nights. Spotlighting was usually conducted during the first five hours after sunset, but was continued until 4.00 a.m. on one occasion (16/2/02) and 5.45 a.m. on another (2/7/03). Otherwise, the methodology was the same as for the previous two sites.

Motion photography

A *Panasonic* VHS movie camera was used on 27 April and again on 31 August 2002 to film animals as they moved along the bridge. Still images were then captured from the video footage using a *Winnov Videum* AV (PC1) video capture and sound card (Version 2.9.2a).

Hair sampling

A hairtube and hair curtain (described above) were installed on the bridge on 11 August 2001 and removed in November 2001. The tube was installed at the northern end (see **Figure 4.15**) and the curtain at the southern end. Otherwise, the methods used were as per Site 2.

LIMITATIONS

There were several limitations to my study. These included the use of scats to census arboreal mammals. Vernes (1999) warned that the use of scat counts to estimate density is often hampered by the difficulty in obtaining accurate estimates of fecal pellet production and no such attempt was made as part of the current study. To further complicate matters, it was not always possible to distinguish between scats deposited by species moving through overhanging vegetation or those crossing the bridge or even the collection net. This is discussed further in the following chapter.

There were also problems with the identification of mammals to species level using scat and hair samples. Lobert *et al*. (2001) quantified the accuracy and reliability of identifying mammals from hair samples. In their study, hair samples were collected from 37 mammal species occurring in southeastern Australia. This material was divided into 252 samples, which were then used in a blind test to determine the accuracy of the technique. The taxa were then grouped into reliability categories based on the accuracy and consistency of the practitioner's identifications. Barbara Triggs was one of two highly skilled practitioners used in the experiment. In all, 23 taxa, including 19 species, were regarded as being reliably identified from hair analysis. Identification of the remaining 18 species involved at least some level of error. Of relevance to the current study, identification of brushtail possums to genus level was considered to be *reliable* (i.e., identified in 100% of cases). Identification to species level of the common brushtail and common ringtail, a close relative of the rainforest ringtails, was considered to be *questionable* (i.e., correctly identified in more than 83% of cases and where confusion with another taxon occurred only once).

At a more basic level, hair samples provide no information on the age, sex and identity of individual animals or the number of times a given animal visits a particular site (Lindenmayer 2002). Although scats can indicate when an animal passed by and its approximate age (Triggs 1996), the methods employed here provide only presence (but not abundance) data on those species detected during the sampling period.

Other limitations concerned the use of electronic recording equipment. The remote cameras and the data logger could not be used to quantify use of the bridges by arboreal mammals due to one or any combination of the following factors:

1. false triggers, e.g., birds, vegetation, wind, even trucks;
2. sensitivity of the infrared setting (1 m radius), which sometimes allowed subject animals to move off the bridge undetected;
3. picture-taking setting – no delay between pictures using the *Buckshot 35A* resulted in multiple exposures per event and rapid film usage, while a two minute delay using the *Buckshot RTV* limited the unit to one exposure per event and meant a temporal gap in data gathering;

4. short battery life; and

5. unreliability due to equipment malfunction.

Use of a portable infrared-triggered digital camera that stores images into an internal storage bank might have avoided some of these problems but financial constraints prohibited this. The electronic equipment probably also induced an avoidance response in the subject animals. This is discussed further in the following chapter.

Finally, as discussed above, it is possible that direct observation can change patterns of behaviour – for example, animals might avoid those parts of their home range subject to frequent survey (in this case, the canopy bridges) or crossing behaviour might be altered. Tree-kangaroos, in particular, appear to be sensitive to this method of detection. Again, this is discussed further in the following chapter.

Chapter 5: Use of canopy bridges by arboreal mammals in the Wet Tropics region – results

Abstract. This chapter documents the results of investigations into the use of canopy bridges by arboreal mammals in the Wet Tropics region. The existing canopy bridge on the B Road was used by at least six arboreal or scansorial species. All three rainforest ringtails present at the site were recorded on the bridge and two, the lemuroid and Herbert River ringtails were observed using it to cross the road. Of eight crossing events seen at the B Road site, six involved animals moving along the top surface of the structure. Consequently, bridges replicating the top surface were erected on a snig track near Millaa Millaa to test whether bridge design and position affect usage. No crossings were observed and proof of crossing was not obtained until remote photographs of a Herbert River ringtail crossing the wide bridge were taken on two separate occasions almost a year after the bridge was installed. In contrast, 52 completed crossing events were observed during the 80 hours spent directly observing the bridge installed over the Old Palmerton Highway. Thirty-five involved rainforest ringtails, 16 involved brushtails, one a striped possum and another an unidentified small mammal. Two partial crossing events, whereby a coppery brushtail and Herbert River ringtail got halfway across before turning back, were also observed. Simultaneous crossings involving two individuals of the same species were observed on three occasions. Whilst tree-kangaroos were not observed crossing, their presence on the bridge was detected by hair sampling.

CHAPTER 5: USE OF CANOPY BRIDGES BY ARBOREAL MAMMALS IN THE WET TROPICS REGION – RESULTS

INTRODUCTION

This chapter details the results of my investigations into the use of canopy bridges by arboreal mammals in the Wet Tropics region. As reported in **Chapter Four**, these investigations were carried out at three separate sites and the results are grouped accordingly.

B ROAD

Evidence that arboreal mammals occur in the vicinity of the bridge

Direct observation provided evidence that arboreal mammals occur in the vicinity of the bridge. Spotlighting was undertaken on ten nights between July 2000 and December 2001 and both lemuroid and Herbert River ringtails were observed in trees adjacent to the road corridor on each occasion. The rate of detection at the bridge site varied between 0.5-3.0 individuals per hour. On one exceptional occasion in October 2000, a field assistant (C. Clague) and I saw nine lemuroid ringtails and two Herbert River ringtails as we walked along a single 100 m transect west of the bridge site. The green ringtail possum was observed less frequently than its sympatric cousins (<0.5 individuals per hour of spotlighting). Positive identifications of the long-tailed pygmy possum and fawn-footed melomys were made at the site in December 2001 and white-tailed rats were occasionally seen crossing the road. A white-tailed rat was also recorded as a roadkill nearby on the Danbulla Forest Drive in April 2000, during a period when the road was closed for maintenance and there were very few vehicular movements. None of the other arboreal species known or expected to occur was directly observed, although some were detected by other methods as outlined below.

The analysis of scats provides further evidence that arboreal mammals occur in the area of the bridge. Scats were collected from the road surface beneath the bridge on 14 occasions between 13 January 2000 and 13 October 2000 and analysed by Barbara Triggs. The results of these analyses are shown in **Table 5.1** (see also **Appendix 5.1**). They support the results of spotlighting inasmuch as lemuroid and Herbert River ringtail possums appear to be the most abundant arboreal mammals at the site. Together, these species accounted for 79% of the scats collected at the site and the green ringtail just 12%. The total number of scats collected for each species (113, 103 and 34 respectively) suggests an abundance ratio of 5: 4: 1. However, a ratio closer to 4: 3: 3 is suggested by the frequency of collection. Consequently, these data require cautious interpretation and application (see discussion on limitations in previous chapter).

The scat analyses confirm that Lumholtz's tree-kangaroo was present at the bridge site. Scats from this species, collected twice, accounted for just 3% of the total. This, together with the fact that the species was not detected by spotlight, supports the contention of a local tour operator that Lumholtz's tree-kangaroo is very rare in the area (R. Mortimer, 2001 pers. comm.). Scats from two terrestrial species, the musky rat-kangaroo, *Hypsiprymnodon moschatus*, and red-legged pademelon, *Thylogale stigmatica*, were also collected.

Table 5.1 Scats collected from the road surface beneath the B Road bridge at intervals between 13/1/00 and 13/10/00

	H. lemuroides	*P. archeri*	*P. herbertensis*	*H. moschatus*[2]	*D. lumholtzi*	*T. stigmatica*[2]	Total
Days scats collected / total days road checked (n=14)[1]	9 (64%)	8 (57%)	13 (93%)	4 (29%)	2 (14%)	2 (14%)	14 (100%)
Days scats collected from centre of road / total days road checked (n=14)[1]	5 (36%)	1 (7%)	6 (43%)	-	-	-	6 (43%)
Scats / total scats collected (n=274)[1]	103 (38%)	34 (12%)	113 (41%)	11 (4%)	8 (3%)	5 (2%)	274 (100%)
Scats collected from centre of road / total scats collected (n=274)[1]	19 (7%)	4 (2%)	24 (9%)	-	-	-	47 (18%)

[1]Repeat signs from same individual likely

[2]Terrestrial spp.

Evidence that arboreal mammals crossed the bridge

Table 5.1 provides an indication of which species occur in the vicinity of the bridge. To get a clearer indication of which species may actually be using the bridge as a crossing route, scats collected from the centre of the road only are also included in **Table 5.1**. These were less likely to be deposited by terrestrial species foraging along the road verge or by arboreal species moving through overhanging vegetation (canopy connectivity is not maintained over the road).

Eighteen percent of the scats collected were deposited in the centre of the road. The terrestrial species as well as Lumholtz’s tree-kangaroo were not represented and rainforest ringtail possum scats were not collected as often (43% of the time that inspections were made). However, the species-abundance ratio remained much the same, with lemuroid and Herbert River ringtails depositing the largest number of scats (51% and 40% respectively), followed by the green ringtail (9%). These data indicate that arboreal mammals use the bridge but they do not discount movement by the possums along the ground surface.

Table 5.2 shows the results of collections made from the net hung under the bridge at intervals between 13 January 2000 and 26 October 2001. Scats were present on 13 of the 15 occasions that the net was checked and they were present in the centre of the net on 10 occasions.

Table 5.2 Scats collected from the net hung under the B Road bridge at intervals between 13/1/00 and 26/10/01

	H. lemuroides	*P. archeri*	*P. herbertensis*	*T. vulpecula*	Young possum[2]	*M. cervinipes*	Total
Days scats collected / total days net checked (n=15)[1]	9 (60%)	1 (7%)	7 (47%)	1 (7%)	5 (33%)	3 (20%)	13 (87%)
Days scats collected from centre of net / total days net checked (n=15)[1]	5 (33%)	-	4 (27%)	-	5 (33%)	1 (7%)	10 (67%)
Scats / total scats collected (n=141)[1]	57 (40%)	3 (2%)	19 (13%)	1 (1%)	44 (31%)	18 (13%)	141 (100%)
Scats collected from centre of net / total scats collected (n=141)[1]	26 (18%)	-	6 (4%)	-	18 (13%)	1 (1%)	51

[1]Repeat signs from same individual likely

[2] Possibly mostly *H. lemuroides* but maybe some *T. vulpecula* (B. Triggs, 2001 pers. comm.)

Table 5.2 shows that scats from the three rainforest ringtail species were collected in the net. Most came from the lemuroid ringtail (57 individual scats or 40% of total), followed by the Herbert River ringtail (19, 13%). Eighteen fawn-footed melomys scats were collected, representing 13% of total scats collected and three green ringtail scats (2%). One brushtail possum scat was collected, along with 44 very small, narrow scats. Barbara Triggs commented that these scats were not typical of any adult possum but many contained fine hairs that were possum-like (definitely not rodent) and some seemed very like lemuroid ringtail hair but there were no adult guard hairs in any of them. She surmised that they were all young possum scats, possibly mostly lemuroid ringtail but maybe with some brushtail possum scats (some had a coarser texture than others).

The lone brushtail possum record is noteworthy, as this species was not recorded in more than 40 spotlight hours spent at the site. This is intriguing because the brushtail is readily observed by spotlight and can also be vocal, particularly during the breeding season, with deep, guttural coughs and sharp hisses being the most common calls (Flannery 1994). The scat was collected from the southern end of the net under an overhanging northern brush mahogany, *Geissois biagiana*.

Table 5.2 also shows that 51 (or 36%) of the scats were deposited in the centre of the net and such scats were present 67% of the time that inspections were made. Neither brushtail nor green ringtail scats were found in the centre of the net. Scats most frequently collected were those from the lemuroid ringtail and the very small, narrow scats Barbara Triggs attributed to young possums (possibly mostly lemuroid ringtail). As there was no vegetation overhanging the centre of the net (see **Figure 5.1**), these records probably represent crossing events (of either the bridge or the net). Lemuroid ringtail scats were also the most abundant (26 individual scats or 51% of total), followed by young possum (18, 35%), Herbert River ringtail (6, 12%) and a single fawn-footed melomys scat. While scats collected from the centre of the net were unlikely to have come from arboreal species moving through overhanging vegetation, it is possible that the scats may have been deposited by possums using the net rather than the bridge.

Figure 5.1 Lemuroid ringtail scats deposited in net below B Road bridge on 30/7/00

Corroborating evidence for arboreal mammals using the bridge was gathered between January and July 2000 using remote photography. The *Buckshot 35A* infrared camera took a photograph of a rainforest ringtail (almost certainly a lemuroid ringtail) on the first night that it was installed inside the entrance to the canopy bridge (**Figure 5.2a**). Additional photographs of lemuroid ringtails were captured in April and July 2000 (**Figures 5.2b, 5.2d**). Nine photographs of a green ringtail possum inside the canopy overpass were captured in May 2000 (see **Figure 5.2c**) and another three in July 2000. At least another eight shots of arboreal mammals were taken but they could not be identified to species level.

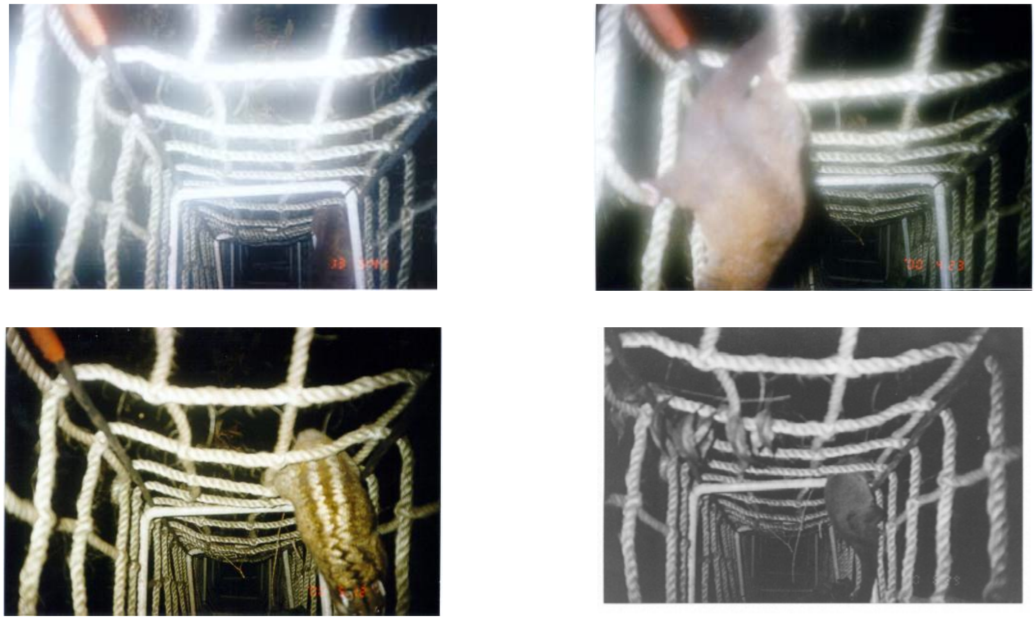


Figure 5.2 Remote photos taken at the entrance to the B Road bridge (clockwise, from top left): a, First photo of a rainforest ringtail (prob. *H. lemuroides*), taken 13/1/00; b, Lemuroid ringtail, taken 23/4/00; c, Green ringtail, taken 12/5/00; d, Lemuroid ringtail, taken 29/8/00 (note B&W film).

The photographs taken by the *Buckshot 35A* generally showed animals moving vertically through the 'tunnel' rather than along it. Direct observation at the site, which commenced in late July 2000, provided some elucidation as well as conclusive proof that animals used the bridge to cross the road. At 9.10 pm on the first evening of spotlighting (29/7/00), a field assistant (J. Sambono) and I saw a lemuroid ringtail cross the bridge. It moved along the top surface in a south-north direction. Seven subsequent crossing events were observed (refer **Table 5.3**) in 40 spotlight hours undertaken on 10 nights between 28 July 2000 and 29 December 2001. Three crossings involved rainforest ringtails (*H. lemuroides* with back-young and 2 x *P. herbertensis*) and small mammals that I could not identify made the remaining four crossings.

Table 5.3 Crossing events observed on B Road bridge in 40 spotlight hours between 28/7/00 and 29/12/01

Date	*Time*	*Species*	*Direction*	*Date*	*Time*	*Species*	*Direction*
29/7/00	2110	*H. lemuroides*	s-n	25/10/01	2310	*P. herbertensis*	n-s
13/10/00	1915	small mammal	n-s	30/11/01	2215	*P. herbertensis*	n-s
	2210	small mammal	n-s		0220	small mammal	s-n
14/10/00	0030	*H. lemuroides*[1]	n-s	1/12/01	0450	small mammal	n-s

[1]Carrying back-young

The above observations provide a crude estimate of a crossing rate for the rainforest ringtails (approximately one every 10 hours). **Figure 5.3** portrays two of the above events. Of the eight animals that crossed, five moved in a north-south direction and three in the opposite direction. No relationship was found between the time of the crossings and the direction travelled.

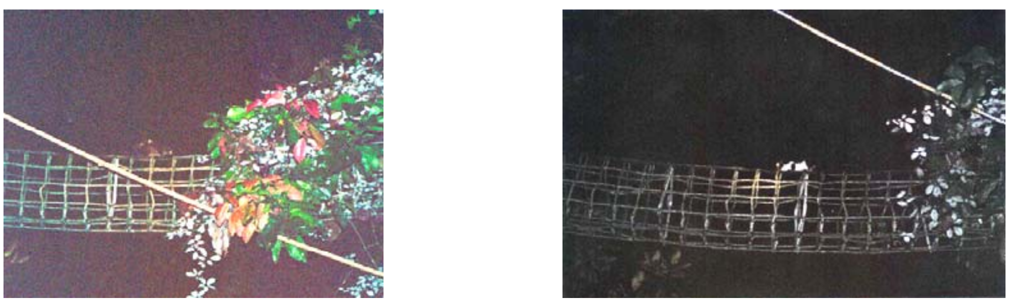


Figure 5.3 Conventional photos of rainforest ringtails moving along the top surface of the B Road bridge: a, left, Lemuroid ringtail with back-young heading north-south on 14/10/00; b, right, Herbert River ringtail heading in the opposite direction on 30/11/01

Six of the eight crossing events involved animals moving along the top surface of the bridge. One unidentified small mammal moved through the bridge, rather than upon it, as did a Herbert River ringtail on 30 November 2001. In the latter instance, the animal moved along the top surface until it confronted the data logger installed about halfway along the bridge (**Figure 5.4a**). The possum then climbed down through the bridge and moved along inside the tunnel (**Figure 5.4b**) before climbing back up and off via the northern brush mahogany at the southern end. This may have been an anti-predatory response to an object the possum perceived as a threat. If so, then it behaved in a manner consistent with the idea behind Rupert Russell's original design.

Another possible explanation for the above behaviour is that the possum was responding to the infrared beam. However, Dr John Nelson (2001 pers. comm.), an expert in the visual, auditory and somatosensory systems of mammals, thought it unlikely that the possum was responding to the beam *per se*. Even though possums are very good at seeing objects in low light they do not see in infrared. Rather, Dr Nelson thought it more likely that the possum could see that there was something different about the area.

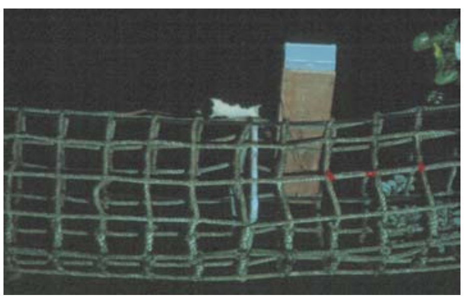


Figure 5.4a, left, Conventional photo showing a Herbert River ringtail approaching the data logger on top of the B Road bridge; and b, right, moving through the structure on 25/10/01 (Photos: Steven Nowakowski)

No animals were observed crossing via the net instead of the bridge, with the exception of a bush rat, *Rattus fuscipes*, released from a small Elliot aluminium box trap set beneath the bridge in July 2000. On one occasion (17/9/00), two Herbert River ringtail scats were found on the road surface under the net suggesting that the animal had moved along the ground beneath it.

The data logger installed on top of the bridge was not particularly successful in quantifying usage. It was operational for just twelve days (Nov 25–27 and Dec 16-24) during the month that it was installed in 2001. **Figure 5.5** shows the total number of 'hits' recorded each day during this period. The number of diurnal hits (dark grey) plus nocturnal hits (light grey) equals total hits per day. It can be seen that most hits occurred during the day with very few occurring at night. The reason for this is still unclear although my experiences with the *Buckshot RTV* infrared camera (that replaced the logger on top of the bridge) leads me to believe that solar radiation combined with wind funneling along the road were responsible for most of the false triggers during the day. The paucity of nocturnal hits was probably due in part to animals actively avoiding the logger (refer discussion, above). Whatever the reason, it is clear that the logger data provided an unreliable index of nocturnal animal activity.

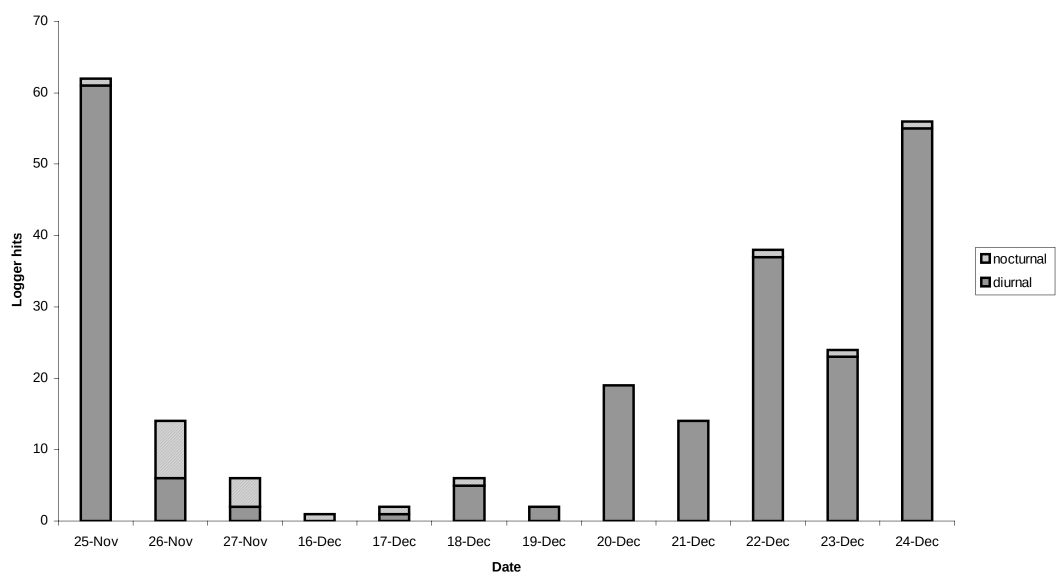


Figure 5.5 Total number of hits recorded by the data logger installed on top of the B Road bridge between 25/11/01 and 29/12/01

After it was decommissioned, the data logger was replaced on top of the bridge by the *Buckshot RTV* infrared camera. As shown in **Table 5.4**, the unit captured 24 additional photographs of arboreal mammals crossing the bridge between 29 December 2001 and 9 February 2002. Seven photographs were obtained of Herbert River ringtails, one of a striped possum and eight of fawn-footed melomys. A further four photographs were of unidentified medium-sized mammals (probably possums) and another four were of unidentified small mammals (probably *Melomys*). Fifteen animals were moving in a north-south direction and nine in the opposite direction, a similar ratio to that observed directly. No relationship was found between the time of the crossings and the direction travelled.

Table 5.4 Crossing events captured by the *Buckshot RTV* unit on the B Road bridge between 29/12/01 and 9/2/02

Date	*Species*	*Direction*	*Date*	*Species*	*Direction*
31/12/01	medium-sized mammal	s-n	16/1/02	small mammal	s-n
2/1/02	*P. herbertensis*	n-s	17/1/02	medium-sized mammal	n-s
3/1/02	medium-sized mammal	s-n	19/1/02	*M. cervinipes*	n-s
	M. cervinipes	s-n	22/1/02	*P. herbertensis*	s-n
4/1/02	*P. herbertensis*	s-n	22/1/02	small mammal	n-s
13/1/02	*P. herbertensis*	n-s		medium-sized mammal	n-s
	P. herbertensis	s-n	23/1/02	*M. cervinipes*	n-s
	M. cervinipes	n-s		*M. cervinipes*	n-s
	M. cervinipes	n-s		small mammal	n-s
16/1/02	*P. herbertensis*	n-s	24/1/02	*M. cervinipes*	s-n
	D. trivirgata	n-s	30/1/02	*P. herbertensis*	n-s
	M. cervinipes	n-s		small mammal	s-n

A selection of the photographs taken with the *Buckshot RTV* infrared camera is included at **Appendix 5.2**. They are clear enough to allow individuals to be distinguished and it can be seen that more than one individual of the same species (*P. herbertensis*) crossed the bridge. The photographs also show that a striped possum used the bridge, despite its not being detected at the site by any other method. Although striped possums are very conspicuous, their low densities and shyness have made them one of the least known of Australian possums (Van Dyck 1995).

With the exception of the striped possum record, the remaining photographs featured either fawn-footed melomys or Herbert River ringtails (even the unidentified small and medium-sized mammal shots were probably of these species). That the scansorial fawn-footed melomys was the most photographed mammal is somewhat surprising. This result might have implications for management in light of recent studies showing that narrow roads inhibit the crossing movements of this species (Goosem 2002). Also surprising is that no photographs were taken of lemuroid or green ringtails, or white-tailed rats. All three species are known to occur in the area. As already reported, the lemuroid ringtail was observed by spotlighting when crossing along the top of the bridge and both the lemuroid and green ringtails were photographed at the entrance to the rope tunnel.

Evidence that arboreal mammals crossed the rope

Table 5.5 shows the results of analyses done on scats collected from the centre of the net hung under the B Road rope at intervals between 12 August and 29 December 2001 (see also **Appendix 5.1**). Scats were present on four of the five occasions that the net was checked. The very small, narrow scats Barbara Triggs attributed to young possums were found in the centre of the net on four occasions and scats belonging to the lemuroid ringtail, Herbert River ringtail and brushtail possum on two occasions each. The young possum scats were the most abundant (19 individual scats or 59% of total); followed by lemuroid and Herbert River ringtail (5, 16%) and brushtail possum (3, 9%) scats. No scats were collected during the first week of rope installation, presumably because the animals were familarising themselves with the new crossing route. However, it is possible that the animals might have been using the net rather than the rope.

Table 5.5 Scats collected from the centre of the net hung under the B Road rope at intervals between 12/8/01 and 29/12/01

	H. lemuroides	*P. herbertensis*	*T. vulpecula*	Young possum[2]	Total
Days scats collected from centre of net / total days net checked (*n*=5)[1]	2 (40%)	2 (40%)	2 (40%)	4 (80%)	4 (80%)
Scats collected from centre of net / total scats collected (*n*=32)[1]	5 (16%)	5 (16%)	3 (9%)	19 (59%)	32 (100%)

[1]Repeat signs from same individual likely

[2]Possibly mostly *H. lemuroides* but maybe some *T. vulpecula* (B. Triggs, 2001 pers. comm.)

The results of hair sampling (see **Appendix 5.1**) confirmed that arboreal mammals crossed the rope. Three of the 20 sections of self-adhesive double-sided tape that were wrapped around the rope had brushtail possum hairs attached, including two sections (9,10) that were centrally located (i.e., wrapped around the rope above the centre of the road). Again, the presence of brushtail hair is noteworthy (as is the presence of three brushtail scats in the net), given that this species was not detected in over 40 spotlight hours spent at the site. Barbara Triggs also found human hair (presumably mine) on one of the tape sections and four contained hair from a domestic dog (presumably mine too!).

No other evidence of arboreal mammals using the rope was obtained, although the *Buckshot 35A* infrared camera was positioned above the rope for a week following its first installation in October 2000 and it captured one photograph of a lemuroid ringtail inspecting the rope (**Fig 5.6a**). Unfortunately, the camera was triggered by a work gang undertaking track maintenance at the time and this used up the balance of the film (**Fig. 5.6b**).

Figure 5.6a, left, Remote photo of lemuroid ringtail inspecting the B Road rope on 17/10/00; b, right, One of many remote photos of track maintenance activities taken on 18/10/00

Evidence of potential predators at the bridge site

Scats were collected from a large (> 3.5 m) amethystine python, *Morelia amethystina*, found basking near the bridge site on 13 January 2000. The amethystine python is a known predator of rainforest ringtails (Winter & Trenerry 1995) and tree-kangaroos (Martin & Johnson 1995) and a sizeable bulge in the snake suggested that it had recently fed. Analysis of hair present in the scats revealed that the prey item was a ground-dwelling red-legged pademelon. There was no evidence that potential predators were congregating at the site, although lesser sooty owls, *Tyto multipunctata*, were heard occasionally. No response was elicited when the calls of large forest owls were played through a small portable loud speaker on 25 October 2001.

SNIG TRACK

Evidence that arboreal mammals occur in the vicinity of the bridges

Direct observation provided evidence that arboreal mammals occur in the vicinity of the two bridges. Spotlighting was undertaken on twelve nights between 13 December 2000 and 28 March 2002 and the three rainforest ringtails as well as coppery brushtail possums and Lumholtz's tree-kangaroos were regularly observed in trees adjacent to the track. The rate of detection of the rainforest ringtails averaged 0.5 individuals per hour and less for tree-kangaroos at the bridge site. Striped possums and long-tailed pygmy-possums are also known from the area (see **Figure 5.7**) and fawn-footed melomys and white-tailed rats were trapped at the site.

Figure 5.7 Remote photos of two arboreal mammals attending a flowering bumpy satinash, *Syzygium cormiflorum*, near the snig track bridge site: a, left, Striped possum; and b, right, Long-tailed pygmy possum (Photos: Doug Clague)

Evidence that arboreal mammals cross natural connections

Seven crossings of a tenuous sarsparilla, *Alphitonia* sp., connection, located about 5 m east of the wide bridge, were observed in the forty spotlight hours spent at the site. Herbert River ringtails made five crossings (2/3/01 [x 3], 24/3/01, 10/8/01), and the green ringtail and coppery brushtail one each (28/3/02 and 2/3/01 respectively). Two lemuroid ringtails were also seen to leap more than 2 m across a canopy gap about 10 m west of the narrow bridge (2/3/01).

Scats deposited in the nets hung under the two bridges also provide evidence that arboreal mammals crossed natural connections at the site. These nets were checked on 60 occasions between 12 December 2000 and 25 March 2001. Scats were collected on 21 occasions from the net under the wide bridge and on 21 occasions from the net under the narrow bridge (i.e., approximately every three days). Scats were collected from the centre of the net under the wide bridge on 14 occasions and from the centre of the net under the narrow bridge on 16 occasions (i.e., approximately every four days). The results of analyses by Barbara Triggs are shown in **Tables 5.6** and **5.7** (see also **Appendix 5.1**).

Table 5.6 shows that 52 scats were collected from the net hung under the wide bridge. Lemuroid ringtail scats were found most frequently and were also the most abundant (19 individual scats or 37% of total), followed by Herbert River ringtail (12, 23%), fawn-footed melomys (9, 17%), green ringtail (5, 10%) and Lumholtz's tree-kangaroo scats (3, 6%), brushtail (2, 4%) and a single rodent scat (probably bush rat, *Rattus fuscipes*). According to Barbara Triggs, another scat came from either a musky rat-kangaroo or possibly a brushtail possum. Although the musky rat-kangaroo occasionally climbs through fallen trees and branches (Dennis & Johnson 1995), it is most probable that the scat was deposited by the latter species. This is supported by the results of a test trial, whereby five scats collected from a coppery brushtail at a resort near Ravenshoe on 11 February 2001 were sent to Barbara Triggs for analysis. She identified them as belonging possibly to a musky rat-kangaroo (see **Appendix 5.1**).

Table 5.6 also shows that 16 (or 31%) of the scats collected from the net under the wide bridge were found in the centre. Lemuroid ringtail scats were found in the centre on four occasions, at least twice as often as any other species. However, just one scat was deposited on each occasion. Conversely, four green ringtail scats were collected on one occasion (13/2/01). Four fawn-footed melomys scats were also collected, two from Herbert River ringtails and one each from Lumholtz's tree-kangaroo and musky rat-kangaroo/brushtail.

Table 5.7 shows that 46 scats were collected from the net hung under the narrow bridge. Lemuroid ringtail scats were found on 11 occasions, which was significantly more than any other species. They were also the most abundant (17 individual scats or 37% of total), followed by scats from the long-tailed pygmy-possum (8, 17%), musky rat-kangaroo/brushtail (6, 13%), Herbert River ringtail and fawn-footed melomys (5, 11%) and Lumholtz's tree-kangaroo (3, 6%). Solitary green ringtail, brushtail (definite) and rodent (probably bush rat, *Rattus fuscipes*) scats were also collected.

Table 5.6 Scats collected between 12/12/00 and 25/3/01 from the net hung under the wide bridge across the snig track

	H. lemuroides	*P. archeri*	*P. herbertensis*	*T. vulpecula*	*?H. moschatus*[2]	*D. lumholtzi*	*M. cervinipes*	*?Rattus* sp.	Total
Days scats collected / total days net checked (n=60)[1]	9 (15%)	2 (3%)	8 (13%)	2 (3%)	1 (2%)	2 (3%)	5 (8%)	1 (2%)	21 (35%)
Days scats collected from centre of net / total days net checked (n=60)[1]	4 (7%)	1 (2%)	2 (3%)	-	1 (2%)	1 (2%)	2 (3%)	-	14 (23%)
Scats / total scats collected (n=52)[1]	19 (37%)	5 (10%)	12 (23%)	2 (4%)	1 (2%)	3 (6%)	9 (17%)	1 (2%)	52 (100%)
Scats collected from centre of net / total scats collected (n=52)[1]	4 (8%)	4 (8%)	2 (4%)	-	1 (2%)	1 (2%)	4 (8%)	-	16 (31%)

[1]Repeat signs from same individual likely

[2] Possibly *T. vulpecula* (B. Triggs, 2001 pers. comm.)

Table 5.7 Scats collected between 12/12/00 and 25/3/01 from the net hung under the narrow bridge across the snig track

	?C. caudatus	*H. lemuroides*	*P. archeri*	*P. herbertensis*	*T. vulpecula*	*?H. moschatus*[2]	*D. lumholtzi*	*M. cervinipes*	*?Rattus* sp.	Total
Days scats collected / total days net checked (n=60)[1]	2 (3%)	11 (18%)	1 (2%)	4 (7%)	1 (2%)	2 (3%)	1 (2%)	4 (7%)	1 (2%)	21 (35%)
Days scats collected from centre of net / total days net checked (n=60)[1]	-	4 (7%)	1 (2%)	2 (3%)	1 (2%)	1 (2%)	1 (2%)	2 (3%)	-	16 (27%)
Scats / total scats collected (n=46)[1]	8 (17%)	17 (37%)	1 (2%)	5 (11%)	1 (2%)	6 (13%)	2 (4%)	5 (11%)	1 (2%)	46 (100%)
Scats collected from centre of net / total scats collected (n=46)[1]	-	4 (9%)	1 (2%)	2 (4%)	1 (2%)	5 (11%)	2 (4%)	2 (4%)	-	17 (37%)

[1]Repeat signs from same individual likely

[2] Possibly *T. vulpecula* (B. Triggs, 2001 pers. comm.)

Table 5.7 also shows that 17 scats were collected from the centre of the net hung under the narrow bridge, comprising 37% of the total. Lemuroid ringtail scats were found most frequently but the musky rat-kangaroo/brushtail scats were the most abundant (5, 29%). Lemuroid ringtail scats were next most abundant (4, 24%), followed by Herbert River ringtail, Lumholtz's tree-kangaroo and fawn-footed melomys scats (2, 12%). Solitary green ringtail and brushtail (definite) scats were also collected.

The above results do not provide conclusive evidence that arboreal mammals crossed the bridges. It is possible that the scats came from animals moving through overhanging vegetation, even those found in the centre of the nets. The fact that scats continued to be deposited in the net below the narrow bridge after it was removed on 25 March 2001 (refer **Appendix 5.3**) supports this view. Scats were collected from the net on six of the 14 occasions it was inspected over 17 days between March 26 and 12 April 2001 (i.e., approximately every 3 days), which meant that the rate of deposition remained consistent after the removal of the bridge. However, scats were only found in the centre of the net on two occasions (i.e., approximately every nine days), which is less than half the rate recorded during the period that the bridge was installed. This suggests that the animals were crossing the bridge but the results remain inconclusive.

Evidence that arboreal mammals crossed the bridges

No crossings were observed in 40 spotlight hours spread over 10 nights at the site but evidence that arboreal mammals were occasionally using the bridges was gathered using alternative methods, including hair sampling. Hair samples collected from the hair curtain on 9 September 2001 were sent to Barbara Triggs for analysis and she positively identified them as belonging to Lumholtz's tree-kangaroo. However, it cannot be proved that the animal used the bridge to cross the track, as the hair curtain was positioned just one metre from the northern end. Intriguingly, the *Buckshot RTV* infrared camera took a photograph of a mammal that had the grey-buff colouring typical of Lumholtz's tree-kangaroo at the northern end of the wide bridge on 15 January 2001 (**Figure 5.8**). A scat from this species was found in the net at this end five days later (on 20/1/01, see **Appendix 5.3**). However, the only proof that arboreal mammals actually crossed the wide bridge came when remote photos of a Herbert River ringtail moving along the wide bridge were taken on two separate occasions in November 2001 (**Figure 5.9**).

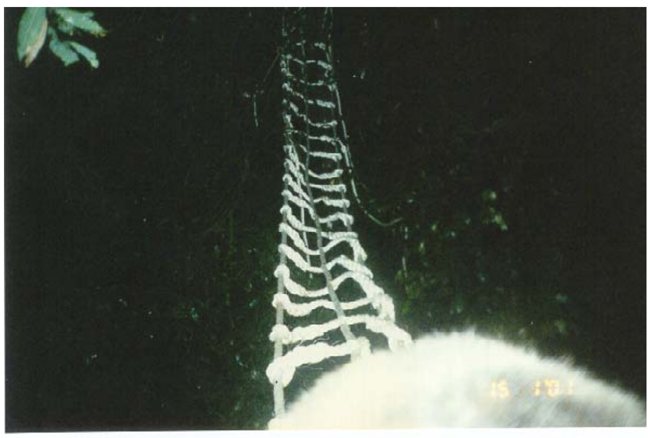


Figure 5.8 Remote photo of unidentified mammal on the wide bridge, taken 15/1/01

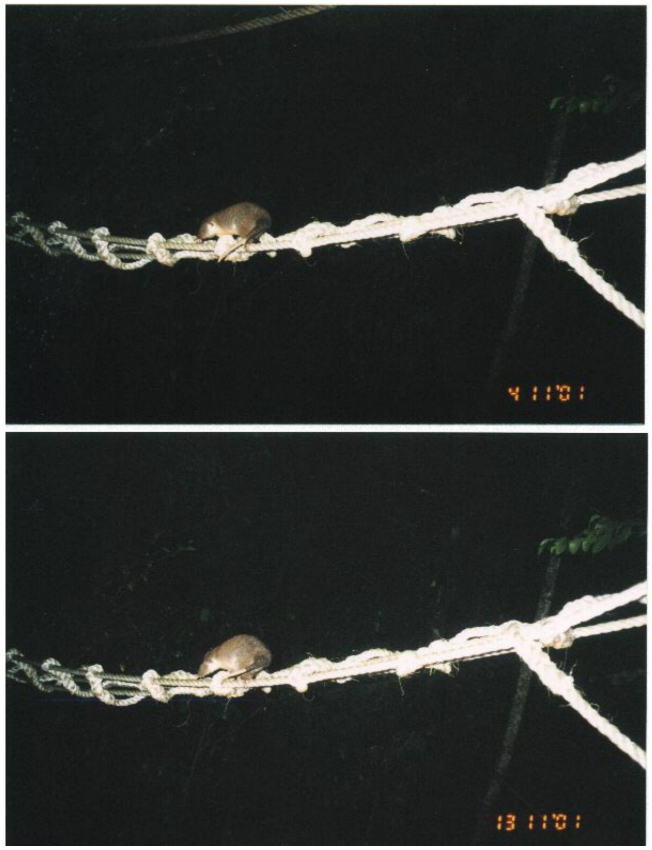


Figure 5.9 Remote photos of a Herbert River ringtail crossing the wide bridge on 4/11/01 (top) and 13/11/01 (bottom)

Evidence of potential predators at the bridge site

Scats were collected from a 2 m long carpet snake, *Morelia spilota*, found basking in lantana, *Lantana camara*, near the bridge site on 12 December 2000. The carpet snake is a known predator of rainforest ringtails (Winter & Trenerry 1995) and a small bulge in the snake suggested that it had recently fed. Analysis of hair present in the scats revealed that the prey item was probably a ground-dwelling musky rat-kangaroo. There was no evidence that potential predators were congregating at the bridges, although lesser sooty owls were commonly heard calling in the area. Doug Clague also noted a predator scat during a net inspection (on 19/2/01, see **Appendix 5.3**).

OLD PALMERSTON HIGHWAY

Evidence that arboreal mammals occur in the vicinity of the bridge

As mentioned in **Chapter Four**, the site was selected in part because it was known to support a healthy population of lemuroid ringtails (R. Wilson, 2001 pers. comm.; see also Wilson 2000). The Herbert River ringtail had been recorded as a roadkill near this site (Goosem 2000b), as had Lumholtz's tree-kangaroo (Schmidt et al. 2000; Izumi 2001). Direct observation provided further evidence that arboreal mammals occur in the vicinity of the bridge. Spotlighting was undertaken on 21 nights between April 2001 and May 2003 and lemuroid and Herbert River ringtails as well as the brushtail possum were observed in trees near the road each night. The rate of detection at the bridge site varied between 0.5-3.0 individuals per hour. Green ringtails and Lumholtz's tree-kangaroos were observed every second night and the rate of detection for these species was <0.5 animals per spotlight hour. On two exceptional occasions (15/5/01 & 11/8/01), a feeding aggregation of at least three tree-kangaroos was observed in a large bollywood about 100 m west of the bridge site.

Evidence that arboreal mammals cross natural connections

As no natural connections occur in the immediate vicinity of the bridge, no evidence that arboreal mammals cross them could be obtained.

Evidence that arboreal mammals crossed the bridge

The *Buckshot RTV* camera captured three photographs of a brushtail possum on the bridge on 9 September 2001 (see **Figure 5.10**) but these do not provide conclusive evidence that the possum actually used it to cross the road. This came on 26 October 2001 when a field assistant (J. Shaffer) and I saw a small lemuroid ringtail cross the bridge from north to south at 10.15 pm (see **Figure 5.11**). The night in question was wet and cold, with 20.5 mm of rain recorded at nearby Whiteing Road (D. Clague, 2001 pers. comm.).

Figure 5.10: Remote photos of a brushtail on the Old Palmerston Highway bridge, taken 9/9/01

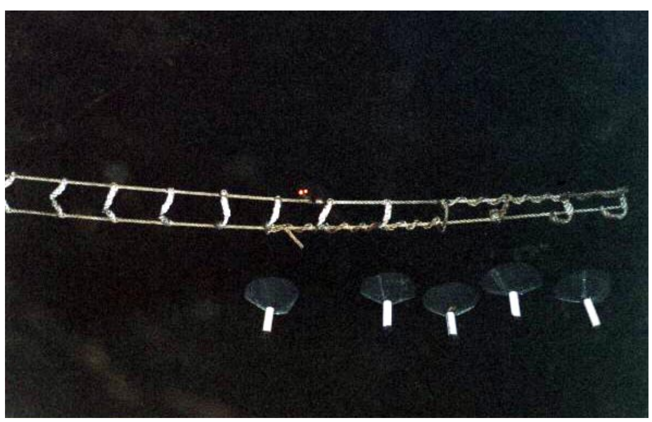


Figure 5.11 Lemuroid ringtail photographed crossing the Old Palmerston Highway bridge at 10.15 pm on 26/10/01 (note scat collection devices) (Photo: Jason Shaffer)

Prior to witnessing this first crossing event I had spent 22 hours spread over eight nights at the site. In the subsequent 58 hours spread over 13 nights at the site I observed 51 completed and two partial crossing events involving at least four arboreal mammal species (refer **Table 5.8**). Only one of the subsequent 13 site visits yielded no crossings (over a four hour period [10.30 pm-2.30 am] on 16-17/11/01). On that occasion, three fresh lemuroid ringtail scats had been deposited beneath the bridge prior to my arrival. Conversely, I saw 13 crossing events in the first half of one evening (over a five hour period [7.45 pm-12.45 am] on 19-20/6/03) and 16 crossing events in the latter half of the final evening spent at the site (over a five and a half hour period [11.50 pm–5.45 am] on 1-2/7/03). Up to five crossings were recorded in a single hour (**Table 5.8**).

As can be seen from **Table 5.8**, a total of 52 completed crossing events were observed during the 80 hours spent directly observing the bridge over 21 nights between 7 April 2001 and 2 July 2003. Thirty-five involved rainforest ringtails (12 x *H. lemuroides* & 22 x *P. herbertensis*), 16 involved brushtails, one a striped possum and another an unidentified small mammal (see **Figures 5.12, 5.14**). A series of still images captured from video footage of crossings made by Herbert River and lemuroid ringtails, on 27 March 2002 and 31 August 2002 respectively, are included at **Appendix 5.4**. Two partial crossing events, whereby a coppery brushtail and Herbert River ringtail got halfway across before turning back, were also observed. These attempts were probably abandoned due to the presence of onlookers.

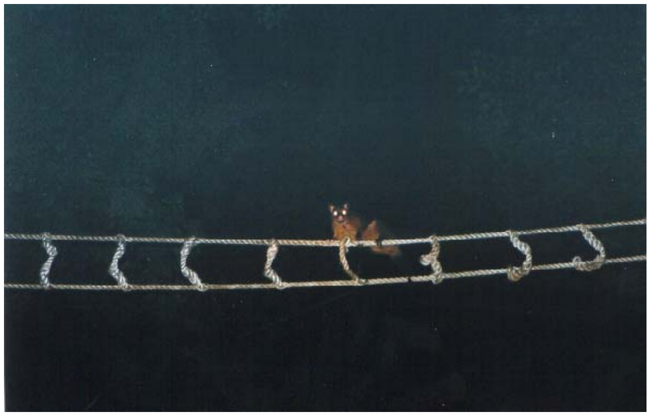
The figures cited here provide a crude estimate of a possum-crossing rate of one every 1.5 hours or so. The rate is lower (less than one every two hours) if only the rainforest ringtails are considered. This estimate increases to a crossing every hour or so (1.75 hours for the rainforest ringtails) when the time spent at the site before the first crossing event (presumably a period of familiarisation) is discounted (cf. an estimate of approximately one possum crossing every ten hours at Site 1).

Table 5.8 Crossing events observed on Old Palmerston Highway bridge in 80 spotlight hours between 7/4/01 and 2/7/03

Date	*Time*	*Species*	*Direction*	*Date*	*Time*	*Species*	*Direction*
26/10/01	22:15	*H. lemuroides*	n-s	19/6/03	20.20	*T. vulpecula*	s-n
15/12/01	03:50	*H. lemuroides*	s-n		20.50	*P. herbertensis*	s-n
9/2/02	21:00	*T. vulpecula*	n-s		21.15	*P. herbertensis*	n-s
16/2/02	23:20	*T. vulpecula*	s-n		21.25	*P. herbertensis*	s-n
17/2/02	02:00	*P. herbertensis*	n-s		22.00	*H. lemuroides*	n-s
8/3/02	21:00	*T. vulpecula*	n-s		22.35	*P. herbertensis*	s-n
	23:20	*T. vulpecula*	s-n		23.20	*H. lemuroides*	s-n
9/3/02	00:40	*P. herbertensis*	s-n		23.25	*P. herbertensis*	n-s
27/3/02	19:00	*P. herbertensis*	s-n	20/6/03	00.30	*H. lemuroides*	n-s
31/8/02	19:00	small mammal	n-s		00.32	*P. herbertensis*	n-s
	22:30	*H. lemuroides*	s-n		00.32	*P. herbertensis*[3]	n-s
8/11/02	20:20	*P. herbertensis*	n-s	2/7/03	00.15	*P. herbertensis*	s-n
	22:30	*T. vulpecula*	n-s		00.30	*T. vulpecula*	n-s
	23:10	*T. vulpecula*[1]	s-n		00.37	*P. herbertensis*	n-s
9/11/02	00:20	*T. vulpecula*	s-n		01.50	*P. herbertensis*	s-n
	00:25	*T. vulpecula*[1]	s-n		02.19	*T. vulpecula*	s-n
29/11/02	23:55	*P. herbertensis*	s-n		02.30	*P. herbertensis*	n-s
30/11/02	00:15	*T. vulpecula*[1]	s-n[2]		02.37	*H. lemuroides*	n-s
23/3/03	20:55	*P. herbertensis*[3]	s-n		03.08	*T. vulpecula*[5]	s-n
3/5/03	20:13	*D. trivirgata*	n-s		03.08	*T. vulpecula*[5]	s-n
	20:40	*P. herbertensis*	s-n		03.11	*T. vulpecula*	s-n
	20:58	*H. lemuroides*	n-s		04.05	*P. herbertensis*	s-n
	21:29	*T. vulpecula*[1]	n-s		04.15	*P. herbertensis*	s-n[2]
	21:29	*T. vulpecula*[4]	n-s		04.25	*H. lemuroides*	s-n
	21:47	*P. herbertensis*	s-n		04.31	*H. lemuroides*[1]	n-s
19/6/03	19.45	*P. herbertensis*	n-s		04.50	*P. herbertensis*	s-n
	20.00	*H. lemuroides*	s-n		05.34	*H. lemuroides*[6]	s-n

[1]Repeat observation of same individual likely; [2]Partial crossing event; [3]Pale fawn specimen, probably juvenile;

[4]Young-at-heel; [5]Antagonistic interaction; [6]Female with distended pouch



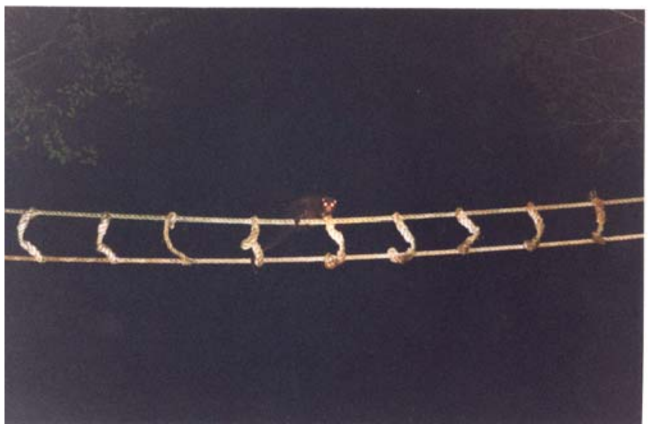


Figure 5.12a, top, Coppery brushtail photographed crossing the Old Palmerston Highway bridge in a north-south direction at 9.00 pm on 8/3/02; b, bottom, Lemuroid ringtail heading in the opposite direction at 8.00 pm on 19/6/03

It is probably no coincidence that the site visits yielding the most activity occurred towards the end of the sampling period. The last site visit took place in July 2003, more than two years after the bridge was erected. Hence the bridge had probably been used as an arboreal runway (after Goosem & Turton 1999; Wilson 2000) for three generations of rainforest ringtails (most Herbert River ringtail births May-July, green and lemuroid ringtails Aug-Nov; see **Chapter Four**). **Figure 5.13** shows the increase in frequency of observed crossing events (including the partial events observed on 30/11/02 and 2/7/03 but not including the unidentified small mammal seen crossing on 31/8/02) over time spent at the site.

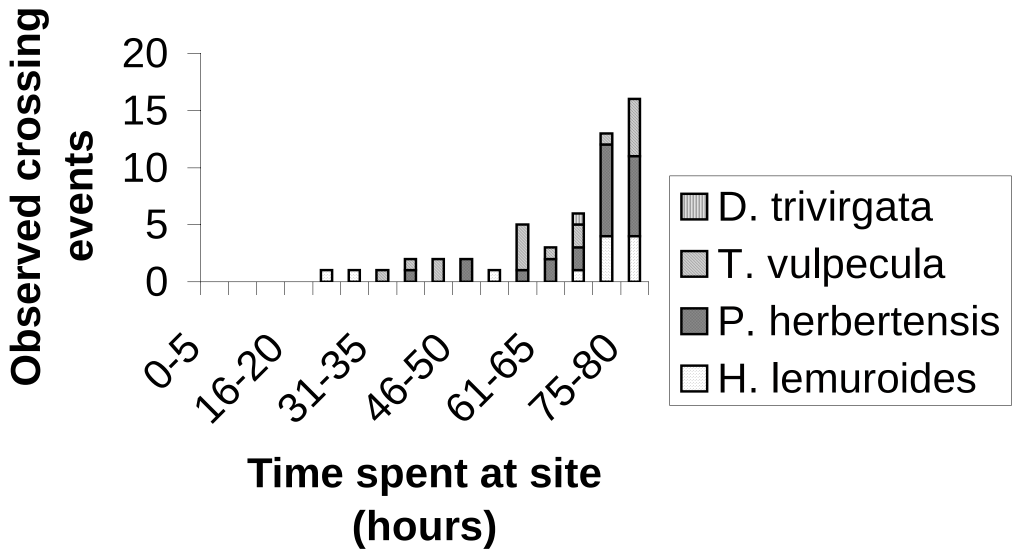


Figure 5.13 Crossing events observed in subsequent five-hour periods spent at the Old Palmerston Highway site between 7/4/01 and 2/7/03 (n=53)

It is worth noting that my last three site visits (which yielded 35 observations in 12 hours – a rate of just under three crossings per hour) took place during the phase after the new moon. Winter & Goudberg (1995b, 1995c) reported that rainforest ringtail possum activity is curtailed on clear moonlight nights, possibly because of their greater visibility to potential predators. A negative relationship between detectability and visibility of the moon has also been shown for other arboreal marsupials such as the feathertail glider, *Acrobates pygmaeus* (Goldingay & Kavanagh 1988), and sugar glider, *Petaurus breviceps* (Wakefield 1961).

It is not known how many individual animals crossed the bridge. As indicated by **Table 5.8**, at least five repeat observations of the same individual were likely. Four were of a richly-coloured coppery brushtail with a white-tipped tail (**Figure 5.14a**) while another involved a lemuroid ringtail which made the crossing in a south-north direction early on the morning of 2 July 2003 and returned in the opposite direction just six minutes later. Based on physical characteristics such as body size and colour, it could be determined that several individual lemuroid and Herbert River ringtails as well as coppery brushtails made the crossing. Further, three events involving two individuals of the same species crossing simultaneously were observed (2 x brushtail, 1 x Herbert River ringtail, see **Figure 5.14b**). On the last of these occasions, at 3.08 am on 2 July 2003, a large coppery brushtail aggressively pursued a smaller grey-coloured specimen in a south-north direction across the bridge. Another coppery brushtail followed them just three minutes later.

The penultimate site visit was conducted during the first half of the evening (7.45pm – 12.45 am) on 19 June 2003, while the final site visit covered the second half of the evening (11.50 pm – 5.45 am) on 2 July 2003. **Figure 5.15** shows the hourly breakdown of crossing events observed up to midnight on 19 June 2003 and after midnight on 2 July 2003. It shows that 10 animals crossed before midnight and 16 crossed after. The hour beginning at 4.00 am had the highest number of crossings (5), while three crossings each were observed in the hours beginning at 8.00 pm, midnight, 2.00 am and 3.00 am. Of the 26 animals that were observed crossing, nine traveled in a north-south direction (four before midnight, five after) and 17 in the opposite direction (six before midnight, 11 after). A female lemuroid ringtail with a heavily distended pouch made the last crossing (just before dawn, at 5.34 am). This is consistent with Winter & Goudberg's (1995a) assertion that the lemuroid ringtail ends its nocturnal wanderings much later than the coppery brushtail and Herbert River ringtail which share its habitat.

Figure 5.14a, top, Richly-coloured coppery brushtail crossing the Old Palmerston Highway bridge at 10.30 pm on 8/11/02; b, bottom, Sub-adult and adult Herbert River ringtail crossing simultaneously at 12.32 am on 20/6/03

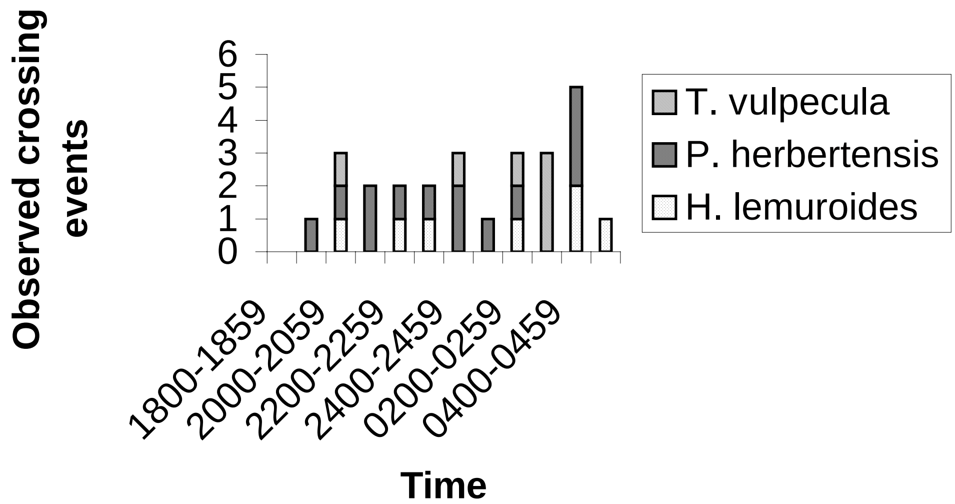


Figure 5.15 Crossing events observed between 7.45 pm and midnight on 19/6/03 and between midnight and 5.45 am on 2/7/03 (n=26)

Four of the six scat funnels suspended below the bridge (as seen in **Fig. 5.11**) were removed on 27 October 2001. Scats were found in one of them and Barbara Triggs identified these as belonging to the lemuroid ringtail (see **Appendix 5.1**). The remaining two funnels were removed on 15 December 2001 and one of them again contained lemuroid ringtail scats. As there was no canopy connectivity above this road, these results confirmed that lemuroid ringtails were crossing the bridge.

The results of hair sampling, shown in **Table 5.9** below, indicated that brushtail possums as well as Lumholtz's tree-kangaroos were also using the bridge. Brushtail hair as well as one white hair (probably feral cat, *Felis catus*) was found on tape removed from the hairtube's northern entrance on 9 September 2001 and brushtail hair was on tape removed from the southern entrance as well. Tape removed from both the upper and lower halves of the hair curtain on 9 September 2001 contained Lumholtz's tree-kangaroo hair. Tape removed from the upper half on 15 September 2001 contained brushtail hair (**Figure 5.16**) as did tape removed from the upper half in November 2001. The alignment of hairs on the tape suggested that the animals had moved in both directions.

Table 5.9 Results of analysis of hair tapes taken from the traps installed on the Old Palmerston Highway bridge in August 2001

Date	*Trap*	*Species*	*Date*	*Trap*	*Species*
9 Sep 01	Tube (north)	*T. vulpecula*	9 Sep 01	Curtain (bottom)	*D. lumholtzi*
	Tube (north)	One white hair, probably *Felis catus*	15 Sep 01	Curtain (top)	*T. vulpecula*
	Tube (south)	*T. vulpecula*	Nov 01	Curtain (top)	*T. vulpecula*
	Curtain (top)	*D. lumholtzi*		Curtain (top)	*T. vulpecula*
	Curtain (top)	*T. vulpecula*		Curtain (top)	*T. vulpecula*

The presence of Lumholtz's tree-kangaroo hair is noteworthy, although it cannot be proved that this species crossed over the road via the bridge. On 16 February 2002, an individual was spotlit in the bollywood at the northern end of the bridge, where it remained stationary for four hours. It is possible that my presence inhibited crossing behaviour by this animal. On the other hand, it is difficult to explain the absence of rainforest ringtail hair, given that lemuroid and Herbert River ringtails were recorded using the bridge during the period that the traps were in place. Indeed, the first lemuroid ringtail that was seen crossing the bridge actually climbed through the hair curtain, although it is unlikely that fur would have adhered to the tape on this night due to heavy rain. The presence of cat hair can probably be explained by the regular sightings of domestic or feral cats along the road. They are agile climbers (Menkhorst & Knight 2001).

Figure 5.16 Brushtail hair attached to tape on the hair curtain installed on the Old Palmerston Highway bridge

Evidence of potential predators at the bridge site

There was no evidence that potential predators were congregating at the site, although lesser sooty owls were commonly heard in the area and a rufous owl was heard calling on 15 May 2001. A southern boobook, *Ninox novaeseelandiae*, flew across the beam of the spotlight into a tree at the southern end of the bridge on one occasion (12/8/01) but this species is not a known predator of adult rainforest ringtails (R. Russell & M. Trenerry, 2003 pers. comm.). As mentioned above, domestic or feral cats were regularly seen along the road and a cat hair was taken from the hairtrap on 9 September 2001.

ANECDOTAL OBSERVATIONS OF CROSSING BEHAVIOUR

Several observations support Gamlin and de Rohan's (1996) assertion (see **Chapter Three**), that animals memorise the best footpaths, remembering convenient gangways and underpasses, shortcuts and launchpads. For instance, a richly-coloured coppery brushtail with a white-tipped tail was observed crossing the Old Palmerston Highway bridge in a north-south direction at 10.30 pm on 8 November 2002 (**Figure 5.14a**). It returned in the opposite direction about two hours later (12.25 am, 9/11/02), within five minutes of another brushtail crossing event (see **Table 5.8**). On another occasion, a Herbert River ringtail moved deliberately through the undergrowth alongside the road to the bridge and crossed without hesitation in a south-north direction *towards* a pair of brushtail possums engaged in noisy, antagonistic behaviour in the bollywood to which the bridge was attached. This appears to contradict Goudberg (quoted in Goosem 2000b, p. 111) who suggested that '…more than one or even two crossing points in an area would be necessary due to [Herbert River ringtails] being susceptible to bullying from coppery brushtails'.

The affinity possums had with the bridges was exhibited in several other ways. At the original bridge site, a lemuroid ringtail carrying a single back-young moved deliberately through roadside vegetation before reaching a spot where a vine had been moved to allow installation of the ropeway. It seemed uncertain about how to proceed and emitted a quiet grunt before moving cautiously to the rope, where it remained stationary awhile, and then moved onto the bridge where it completed a crossing (14/10/00) (**Figure 5.3a**). At 9.29 pm on 3 May 2003, an adult coppery brushtail escorted a juvenile across the Old

Palmerston Highway bridge while a field assistant (L. Sutakowsky) and I were engaged in a noisy (but cordial) exchange with the local constabulary underneath it. As with the Longview squirrels (see **Chapter Two**), possums were even seen escorting their young and teaching them the ropes! Two other crossing events involving two individuals of the same species crossing simultaneously were observed (see **Figure 5.14b**).

It took five months before a completed crossing of the Old Palmerston Highway bridge by a small lemuroid ringtail was observed. This contrasts with the findings of the AMBS (2000), that common ringtail possums used the overpass structure across Wakehurst Parkway within several weeks of installation. Given that common ringtails are known to use cables and powerlines as transport corridors, this result is not surprising. One would expect the rainforest ringtails to take longer to accept canopy bridges as crossing routes, given their reluctance to venture beyond the shelter of the closed canopy (see Winter 1991).

Once familiar with the Old Palmerston Highway crossing route, however, the canopy-dwellers seemed resolutely determined to use it. For example, many animals turned tail and retreated when first captured in the spotlight (e.g., Herbert River ringtail in **Appendix 5.4**). Invariably, a second crossing would be attempted, sometimes up to 20 minutes later. On one occasion, a lemuroid ringtail crossed the bridge even though it was sagging heavily after being vandalized (3.50 am, 15/12/01). At its lowest point, the bridge was only 4.75 m above the road surface (**Figure 5.17a**). This is consistent with a 1998 observation of a striped possum using a telephone cable that sagged considerably (A. Freeman, 2000 pers. comm.). The crossing of a coppery brushtail with young-at-heel above three observers engaged in a noisy exchange is another case in point. Up to five possums per hour were making this particular crossing by the end of the sampling period and the rate of crossing over the last 12 hours averaged about three per hour. This was equal to the highest detection rate of lemuroid and Herbert River ringtails and brushtails in trees adjacent to the road.

Figure 5.17a, left, Old Palmerston Highway bridge after being vandalized in early December 2001 (ht. 4.75 m) and b, right, Correct height of bridge (ht. 7.5 m)

SUMMARY

The trials detailed in this chapter demonstrated that arboreal and scansorial mammals will use canopy bridges to cross roads in the Wet Tropics region, especially where canopy connectivity has not been maintained. At least seven mammal species were recorded by a variety of means on the bridges erected at the three study sites. These included the green, Herbert River and lemuroid ringtails and Lumholtz's tree-kangaroo, all species of conservation significance. Of such species, only the lemuroid and Herbert River ringtails were actually observed using the bridges to cross roads, although photos of a green ringtail were taken inside the bridge at the B Road site and tree-kangaroo hair samples were taken from traps installed on the wide bridge at the snig track site and on the Old Palmerston Highway bridge. Scats from the latter two species were also collected from the centre of the nets suspended below both bridges at the snig track site.

Chapter 6: Discussion

Abstract. This chapter discusses the results of the research conducted for this thesis. The implications of the findings, that arboreal and scansorial mammals will use canopy bridges to cross roads in the Wet Tropics region, especially where no canopy connectivity remains, are explored not only in terms of wildlife management but also with reference to cost, road user safety and presentation of the WTWHA to visitors. It is suggested that the incorporation of overpass facilities in the road network has the potential to play an important role in the presentation and transmission of World Heritage values, although the type of overpass structure selected will have a bearing on whether a permit will be required under the Queensland *Wet Tropics World Heritage Protection and Management Act 1993*. Rope ladders are proposed as the preferred solution and it is suggested that as many as practicable be built across roads in upland areas of the Wet Tropics where no canopy connectivity remains. They should be installed every 100 - 120 m, at least 6 m above the road surface. I estimate that a huge improvement in the present situation could be achieved by spending AU$600,000 on road bridges for wildlife that is equivalent to the cost of installing 20 m of the Kuranda Range Road which is being rebuilt at present. Research showing that the rainforest ringtails, coppery brushtail and Lumholtz's tree-kangaroo are at risk from climate change lends extra significance to the findings of the study. The thesis concludes with ideas for further research that would increase our understanding of the use of canopy bridges by arboreal mammals, particularly in the Wet Tropics of northeastern Queensland.

CHAPTER 6: DISCUSSION

INTRODUCTION

In this chapter, I discuss the results of the research conducted for this thesis. I summarise what has been done overseas and in Australia with respect to canopy bridges and place the trials undertaken in the Wet Tropics in a broader perspective. I explore the implications of this study, not only in terms of wildlife management but also with reference to cost, road user safety and presentation in a region where there is a wide range of values held by different sections of the community in relation to roads. One constraint of this study was that replication was impossible. However, a pilot study such as this was needed to provide insight before a more large-scale highly replicated study could be attempted.   The thesis concludes with an outline of my ideas for further research that would increase our understanding of the use of canopy bridges by arboreal mammals, particularly in the Wet Tropics region of northeastern Queensland.

WHAT HAS BEEN DONE?

In a review of fragmentation of habitat by roads and utility corridors, Andrews (1990) wrote that (with the exception of bamboo poles connecting orchard trees in China to facilitate the movement of a predatory citrus ant) no canopy bridges have been documented. I found that canopy bridges have been used in at least 11 countries, including Australia. Ropeways have been used in the United States and England, Scotland and Wales. Colobridges have been used in Kenya and Zanzibar and similar bridges have been used in Belize, Mexico and Taiwan. Pole bridges have been used in

Brazil. In Australia, ropeways have been trialed in northern NSW, Wilson (2000) tested vine linkages in the Wet Tropics region and ropeways were recently installed over a busy road in Tasmania. A more elaborate tunnel-like structure was trialed in Sydney (AMBS 2000) and a rope tunnel was erected in the Wet Tropics region in 1995. As of this writing, two canopy bridges are being trailed or considered for use in Victoria and one apiece in New South Wales and Queeensland.

RESULTS OF CANOPY BRIDGE TRIALS UNDERTAKEN IN THE WET TROPICS REGION

Species use

As reported in **Chapter Five**, trials undertaken in the Wet Tropics region have demonstrated that arboreal and scansorial mammals will use canopy bridges to cross roads, especially where no canopy connectivity remains. **Table 6.1** shows that at least seven mammal species were recorded by a variety of means on the bridges erected at my three study sites. The table does not include scat data from the ends of the nets hung beneath the bridges because of the confounding effect of overhanging vegetation. Two species that were represented in the scat collection data from Site 2, the long-tailed pygmy possum and bush rat, have been omitted due to this uncertainty. A further two species that might be considered likely users of canopy bridges but were not recorded using them during the current study are the white-tailed rat and highly endangered spotted-tailed quoll.

Table 6.1 Arboreal/scansorial mammals recorded[1] on the bridges erected at my three study sites

	D. trivirgata	*H.lemuroides*	*P.archeri*	*P. herbertensis*	*T. vulpecula*	*D. lumholtzi*	*M. cervinipes* (or small mammal)
Rope tunnel (B Road)	**IR**	**O**, **IR**, S	IR	**O**, **IR**, S	S	-	**O**, **IR**, S
Ropeway (B Road)	-	S	-	S	S, H	-	-
Wide rope bridge (snig track)	-	S	S	**IR**, S	S, H	S, H	S
Narrow rope bridge (snig track)	-	S	S	S	S	S	S
Long rope bridge (OPH)	**O**	**O**, S	-	**O**	**O**, IR, H	H	**O**

[1]Record code: O - observed, IR - infrared photo, S – scat sample, H – hair sample; those shown in **bold** considered to represent completed crossing events.

Rope tunnel

As shown in **Table 6.1**, investigations at the site of the existing canopy bridge on the B Road, near Cairns, revealed that the structure was used by at least six arboreal or scansorial species. All three rainforest ringtails present at the site were recorded on the bridge and two, the lemuroid and Herbert River ringtails were observed using it to cross the road. An important finding was that more than one individual Herbert River ringtail was involved (as were two lemuroid ringtails, if the back-young observed on 14/10/00 is considered in this context). The green ringtail was not observed crossing but was photographed at the entrance to the rope tunnel. The other target species for this study, Lumholtz's tree-kangaroo, was not recorded on this bridge. However, it is considered to be rare in the area.

Rope ladders

Of eight crossing events seen at the original bridge site, six involved animals moving along the top surface of the structure. Consequently, rope bridges replicating the top surface were erected on a snig track near Millaa Millaa to test whether bridge design and position affect usage. Two 10 m long bridges (effectively rope ladders or ‘monkey bridges’) were swung horizontally across the track, which retained canopy connectivity overhead. As shown in **Table 6.1**, scat and hair collection and analysis suggested that at least six arboreal and scansorial mammals, including tree-kangaroos, were using the two bridges but the results were inconclusive. No crossings were observed and proof of crossing was not obtained until remote photographs of a Herbert River ringtail crossing the wide bridge were taken on two separate occasions almost a year after the bridge was installed. In contrast, seven crossings of a natural connection above the bridges were observed plus a crossing event involving two lemuroid ringtails leaping at least 2 m across a canopy gap.

Subsequently, the narrow bridge initially installed over the snig track was removed, lengthened to 15 m and erected over a sealed, dual carriageway between Millaa Millaa and Ravenshoe. The configuration of the road corridor meant that it was of a sufficient width and length to represent a likely impediment or heightened risk for the movement of arboreal mammals. Although it was five months before a small lemuroid ringtail was seen crossing the bridge, such events soon became commonplace. As shown in **Table 6.1**, at least four arboreal or scansorial species were observed crossing the bridge. Sixteen completed crossings and one partial crossing were made by brushtail possums (both coppery and grey-coloured) and more than one individual animal was involved.

Herbert River ringtails made 22 crossings and 12 lemuroid ringtail crossings were observed. One partial Herbert River ringtail crossing was also observed as were single crossings completed by a striped possum and a small, unidentified mammal. Simultaneous crossings involving two individuals of the same species were observed on three occasions (2 x brushtail, 1 x Herbert River ringtail).

Based on hours spent spotlighting at the site, a crude possum-crossing rate of one every 1.5 hours is estimated. This rate increases to a crossing every hour when the time spent at the site before the first crossing event (presumably during a period of familiarisation for the subject animals) is discounted. Thirty-five crossing events were observed in the last 12 hours spent at the site, which equates to a rate of just under three crossings per hour. This compares with a possum-crossing rate of approximately one every ten hours at the established bridge site on the B Road. Again, tree-kangaroos were detected on the bridge but it cannot be proved that they used it to cross the road.

Ropeways

A single ropeway was trialed at the B Road bridge site and scat analysis suggested that it was used by lemuroid and Herbert River ringtails. Hair sampling also suggested that brushtail possums used the rope to cross the road. No crossings of the ropeway were actually observed although a remote photograph of a lemuroid ringtail inspecting it was taken.

Many possums, especially Herbert River ringtails and brushtails, were observed exiting the Old Palmerston Highway bridge via the heavy rope leading from the southern support tree (silver basswood) into the nearby forest. Lemuroid ringtails generally climbed up into the canopy of the silver basswood. On one occasion (19/6/03), a Herbert River ringtail was observed moving along the rope to get to the bridge, which it then proceeded to cross. This proves that rainforest ringtails will use ropeways to move through the canopy, albeit in a closed forest environment.

The habitual use of a heavy rope by a rescued green ringtail over a period of five years and the recovery of a green ringtail from a powerline in Atherton, reported during this study, further supports the case that rainforest ringtails will accept a single-rope crossing. However, it is noted that lemuroid and Herbert River ringtails used the existing bridge in preference to the single rope to cross the B Road when both options were available to them. Of course, this might be an artifact of habituation rather than a reflection of actual preference.

THEORETICAL IMPLICATIONS

The above findings indicate that canopy bridges have the potential to ameliorate the barrier effects of roads for at least some arboreal mammals, as well as to reduce road mortality for generalist species that are otherwise known to move along the ground (such as brushtail and striped possums). They also show that some scansorial species, such as the fawn-footed melomys, will readily use canopy bridges to cross roads. This is important, as studies have found that roads inhibit the movement of this species (Goosem 2001). Conversely, some scansorial species, such as the white-tailed rat, were noticeably absent from the data although they were commonly encountered at the study sites. Presumably the white-tailed rat prefers to cross linear disturbances such as roads at ground (or sub-ground) level. Goosem (2001) found that roads did not present a major barrier to this species and she recorded them using road culverts as a crossing route (Goosem 2000a). The species figured prominently in Goosem's (2000a) roadkill statistics and it was recorded as a roadkill near Site 1 during the current study.

Another species that most commonly moves between trees at ground level and is prone to roadkill is Lumholtz's tree-kangaroo. Although these animals were recorded on the bridges during the current study, it remains unclear whether they will actually use them to cross roads. Newell (1999a) thought it unlikely, writing that:

> Unfortunately, inducing tree-kangaroos to use a specific thoroughfare across or under a road is most likely impractical. Movement across most aerial links is unfeasible for tree-kangaroos, as unlike their smaller possum cousins with a much smaller body size, they are incapable of moving between fine branches in the upper canopy (Newell 1999a, p. 7).

It is interesting that Newell (1999a) cited body size as a limiting factor in the inability of tree-kangaroos to use most aerial links but identified the leaf-eating colobine monkeys (Genera *Presbytis* and *Colobus*) as their ecological equivalents in Old World tropical rainforests (Newell 1999b). The Angola colobus monkey, *Colobus angolensis*, is roughly double the size of Lumholtz's tree-kangaroo (9-20 kg [Kingdon 1997] cf. 6-9.5 kg, see Chapter Four) and as discussed in **Chapter Two**, Angolan colobus monkeys frequently uses canopy bridges to cross busy roads in Kenya. It was probably a combination of the tree-kangaroo's relatively poor dexterity and grasping ability, rather than size *per se*, that led Newell to his conclusion that inducing tree-kangaroos to use a specific thoroughfare across a road is most likely impractical. However, as discussed in **Chapter Three**, Lumholtz's tree-kangaroos have been observed using vines to cross natural linear barriers and they use ropes in captivity.

No green ringtail possums were actually observed crossing roads via the bridges, although the species was photographed at the entrance to the B Road bridge (see **Figure 5.3c**) and scats were collected from the centre of the nets beneath both snig track bridges. The green ringtail is the rarest of the rainforest ringtails in unfragmented forest (Laurance 1995) and the lack of any verified crossings (as well as low rates of detection and scat counts) could be an artifact of its rarity at the sites investigated. Alternatively, this species might be more comfortable crossing canopy gaps at ground level or it could be that greens accept linear barriers as part of their territorial boundaries (R. Russell, 2003 pers. comm.). A green ringtail was seen crossing a road at ground level during the current study (Tinaroo Falls Dam Road, 5/5/00).

Canopy connections and climate change

For the lemuroid ringtail and to a lesser extent the Herbert River ringtail, canopy connections are probably crucial (Wilson 2000). The fragmentation effects of roads in the Wet Tropics region are compounded by other threatening processes such as the impacts of tourism, land clearing on private land (**Figure 6.1**) and global climate change (Wilson 2000). It is feared that the impacts of climate change in the tropical rainforests of the Wet Tropics could result in many extinctions (Williams et al. 2003). In particular, work on the possible ecological effects of climate change on the conservation status of the leaf-eating mammals of the Wet Tropics (e.g., Kanowski 1999; Krockenberger 2002;

Williams 2002; see also O'Neill 1999) has emphasised the threat to these species posed by rising temperatures and carbon dioxide levels. As Kanowski (1999) wrote:

> …to the extent that the folivores endemic to the rainforests of north Queensland are intolerant of the hot climate experienced on the lowlands, then global warming is likely to reduce the area of habitat that is climatically suitable for them (Kanowski 1999, p. 174).

Kanowski (1999) proposed that the 'core' habitat of the folivores (i.e., the climate zone presently above 800 m which supports abundant populations) would be particularly adversely affected. In the Atherton Uplands, Kanowski (1999) calculated that the area of core habitat would be expected to contract by two-thirds, from 650 km^2 to 220 km^2, in response to a 1°C increase in temperature and by 95%, to 32 km^2, in response to a 2°C increase. Further, even under a 1°C rise, the core habitat would be fragmented into a series of isolates on the tops of the mountain ranges (see **Figures 6.2-6.4**).

Figure 6.1 Accessible areas continue to be cleared in the Wet Tropics region. This photograph was taken near Site 3 in March, 2001.

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Figure 6.2 Current core bioclimatic zone of rainforest folivores (after Kanowski 1999)

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Figure 6.3 Core bioclimatic zone of rainforest folivores after a 1°C increase in temperature (after Kanowski 1999)

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Figure 6.4 Core bioclimatic zone of rainforest folivores after a 2°C increase in temperature (after Kanowski 1999)

The rainforest folivores do not seem to be able to deal with high temperatures because their body temperatures rise too much. Results of recent studies suggest that green ringtails would find it more difficult to survive and find the water they needed in leaves if heat waves become more severe and frequent (A. Krockenberger, 2003 pers. comm.). A more insidious threat may emanate from the very mechanism of global warming: rising concentrations of carbon dioxide in the atmosphere. Kanowski (quoted in O'Neill 1999) believes that in a warmer world, metabolic changes will cause trees to change the balance of proteins in their leaves and they will also synthesise more tannins. Consequently, as animals get forced higher and higher into the remaining cool areas, their feed will become less nutritious because the trees at higher altitudes generally grow in poor granite soils. Already, rainforest trees that formerly occupied fertile lowland soils have retreated on to rocky granitic soils at higher altitude, which are scarcely more fertile than coarse sand (O'Neill 1999). This change may force the rainforest folivores to invest more energy in digesting and detoxifying their leafy diet, a diet that has been marginal since the last glacial period (O'Neill 1999).

Based on the above work, Reynolds (2002) placed the lemuroid ringtail alongside the critically endangered Leadbeater's possum, *Gymnobelideus leadbeateri*, from central Victoria as Australian mammal species particularly at risk from climate change because they are less able to adapt compared to species with more catholic habitat requirements. Andrews (1990), in her review on fragmentation of habitat by roads and utility corridors, also identified the lemuroid ringtail and Leadbeater's possums, along with the Herbert River ringtail possum, as arboreal mammals at risk from fragmentation. The Herbert River ringtail, coppery brushtail and Lumholtz's tree-kangaroo were included in

Reynolds (2002) list as mammal species at risk from climate change. This lends extra significance to the findings of my study - that simple, inexpensive overpass structures will enhance the safe movement of the lemuroid and Herbert River ringtails as well as the coppery brushtail possum.

PRACTICAL IMPLICATIONS

The legal obligations of managers of road systems and wildlife in the Wet Tropics region have been discussed in **Chapter Three**. The current study has found that simple, inexpensive overpass structures will enhance the safe movement of at-risk arboreal folivores in this area. Therefore, there is a strong case for incorporating overpass facilities into the Wet Tropics road network. However, managers must also take into account cost and road user safety as well as presentation in a region where there is a wide range of values held by different sections of the community in relation to roads.

Including construction costs, the amount spent on the original B Road bridge was about AU$2,000 (R. Russell, 1998 pers. comm.). This bridge was an elaborate rope tunnel attached to telegraph poles erected by the then Far North Queensland Electricity Board. My study has found that a rope ladder swung horizontally across the road will suffice. The ladders built for the current study by a local chandlery cost about AU$500 each. They were tied off to strong trees on either side of the road. Results of trials of single ropeways were inconclusive, although it appears that a ropeway was used by at least three arboreal species at the original bridge site and animals moving on and off the Old Palmerston Highway bridge also used a heavy rope extending from the bridge into the adjacent forest. As reported earlier, the use of a heavy rope by a rescued green ringtail and the retrieval of an individual from a powerline suggest that rainforest ringtails will accept single-rope crossings. This should not be surprising as rainforest ringtails regularly use vines and thin branches in their natural environment. However, Wilson (2000) found no evidence of rainforest ringtails using an artificial vine linkage across a road and both lemuroid and Herbert River ringtails preferred to use the existing B Road bridge to a single ropeway installed beside it.

There are several reasons why I would recommend rope ladders over single ropeways as overpass facilities for arboreal mammals, particularly in the Wet Tropics region. First, it is unlikely that Lumholtz's tree-kangaroos, a target species, would use lengthy ropeways over roads. While it could not be proved that tree-kangaroos crossed roads via canopy bridges in my study, the results of hair and scat sampling indicated that they were at least on three of the rope ladders. The rope ladders also provide stability and although the possums that crossed them usually did so hand over hand via one or other of the struts, they were often seen to wrap their tails around the rungs or opposing strut when caught in the spotlight (see **Figure 5.12**). This stability might be crucial when two or more animals use the bridge simultaneously or in the event of strong winds. The rope ladders and tunnels also have an advantage in that they provide animals with room to manoeuvre should another animal confront them. Possums were seen zigzagging from side to side, in what appeared to be an avoidance response to the presence of observers. I also saw a coppery brushtail move in a bounding gait across the Old Palmerston Highway bridge by leaping from rung to rung (at 12.20 am on 9/11/02 – it was followed five minutes later by another brushtail).

Presentation of World Heritage values

Canopy bridges have the potential to play an important role in the presentation and transmission of World Heritage values in the Wet Tropics region. This is one of the core responsibilities of WTMA, according to the primary goal for management, that is:

> To provide for the implementation of Australia's international duty for the **protection, conservation, presentation, rehabilitation** and **transmission** to future generations of the Wet Tropics of Queensland World Heritage Area, within the meaning of the World Heritage Convention (WTMA 1997, p. 8).

QDMR (1997) claimed that roads play an important part in awareness of the region's conservation significance by presenting the forests and coastline along the major highways. I contend that rope ladders (or 'monkey bridges'), as well as being more likely to facilitate crossing by a wider array of species, are aesthetically pleasing to road users. It is not inconceivable that they could become tourist attractions in their own right, like the first squirrel bridge (the 'Nutty Narrows Bridge') in Longview, Washington State (see Longview City Council 2001). At the very least, the installation of canopy bridges would send a message to visitors distressed by the numbers of road-killed animals they see that managing authorities were attempting to deal with the problem. Indeed, a Japanese tour group donated funds to the current study '…to help wildlife on the Tableland' (R. Tagawa, 2002 pers. comm.). Rope ladder facilities would also raise community awareness about the dual problem of roadkill and habitat fragmentation in the Wet Tropics.

This study created considerable public interest and was widely reported in the print and electronic media (see **Appendices 6.1, 6.2**). A captioned photograph even appeared in a children's book, 'Animals at Risk' (Keyt 1998) (**Figure 6.6**). The reasons for this interest are not entirely clear but it was probably triggered by the ordinary person's affection for animals that are 'cute and cuddly' (Horwitz et al. 1999). The project also tapped into the widely held belief that solving our environmental problems only requires the right technologies. No trade-offs to 'save' the environment were involved – the solution did not interfere with the ordinary person's current 'use' of the environment and so no behavioural modification was required of people (see Bell et al. 1996). In short, it was a 'good news story'.

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Figure 6.5 Excerpt from children's book, 'Animals at Risk' (Keyt 1998)

It was curious that the media chose to focus on the potential for ‘prey funneling’. This effect has been well documented in the literature (e.g., Andrews 1990; Thwaites 1998) and it refers to the problem of (mostly feral) predatory animals focusing their hunting activities on corridors that act as funnels for prey. A good example is the appearance of foxes, *Vulpes vulpes*, at the ‘tunnel of love’ built for mountain pygmy-possums (refer **Chapter 2**) soon after it was opened (D. Hespe, 1999 pers. comm.). Prey funneling could be expected to occur to some degree at the bridges, given that predators of the rainforest ringtails are known to congregate at well-known runways (Goosem 2000b). Realistically, however, these predators are sparsely distributed throughout the rainforest and are likely to be species of conservation significance in their own right (e.g., rufous owl, spotted-tailed quoll). As reported in **Chapter Five**, and notwithstanding the single cat hair left at the Old Palmerston Highway site, no evidence of prey funneling was obtained during the current study.

The bridge over the Old Palmerston Highway generated interest in the nearby towns of Millaa Millaa and Ravenshoe in particular (especially once the scat collectors were suspended below it). In one conversation with a passing motorist, I was asked why the bridge was not coloured green. Silver rope was used for the Old Palmerston Highway bridge as this had the highest UV rating. I understand that UV-rated rope is available in a sea-green color, but that it has a lower rating than silver rope and therefore is not as durable. The original B Road bridge was made with silver rope and is showing little sign of decay after eight years. In QDMR’s Best Practice Manual, it was suggested that vines would eventually cover the bridge, thereby creating a natural appearance. While this has occurred to some degree (see **Figure 6.7**), it probably creates more problems than it solves because of decay etc.

Figure 6.6 Water vine, *Cissus hypoglauca*, creeps over the original bridge on the B Road. This is a favoured food species of the rainforest ringtails (Winter & Goudberg 1995b).

Such problems could be overcome by the use of non-perishable materials. The Colobus Trust replaced the original wood and rope colobridges in Kenya because they were decaying due to the hot and humid climate and threatened to collapse. The new bridges were made of high-tension cable, chain link rungs and rubber piping. These bridges proved just as popular with the monkeys (Born Free Foundation 2002). Similarly, as reported in **Chapter Two**, the Longview squirrel bridge was built from aluminium and lengths of fire hose. However, it has already been reported in **Chapter Two** that ropeway trials for koalas were aborted in northeastern NSW due to liability concerns (C. Moon, 1999 pers. comm.). Similarly, the ropeways on the Isle of Wight were removed because they could not be insured (Wight Squirrel Project Newsletter No: 7). Managing authorities in the Wet Tropics would be reluctant to erect heavy, elaborate structures in a region regularly visited by strong winds as well as inquisitive tourists.

Permit requirements

The type of overpass structure selected will also have a bearing on whether a permit will be required under the Queensland *Wet Tropics World Heritage Protection and Management Act 1993*. As mentioned in **Chapter Three**, departments responsible for roads in the WTWHA must ensure that management of roads and tracks within the Area is consistent with provisions of the *Wet Tropics Management Plan 1998* and policies for its implementation. The most important consideration is the likely impact of a proposed activity on the Area's integrity. It is unlikely that WTMA would consider it necessary to place conditions on the installation of rope ladders as the activity could be regarded as 'minor and inconsequential' and 'of benefit to world heritage values' (B. Jennison, 2003 pers. comm.). These values include, but are not limited to (after Wet Tropics Management Act, s59):

I. Wildlife prescribed under the *Nature Conservation Act 1992* as presumed extinct, endangered, vulnerable or rare; and
II. The habitats of wildlife mentioned in subparagraph (I); and
III. Other threatened plant and animal communities; and
IV. Natural ecological processes.

However, a permit would probably be required if a more substantial structure was proposed and/or it was deemed to impact on the Area's scenic amenity, particularly with regard to the degree of visual dominance or any alteration of the landscape arising from the activity (B. Jennison, 2003 pers. comm.).

A permit would definitely be required if canopy clearing was involved. The Plan, in considering roadworks, requires that consideration be given to 'no net loss' of World Heritage values (D. Rivett, 2003 pers. comm.). As already discussed, these values include the rainforest ringtails and tree-kangaroos, their habitat and the ecological processes on which they depend. This is reflected in the Flora and Fauna Conservation Guidelines developed by WTMA for the maintenance of infrastructure, roads, service corridors and access tracks, one of which is to 'maintain canopy connectivity above roads wherever possible, to provide potential crossing points' for arboreal mammals (WTMA 1997, p 57). However, where roadworks do require canopy clearing and there is no prudent and feasible alternative, canopy bridges might be effective as an ameliorative tool in working towards 'no net loss' (D. Rivett, 2003 pers. comm.). It is likely that these issues will need to be resolved on a case-by-case basis (B. Jennison, 2003 pers. comm.).

Vandalism

Another factor to be considered in design selection should be protection against vandalism. The Old Palmerston Highway bridge was vandalised during my study and ropes used as internal furnishings in the large fauna underpasses built as part of the East Evelyn project on the Atherton Tablelands were 'souvenired' (M. Goosem, 2002 pers. comm.). The Colobus Trust reported that thieves regularly use the colobridges for 'spare parts'. In 2001 the Trust lost wire, tension bolts and even ladders. Not only did this make the bridges unstable for the colobus (in some cases unusable) but also hazardous to the general road users (*Colobus Update*, December 2001).

Bell et al. (1996) distinguished between several types of vandalism:

- acquisitive (looting, petty theft);
- tactical ideological (to draw attention to oneself or to an issue of concern);
- vindictive (aimed at revenge);
- play (to combat boredom); and
- malicious (due to diffuse frustration and rage, often occurring in public settings).

It is not unreasonable to suggest that motivation exists for all types of vandalism on the Atherton Tablelands. As reported by Hazel (1999), the Tablelands experience an unemployment rate of 10.4% (based on ABS 1996 figures). Whilst this may not be significant against the national average (9.2%), it is significant when examining the statistics of individual shires. The Old Palmerston Highway bridge is located on the boundary between the Shires of Eacham and Herberton (see **Appendix 4.2**). Herberton Shire had an unemployment rate in 1996 of 19.6% and some individual communities within this Shire experienced unemployment rates as high as 28% (Hazel 1999). The communities on the Tablelands also experience higher than national average populations of indigenous persons and those born overseas and there has been a significant downturn in primary industries such as agriculture, mining and especially timber. All these factors contribute to a depressed economy; the average household median income is AU$163 below the national average (Hazel 1999). Further, resentment toward World Heritage listing lingers in once mill-dependent communities. Not until recently did a majority of North Queensland residents approve the World Heritage Area (McDonald & Lane 2000).

Bell et al. (1996) suggest that aesthetic factors associated with an object's appearance (e.g., physical beauty) and the extent to which the site or facility is hardened (made difficult to vandalize) can affect the level of vandalism. In other words, increasing perceptions of control can be an effective means of lowering vandalism (see also Fisher & Baron 1982). Managing authorities in the Wet Tropics might consider site beautification and on-site interpretation and education (perhaps in the form of signage) as two ways of creating this perception.

Bridge placement

Perhaps the most important practical consideration for the managing authorities is bridge placement within the landscape. As already discussed, there are scenic amenity issues related to this. With respect to arboreal mammals, however, three indicators should be used as a basis for selecting locations:

1. Potential crossing points for 'canopy-dwellers'.
2. Known crossing locations of other arboreal mammals.
3. Sites with the highest roadkills.

Figure 6.3 shows the current core bioclimatic zone of the rainforest folivores (after Kanowski 1999) overlain by the regional road network. Colour coding on the map at **Appendix 6.3** indicates the functional road hierarchy in this area. I contend that all rainforest roads lacking canopy connectivity in upland areas represent priorities for the provision of overpass crossings for canopy-dwellers. Major roads (or dual carriageways, shown in red in **Appendix 6.3**) represent a logical starting point for ground-truthing for authorities.

These investigations could be further refined by targeting forests on nutrient-rich basalts, which support a greater abundance of lemuroid and Herbert River ringtails, coppery brushtails and Lumholtz's tree-kangaroos than forests on nutrient-poor acid igneous or metamorphic rocks (Kanowski et al. 2001). As many bridges as practicable should be built and these should be installed every 100 - 120 m, which represents the linear arrangement of possum home ranges along road frontages on the southern end of the Atherton Tablelands (converted from home ranges of 0.15 – 1.23 ha by Wilson [2000]). My research suggests that bridges should be located at least 6 m above the road surface.

Although I found no proof that tree-kangaroos actually used canopy bridges to cross roads, enough evidence exists to suggest that crossing facilities may have a role to play within an integrated approach to road management for this species. Izumi (2001) identified five problem (high mortality) spots for tree-kangaroos in the study area and prioritised potential corridors for the species between suitable habitats on the Atherton Tablelands (**Appendix 6.4**). These locations may be a useful tool to determine the priorities for locating mitigation measures required to reduce the impacts of roads on tree-kangaroos and other dispersing species (Izumi 2001).

While purpose-built culverts are probably the best options for tree-kangaroos – one was observed using a rail tunnel (Kanowski, quoted in Goosem 2000b) and another the East Evelyn underpasses (M. Goosem, 2003 pers. comm.) - they are expensive, regardless of whether they are retrofitted or included in the initial road design. The four culverts installed as part of the East Evelyn road upgrade project cost about AU$150,000 each to install (M. Frankcombe, 2003 pers. comm.). For a combined total of AU$600,000, it would be possible to erect approximately 1,200 rope canopy bridges!

As reported in **Chapter Three**, Wilson (2000) found that there are approximately 915 km of roads within rainforest habitat above 800 m altitude in the Wet Tropics (based on AUSLIG data, which did not include logging and snig tracks). This translates to a requirement of about 9000 bridges if they are installed at intervals of 100 - 120 m as suggested. However, this presupposes that canopy connectivity has not been maintained above these roads. In actual fact, 1,200 rope bridges would probably go a long way towards reinstating functional canopy connectivity for arboreal folivores in their core bioclimatic zone. It is worth noting that AU$600,000 is equivalent to the cost of installing about 20 m of the Kuranda Range Road which is being rebuilt at present.

In addition to tree-kangaroos, managing authorities might consider known hotspots of roadkills of other arboreal mammals in the Wet Tropics region as suitable locations for installation of canopy bridges. These locations include but are not limited to:

- Bruce Highway, south of Cardwell, for the critically endangered mahogany glider.
- Carr Road, near Mount Lewis, for striped possums and green ringtails.
- Kennedy Highway, through Tolga Scrub, for brushtail possums and green ringtails, and in the vicinity of Longlands Gap and the Crater, for a suite of species.
- Kuranda Range Road for striped possums and green ringtails.
- Mossman - Mount Molly Road, both at the lookout and near the Carr Road intersection, for striped possums and green ringtails.
- Yorkeys Knob Road, near the Dunne Road intersection, for striped possums (**Figure 6.7**).

Where possible, bridges should be aligned along existing linkages (e.g., riparian corridors). This is especially important where these linear landscape elements differ from the matrix on either side (see **Figure 6.7**).

Figure 6.7 A roadkilled striped possum along Yorkeys Knob Road, at a location where the road bisects a riparian corridor. This species was recorded using canopy bridges to cross both the B Road and Old Palmerston Highway.

FUTURE RESEARCH

At the commencement of my research, little was known about the effectiveness of canopy bridges, either in Australia or overseas. A canopy bridge had been built in the Wet Tropics but it had not been systematically monitored. My research has helped answer the questions posed in **Chapter One** and contributed to an understanding of the impacts of roads on arboreal mammals and methods of amelioration. One problem with my study was that replication was impossible due to financial and bureaucratic constraints (resulting in experimental design inadequacies). However, it serves as a pilot for the development of artificial crossing routes for arboreal mammals in rainforests and has resulted in many positive outcomes. One of these has been the collaboration between researchers working on similar projects in Australia and around the world. In each case, those involved have benefited from the exchange of information and ideas although several common questions have arisen. These are included in the list below:

- What is the optimum canopy bridge design?
- What are the optimum and/or maximum length of canopy bridges?
- Would a system of ropes extending into the adjacent forest encourage animals to use canopy bridges?
- Would some sort of fencing, such as floppy-top fencing, be appropriate for funneling animals prone to roadkill to canopy bridges?
- Do gliders utilise canopy bridges?
- Do tree-kangaroos and other rare and threatened species, such as spotted-tailed quolls, use them to cross roads?
- How are canopy bridges used within the landscape, i.e., how many individuals use them and how often, is there inter- or intra-specific competition and what effect does this have on local populations?
- What induces crossing behaviour, especially where roads (e.g., Old Palmerston Highway) have long separated populations?
- Does crossing activity vary seasonally?
- Is crossing activity affected by other environmental parameters?

These questions should be considered in any future examination of the efficacy of canopy bridges in assisting arboreal and scansorial mammals to cross roads.

CONCLUDING REMARKS

The research described in this thesis has demonstrated that canopy bridges have been successfully used in Australia and around the world to reduce the deleterious effects of roads on arboreal wildlife. I have demonstrated that canopy bridges are readily utilised by species of conservation significance in the Wet Tropics region that are prone to the adverse effects of habitat fragmentation. These include the lemuroid and Herbert River ringtail possums. This is a particularly important finding in the context of current work suggesting that these species may only survive in a few, high altitude ‘temperature islands’ scattered across the region should temperatures rise by just 1-2°C. Even without significant climate change, the increasing human population will inevitably result in a greater demand for transport and services and roads of greater capacity. Quite clearly, the best way to reduce fragmentation effects is to stop building new roads or widening existing ones. Where this is not possible, canopy bridges have merit as roads and other developments increasingly dissect habitats. They should be used as part of an integrated approach to road management in the region, especially in upland areas where canopy connectivity above roads cannot be maintained.

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Personal communications

PERSONAL COMMUNICATIONS

Name	*Organisation*	*Date*
Bruce Beavis	C4 (Community for Coastal and Cassowary Conservation)	January 2002
Paul Beier	Northern Arizona University	March 1999
Helen Butler	Wight Squirrel Project	July 2001, December 2002
Margit Cianelli	Wildlife carer	March 2001
Doug Clague	Local resident & naturalist	October 2001
Kay Coomber	Local resident & naturalist	September 2001
Karen Coombes	School Of Topical Biology, JCU	September 2001
Amanda Freeman	TKMG (Tree Kangaroo and Mammal Group)	August 2000
Miriam Goosem	TESAG, JCU	December 2002
Mike Harvey	QDMR	October 2002
David Hespe	Ex-Fisheries and Wildlife, Victoria	December 1999
Bruce Jennison	WTMA	April 2003
Paula Kahumbu	Colobus Trust	August 2001
Andrew Krockenberger	School Of Topical Biology, JCU	December 2002
Ray Lithgow	QDMR	October 2002
Lawrence May	QPWS	October 2002
Chris Moon	Wildlife consultant	July 1999
Claudia Morris	QPWS	October 2002
Rob Mortimer	Spotlighting tour operator	December 2001
Francis Ndiege	Colobus Trust	August 2001
John Nelson	Monash University	December 2001
Claudio Padua	Brazilian Centre for Conservation Biology	January 2003
Peter Reynolds	Wildlife consultant	February 2001

David Rivett	Environmental consultant	April 2003
Rupert Russell	QEPA	February 1998, April, July 2003
Rika Tagawa	Cairns Express N.Q.	July, September 2002
Mike Trenerry	QEPA	July 2003
Barbara Triggs	Dead Finish	July 2001
Warren Twist	QDMR	March 2003
Terry Webb	WTMA	September 2002
Garry Werren	ACTFR	March 2003
Steve Williams	School Of Topical Biology, JCU	December 2002
Robyn Wilson	TESAG, JCU	April 2001

Appendices

Appendix 4.1

Detailed plant species lists from the three study sites

Detailed plant species lists

B Road (Site 1)

Canopy species include: *Alphitonia petriei, Elaeocarpus largiflorens, Ficus destruens, Franciscodendron laurifolium, Garcinia* sp. (Davies Creek JG Tracey 14745), *Hylandia dockrillii.*
Subcanopy species include: *Beilschmiedia tooram, Brackenridgea nitida* ssp. *australiana, Ceratopetalum virchowii, Chionanthus axillaris, Elaeocarpus* sp. (Mount Bellenden Ker L.J. Brass 18336), *Geissois biagiana, Lomatia fraxinifolia, Musgravea stenostachya, Placospermum coriaceum, Polyscias murrayi, Opisthiolepis heterophylla, Oraniopsis appendiculata, Rhodomyrtus pervagata.*
Understorey/groundlayer species include: *Acronychia acidula, Adiantum silvaticum, Alpinia arctiflora, Antirhea tenuiflora, Apodytes brachystylis, Archirhodomyrtus beckleri, Ardisia brevipedata, Arytera lautereriana, Austromatthaea elegans, Balanops australiana, Beilschmiedia collina, Beilschmiedia tooram, Blechnum cartilagineum, Caldcluvia australiensis, Bobea myrtoides, Carnarvonia araliifolia var montana, Casearia costulata, Clerodendrum grayi, Cryptocarya angulata, Cryptocarya densiflora, Cryptocarya putida, Cupaniopsis flagelliformis, Dianella bambusifolia, Diospyros* sp. (Tinaroo Range J.G. Tracey 13936), *Doryphora aromatica, Elaeocarpus foveolatus, Endiandra bessaphila, Exocarya scleroides, Fagraea fagraeacea, Ficus leptoclada, Gahnia sieberiana, Geniostoma rupestre, Gevuina bleasdalei, Helicia australasica, Lastreopsis rufescens, Lethedon setosa, Levieria acuminata, Lindsaea brachypoda, Lomandra hystrix, Lomatia fraxinifolia, Mackinlaya macrosciadia, Maesa muelleri, Marattia oreades, Melicope broadbentiana, Motherwellia haplosciadea, Neisosperma poweri, Niemeyera prunifera, Otanthera bracteata, Perrottetia arborescens, Polyosma alangiacea, Polyosma rhytophloia, Polyscias elegans, Polyscias purpurea, Psychotria* sp. (Danbulla S.T. Blake 15262), *Pullea stutzeri, Quintinia fawkneri, Randia hirta, Rhodomyrtus pervagata, Rubus moluccanus, Sarcotoechia* sp. (Mountain Sarcotoechia WWC 100), *Solanum dallachii, Synima cordierorum, Synoum glandulosum, Syzygium wesa, Tasmannia membranea*.
Vines include: *Calamus australis, Cissus hypoglauca, Freycinetia excelsa, Melodinus baccellianus, Melodinus australis, Pararistolochia deltantha, Parsonsia latifolia, Piper caninum, Ripogonum album, Smilax australis, S. glyciphylla.*

Courtesy Bob Jago and Bruce Wannan

Snig track (Site 2)

Acronychia acidula, Aglaia tomentosa, Alphitonia petriei, A. whitei, Beilschmiedia tooram, Cryptocarya corrugata, C. oblata, Elaeocarpus angustifolius, Endiandra monothyra subsp. *monothyra, Flindersia bourjotiana, F. brayleyana Franciscodendron laurifolium, Maesa dependens, Melicope broadbentiana, Neolitsea dealbata, Rhodomyrtus pervagata, Smilax* sp., *Toechima erythrocarpum.*

Courtesy Doug Clague

Old Palmerston Highway (Site 3)

Alocasia brisbanensis, Alphitonia whitei, Alpinea arctiflora, Calamus australis, Cryptocarya melanocarpa, Dendrocnide sp., *Elaeocarpus angustifolius, Hibbertia scandens, Lantana camara, Litsea leefeana, Neolitsea dealbata, Omalanthus novo-guineensis, Polyscias elegans, Rubus moluccanus.*

Courtesy Doug Clague

Appendix 4.2

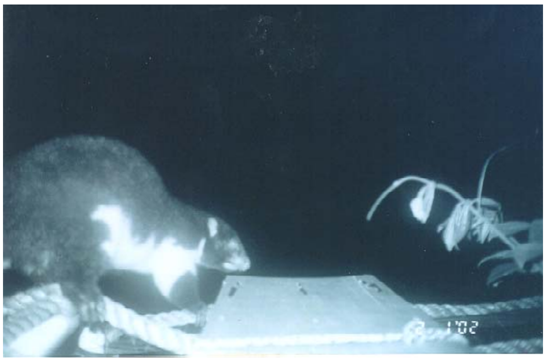
QDMR Old Palmerston Highway bridge permit conditions

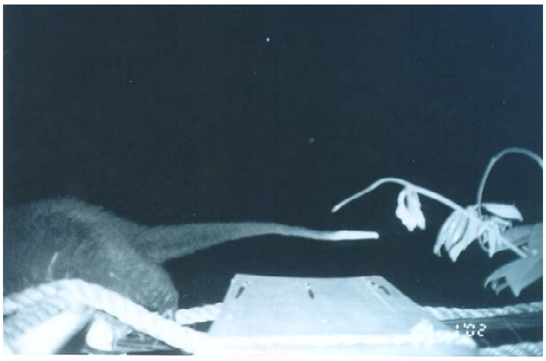
Appendix 5.1

Barbara Triggs' hair and scat analyses

Appendix 5.2

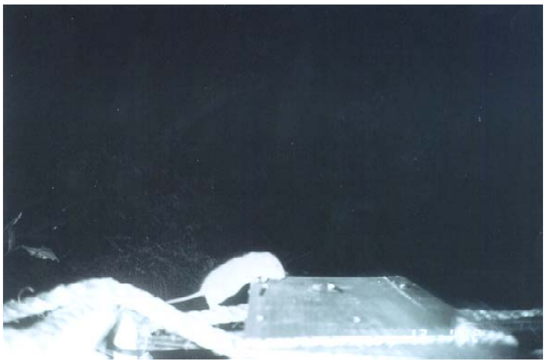
Selected *Buckshot RTV* photographs taken at the B Road site between 29/12/01 and 9/2/02

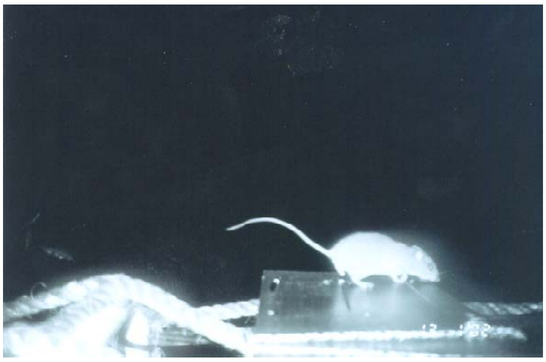

P. herbertensis, 2/1/01


P. herbertensis, 4/1/01


P. herbertensis, 13/1/01

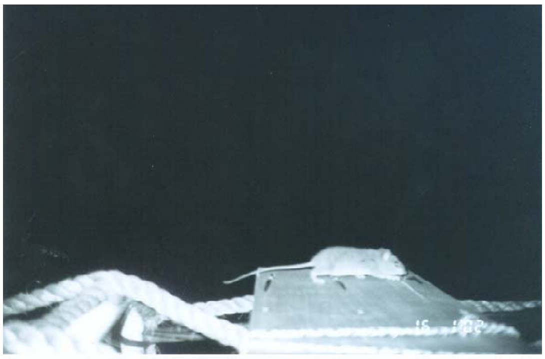

P. herbertensis, 13/1/01


M. cervinipes, 13/1/01


M. cervinipes, 13/1/01


P. herbertensis, 16/1/01

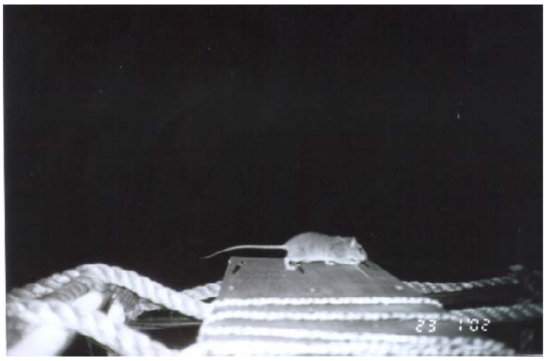

D. trivirgata, 16/1/01



M. cervinipes, 16/1/01

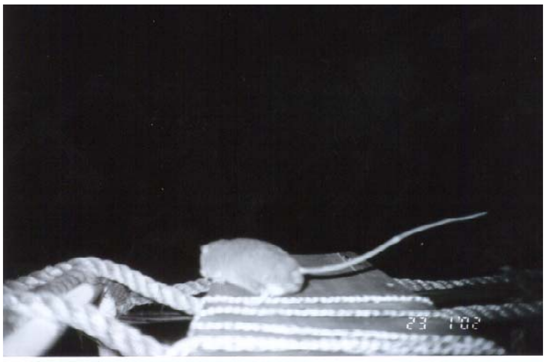
M. cervinipes, 19/1/01

P. herbertensis, 22/1/01



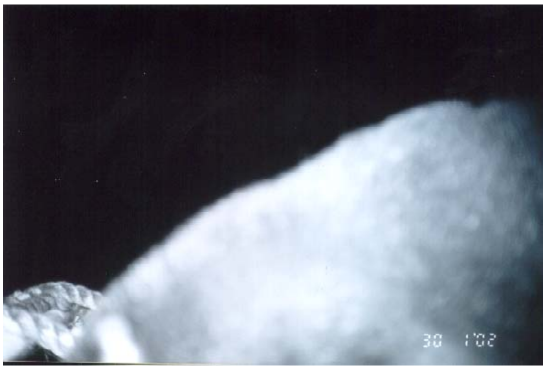
M. cervinipes, 23/1/01

M. cervinipes, 23/1/01



M. cervinipes, 24/1/01

P. herbertensis, 30/1/01



Medium-sized mammal, 30/1/01

Appendix 5.3

Scat collection results from the snig track site (22/1/01-26/3/01) (D. Clague, pers. comm.)

Appendix 5.4

Selected stills captured from video footage of two crossing events at the Old Palmerston Highway site (27/3/02 & 31/8/02)

Old Palmerston Highway bridge

P. herbertensis, 27/3/02

P. herbertensis, 27/3/02

P. herbertensis, 27/3/02

P. herbertensis, 27/3/02

P. herbertensis, 27/3/02

P. herbertensis, 27/3/02

H. lemuroides, 31/8/02

P. herbertensis, 27/3/02 *H. lemuroides*, 31/8/02

Appendix 6.1

Selected press clippings

1. Brook S. (2000, January 4). Canopy bridges: corridor or death's door? *The Australian*, p. 3.

2. Roberts, G. (2002, January 12). A new twist on the zebra crossing helps to save wildlife. *The Age*. p. 5.

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Appendix 6.2

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Appendix 6.3

Road hierarchy in current core bioclimatic zone of rainforest folivores

Appendix 6.4

Problem (high mortality) spots and prioritised potential corridors for tree-kangaroos in the study area (from Izumi 2002)

Figure 4.3: *Fie* problem (high mortality) spots versus three low mortality spots for Tree-kangaroos on the Atherton a d Evelyn Tablelands

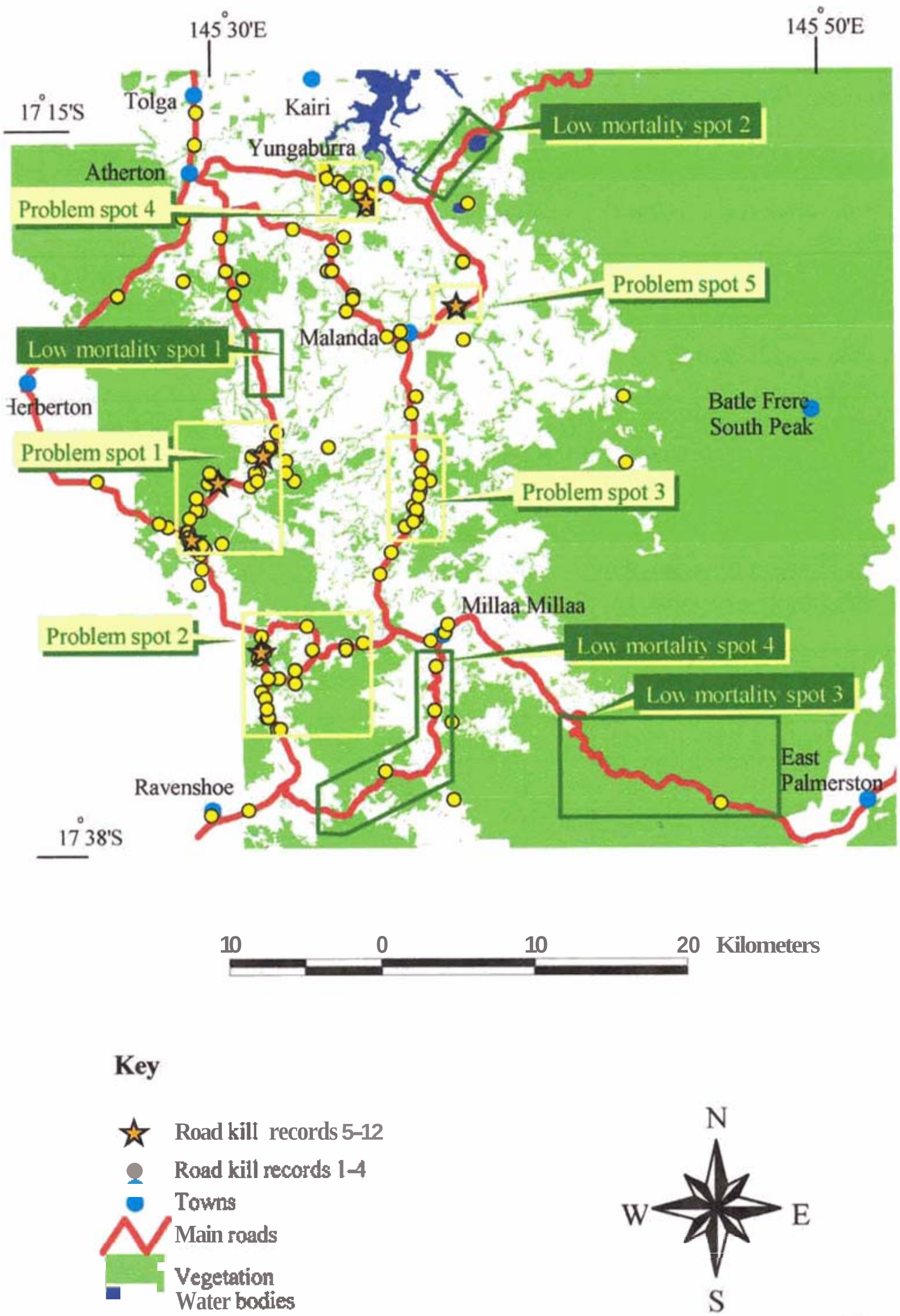

Figure 5.13: Prioritized potential corridors for Tree-kangaroos between suitable habitats.