The Role of Fauna Underpasses in New South Wales

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Abstract

Underpasses have been constructed under many highways in New South Wales, Australia usually where new roads have been constructed through suspected or known fauna habitat or movement corridors.

Despite the clear potential benefits of underpasses in facilitating fauna movement, evidence of their effectiveness is limited, equivocal and usually relates to overseas situations. Some of the key concerns raised about the usefulness of underpasses relate to the cost of their installation, levels of predation by introduced carnivores and the extent to which it is expected to utilize artificial habitat for movement.

The Australian Museum (through AMBS Consulting (AMBS)) and the NSW Roads and Traffic Authority (RTA), worked together to identify some typical underpass situations on the F3, a major freeway north of Sydney, and monitored their usage by native and introduced animals over a period of 9 months. Three underpasses were monitored which varied in respect to size, configuration, location and adjoining habitat and land use.

The study utilised a remote photographic method that proved effective and demonstrated that a wide range of native animals will move through a number of different types of underpass, ranging from small (approximately 1.5 m diameter) to very large (10 m diameter). The largest underpass recorded the greatest range of native species, ranging from rats to wombats and wallabies, however, the most frequently used underpass was a 1.5 m pipe. Introduced animals also use tunnels but, in this study, to a lesser extent than previously speculated.

It is concluded, therefore, that underpasses of varying sizes and designs can have a significant role to play in the safe movement of animals across road corridors, but that there are some clear guidelines to be observed in the location, design and management of these structures to optimise their efficacy.

Introduction

Background

Major road construction in NSW is focussed on expanding and improving the major coastal traffic route to Queensland, the Pacific Highway, north of the town of Hexham. Over the next 10 years the Commonwealth Government of Australia and the NSW State Government will spend a combined AUS$2.2 billion on the upgrade of the Pacific Highway. Upgrading this road will include major realignment, widening and road improvement works.

NSW is extremely rich biologically and supports populations of species considered to be of conservation significance at both state and national levels. In addition, the route of the Pacific Highway coincides with known populations of charismatic fauna such as Koala. It is inevitable that a project of this scale will cause potential adverse impact to wildlife and their wildlife habitat. In addition, environmental impact, including impacts on wildlife, will feature significantly in community concerns expressed during the community consultation process.

The fauna issues, and corresponding community concerns encountered in such a major road program, are exemplified by the proposed deviation of the Pacific Highway between Bulahdelah and Coolongolook. This realignment will involve the construction of 22km (approx. 14miles) of new road which will pass through areas of known fauna habitat. An increasingly sophisticated and knowledgeable constituent of the community now calls for the implementation of specific measures to facilitate the safe passage of animals across roads.

The RTA is committed to addressing fauna conservation issues and community concerns. In addition, therefore, to standard measures to mitigate impacts of the road construction on wildlife, the RTA is in the process of constructing 16 fauna underpasses, including 4 arch structures and 5 frog underpasses along this stretch of the upgrade. The cost of these measures, considering the length of road they service, is considerable (estimated AUS$3 million). The RTA is eager, therefore, to ensure that these features function effectively.

As a consequence the RTA has embarked on an ambitious program of research to investigate the use and effectiveness of fauna underpasses and overpasses. The study described in this paper represents the first stage in this program. The next stage will involve commissioning a related project on the usage of overpasses.

Objectives

Roads impact native fauna in various ways, including removal and fragmentation of habitat, creation of barriers to movement and genetic exchange, subdivision and isolation of populations, and wildlife injury and mortality on roads. Underpasses and overpasses are increasingly being used to mitigate the impacts of roads on fauna, however, concerns have been raised about the cost of their installation, levels of predation by introduced carnivores and the extent to which native fauna are expected to utilise artificial habitat for movement.

Evidence of the effectiveness of underpasses in Australia is limited as very few studies have been undertaken to critically evaluate the usage of these structures by a wide range of wildlife. Furthermore, those studies that have monitored the use of underpasses have relied upon techniques such as trapping (for example Hunt et al. 1987) or sand trays (for example Pieters 1992, 1993) to record animal movements. Consequently Australian Museum Business Services (AMBS Consulting) was contracted by the NSW Roads and Traffic Authority (RTA) to monitor wildlife using underpasses between Sydney and Newcastle in New South Wales, Australia. This study, involving the innovative use of automated photographic monitoring equipment, is the first of its kind engaged by the RTA.

The objectives of the monitoring program were to:

- identify species likely to use the underpasses;
- determine the level of usage of the underpass by all native fauna, particularly target species;
- determine levels of 'road injury/kill' in each study area;
- assess the effectiveness of exclusion fencing and the appropriateness of landscaping at and near the underpasses.

Methods

Approach

Three underpasses were selected beneath the F3 Freeway, between Sydney and Newcastle. Each underpass was monitored for 9 months during the period mid-August 1996 to mid-June 1997. The three underpasses selected for monitoring varied in design, with regard to both shape and size. In addition, the underpasses were located in areas exhibiting variations in faunal habitat and surrounding land uses.

The objectives of this project were met by using the following approach:

- identification of species likely to use underpasses selected for monitoring, particularly species of conservation significance (those listed on the NSW Threatened Species Conservation Act 1995);
- collection and analysis of data from automated photography, supplemented by data collected from sand trays and road-kills;
- additional site visits and conventional fauna surveys.

Species Likely to be Recorded Using Underpasses

An underpass can only provide passage for those species which occur in the area in which it is located. An absence, or paucity, of records of a species utilising a particular underpass may therefore not necessarily be a true indication of the effectiveness of such a structure for that species. Species that are absent from, or in very low population densities in, adjoining habitat are unlikely to be frequently recorded within underpasses. Conversely, there may be circumstances where a species is known to occur in surrounding habitat but does not appear to utilise the underpass. From an underpass design and management perspective, this latter scenario is the more significant as it is more likely to relate to limitations in the efficacy of the underpass structure.

The results of the automated monitoring equipment are of interest in their own right as they provide direct evidence of the range of species using the underpass and the frequency of that usage. To place the results of the automatic monitoring equipment in context, however, information is required on the 'pool' of species occurring in the locale of the underpass. To provide this information surveys for terrestrial (ground-dwelling) and arboreal (tree-dwelling) fauna, particularly small to medium-sized mammals, were undertaken. These data were complemented with information from fauna databases, literature searches, opportunistic observations and road-kill/injury data obtained throughout the study. Based on this information, a list of terrestrial species (Table 1), which are likely to be recorded using one or more of the underpasses, was compiled. Animals small enough to be able to pass under the IR beam without triggering the equipment, including snakes, and small frogs, skinks and mammals, were not considered likely to be consistently recorded.

Table 1

Terrestrial mammal and reptile species likely to be recorded using monitored underpasses

COMMON NAME	SCIENTIFIC NAME
MAMMALS	
Dog (dingo and domestic)	*Canis familiaris* *
Tiger Quoll	***Dasyurus maculatus***
Cat (feral and domestic)	*Felis catus* *
Northern Brown Bandicoot	*Isoodon macrourus*
Eastern Grey Kangaroo	*Macropus giganteus*
Rabbit	*Oryctolagus cuniculus* *
Long-nosed Bandicoot	*Parameles nasuta*
Bush Rat	*Rattus fuscipes*
Swamp Rat	*Rattus lutreolus*
Black Rat	*Rattus rattus* *
Short-beaked Echidna	*Tachyglossus aculeatus*
Common Wombat	*Vombatus ursinus*
Red Fox	*Vulpes vulpes* *
Swamp Wallaby	*Wallabia bicolor*
REPTILES	
Eastern Water Dragon	*Physignathus lesueurii*
Eastern Blue-tongued Lizard	*Tiliqua scincoides*
Heath Monitor	***Varanus rosenbergi***
Lace Monitor (Goanna)	*Varanus varius*

KEY: * — Introduced species
Bold text — listed on the Threatened Species Conservation Act 1995

Automated Photographic Monitoring

Automated photographic monitoring equipment was set up in such a way that the following information relating to fauna usage of each underpass was consistently recorded:

- identity of medium to large species moving through the underpass;
- direction of movement (to indicate whether complete passage was made);
- frequency of movement (that is, number of times complete passage was made);
- time and date of movement.

The photographic monitoring equipment comprised (Figure 2):

- a fixed position 35 mm camera — fitted with automatic winder, 'dateback' recording device and in-built flash — linked to an infrared photo relay sensor.
- portable, sealed, rechargeable 12V power supply to power the equipment.
- an infrared photo relay sensor, comprising a transmitter lens which focused a projected pulsed infrared beam from an IR diode within the sensor. This beam was reflected by a reflector back to a receiving lens which focussed the reflected beam onto an internal electronic pickup within the IR unit. The IR unit and reflector, which were set between 3 and 4 cm above the ground, were located in such a way that animals, particularly larger vertebrates, moving through the underpass at ground level would break the beam and be photographed.

Supplementary Information

Supplementary information was obtained from: fauna surveys of adjacent habitat (trapping and nocturnal searches) sand beds located approximately 2 m inside both entrances of each underpass; opportunistic observations of animals, or their tracks, marks and signs; and, collection of data on road kills.

Limitations of Fauna Surveys

As the species considered likely to use underpasses (Table 1) were predominantly mammals, the fauna trapping program was limited to this particular fauna group. Limitations of the trapping program include:

- seasonal effects — terrestrial and arboreal trapping were only carried out during one season of the year, late winter and late summer respectively;
- weather conditions;
- excessive noise from highway traffic;
- spotlighting was only undertaken in evening — no pre-dawn spotlighting undertaken; and,
- surveys for reptiles were not included.

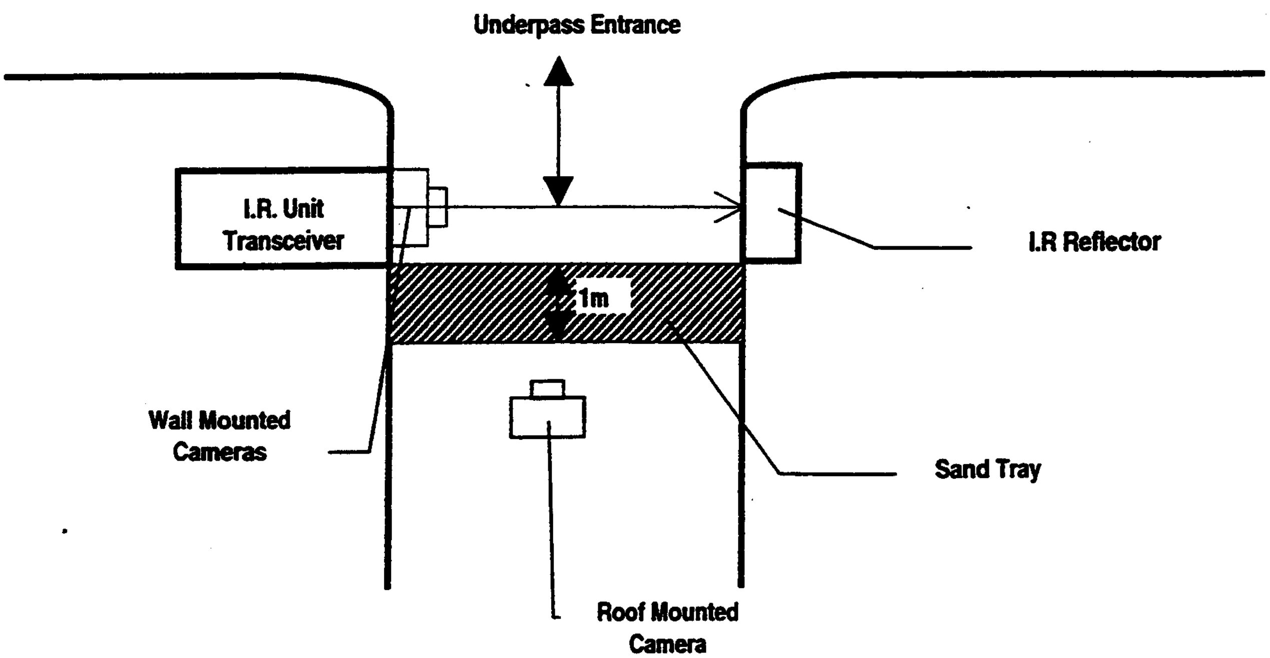

Figure 2. Schematic plan view of automated camera equipment.

Results

Photographic Monitoring

All three underpasses were utilised by a variety of animal species (Table 2; Appendix A). A total of 17 native species were recorded using the underpasses. Thirteen native species were recorded using the Mooney Mooney underpass, five native species at the Sparks Road site and seven native species at the Palmers Road site.

The Common Wombat, Swamp Wallaby, rats and bandicoots were the most frequently recorded in the Mooney Mooney underpass. Other species photographed moving through this underpass include the Lace Monitor, Diamond Python (*Morelia spilota ssp. spilota*), Domestic Dog, Domestic Cat, Red Fox and Tiger Quoll, the latter being a threatened species in NSW.

Black Rat, Cat and Eastern Water Skink were the most frequent users of the Sparks Road underpass. Additional species photographed include the Swamp Rat and Common Wombat. The species most frequently recorded using the underpass at Palmers Road were bandicoots and rats.

The only arboreal mammal species photographed using one of the monitored underpasses was the Eastern Pygmy-possum (*Cercartetus nanus*), which was recorded using a ledge in the Mooney Mooney underpass. Larger arboreal mammal species including the Koala (*Phascolarctos cinereus*), Common Brushtail Possum (*Trichosurus vulpecula*) and Greater Glider (*Petauroides volans*) have been recorded in the general area surrounding each of the underpasses (Appendix A), but were not recorded using any of the underpasses (Table 2; Appendix A).

The performance of the monitoring system and the periods of successful monitoring (that is, number of days photographic equipment was functional) were generally similar for each site (Appendix A). The Sparks Road and Palmers Road sites were vulnerable to flooding and as a consequence, several days of monitoring were lost each time high periods of rain were experienced. Such was the case at the end of August and September 1996. Additional reasons for unsuccessful days of monitoring include: camera flash failure; batteries running flat; and, the IR unit being knocked out of alignment.

Road-Kills/Injuries

All the data collected for road-kills/injuries relate to road-kills only, with no road injuries reported during the study. Very few injured animals are rescued along the freeway itself apparently because:

- the speed at which traffic is moving deters motorists from stopping;
- the speed of passing traffic makes retrieving an injured animal from the side of the freeway extremely difficult; and,
- an animal which is not killed outright by colliding with a vehicle may flee into adjoining bushland.

In total, 140 road-kills were recorded during this study (Appendix B). Of these, 43 were native mammal species. No species of conservation significance were recorded as road-kill during this study.

Discussion

Species Recorded Using Monitored Underpasses

This study has demonstrated that a surprisingly large range of animals utilise underpasses. In each case, however, the range of animals using the underpass was only a subset of the fauna known to occur in the general area surrounding each site Table 2.

The number of species and the number of individuals using each of the underpasses varied considerably. More than twice as many individuals were recorded at Palmers Road (313 passages) than at Mooney Mooney (153 passages), both these sites being more frequently used than the underpass at Sparks Road (34 passages). In terms of the range of species using each underpass Mooney Mooney recorded a greater range of fauna (16 species) than Palmers Road (9 species) and Sparks Road (7 species). The extent of fauna usage of the Sparks Road underpass is clearly less than that of the other sites, even when allowance is made for the fact that the camera equipment at this site had the greatest rate of false registrations and was affected to a greater extent by flooding events. However, it is not possible to determine which of the differences between the three underpasses account for the different patterns of underpass use recorded during this study. Further assessment of the factors affecting the use of different underpasses requires more investigation. As expected, however, the greatest range of native species recorded was at Mooney Mooney, this being the largest structure which is additionally located in an area with a diverse native fauna.

Arboreal mammals such as gliders and possums have all been recorded in the vicinity of each underpass (Table). Yet the only arboreal mammal species recorded using an underpass was the Eastern Pygmy-possum, which was photographed using a ledge in the Mooney Mooney underpass. No larger arboreal mammal species such as the Koala or Common Brushtail Possum were recorded in any of the monitored underpasses, the latter being a species documented by Pieters (1992) using a box culvert underpass.

Table 2

Animal species recorded within each underpass and surrounding area.

Species listed above the line were photographed using the underpass, those below the line are known to occur within the general area of the underpass, as per database and literature searches, surveys undertaken for this study, and opportunistic observations, but were not recorded within the underpass itself. Species listed as 'threatened' in NSW are highlighted in bold and introduced species are indicated by an asterisk (*). Italics indicates species may not have been consistently recorded by automatic monitoring equipment due to small size.

Mooney Mooney	Sparks Road	Palmers Road
Dusky or Brown Antechinus *Eastern Pygmy-possum* *Swamp Rat* *Bush Rat* *Long-nosed Bandicoot* *Short-beaked Echidna* ***Tiger Quoll*** *Common Wombat* *Swamp Wallaby* *Eastern Water Dragon* *Lace Monitor* *Diamond Python* *Wonga Pigeon* *Cat** *Dog** *Red Fox**	*Swamp Rat* *Bush Rat* *Common Wombat* *Black Rat** *Cat** *Eastern Water Skink* *Brown-striped Frog*	*Swamp Rat* *Bush Rat* *Long-nosed Bandicoot* *Northern Brown Bandicoot* *Short-beaked Echidna* *Eastern Water Dragon* *Peron's Tree Frog* *Cat** *Dog**
Common Dunnart ***Fawn-footed Melomys*** ***Eastern Chestnut Mouse*** *Feathertail Glider* *Northern Brown Bandicoot* *Sugar Glider* ***Squirrel Glider*** *Common Ringtail Possum* *Common Brushtail Possum* *Mountain Brushtail Possum* *Greater Glider* ***Yellow-bellied Glider*** ***Koala*** ***Parma Wallaby*** *Red-necked Wallaby* *Wallaroo* *Potoroo* *Eastern Grey Kangaroo* *House Mouse** *Black Rat** *Rabbit** *Brown Hare** *Pig** *Goat** *Cow**	*Short-beaked Echidna* *Common Brushtail Possum* *Swamp Wallaby* *Eastern Grey Kangaroo* *Greater Glider* ***Yellow-bellied Glider*** ***Koala*** *Sugar Glider* *Dingo/Dog** *Red Fox**	*Feathertail Glider* *Brown Antechinus* *Sugar Glider* ***Squirrel Glider*** *Common Brushtail Possum* *Common Ringtail Possum* *Greater Glider* ***Yellow-bellied Glider*** ***Koala*** *Common Wombat* *Swamp Wallaby* *House Mouse** *Black Rat** *Rabbit** *Brown Hare** *Red Fox ** *Pig* (feral)* *Horse* (feral)*

Species of Conservation Significance

Although fauna underpasses are expected to facilitate the movement of a wide range of animal species, there is particular interest in the movement of species of conservation significance. This interest is most intense where a new road development bisects the known or suspected home range of a threatened species population.

The only threatened species recorded using the underpasses in this study was Spotted-tailed Quoll (*Dasyurus maculatus*). This species was recorded in the Mooney Mooney underpass on one occasion. A single record suggests this individual was probably not using the underpass as part of its regular foraging area.

The Koala, also listed as a threatened species, has been recorded in the general area surrounding each of the three underpasses but was not recorded using any of the underpasses (Table 2). This species has been documented crossing large areas of open ground (Prevett, 1991), but is considered, along with other arboreal marsupials, unlikely to use underpasses to a significant degree.

Feral Predators

It is frequently asserted that fauna underpasses may act as 'prey traps' for introduced predator species such as Dog, Red Fox and Cat. For example, in a study of the movement of mammals through tunnels and culverts under railway lines in the Wollongong area, use of new tunnels was predominantly by feral predators (93% of all tracks), leading Hunt et al. (1987) to conclude that feral predatory mammals such as Red Fox, Dog and Cat may focus their activities on tunnels which act as funnels for prey. This effect would probably be more extreme in tunnels that lack protection for prey species such as vegetative cover, both inside and adjacent to the entrances (Hunt et al. 1987).

It is reasonable to expect that if feral predators were preferentially attracted to underpasses, predatory activity would be more obvious in the form of a large number of recorded passages of predators, or the remains of prey carcasses. In this study, however, Cat, Dog and Red Fox were infrequently photographed at the monitoring sites (Table 3), and at all three underpasses the number of passages made by feral predators was much lower than that recorded for prey species such as rats and bandicoots.

In this study it could not be determined to what extent feral predators may be taking prey in habitat adjacent to the underpasses. It is possible that feral predators are preying upon species within the approaches to the underpasses, without entering the underpasses and being photographed.

Table 3
No of times feral predators photographed in underpasses

	Site		
Species	Mooney	Palmers Road	Sparks Road
Cat	3 (2.0%)	2 (0.6%)	6 (17.6%)
Dog	3 (2.0%)	3 (1.0%)	0
Red Fox	2 (1.3%)	0	0

Note: Figure in brackets indicates the proportion of feral predators photographed as a percentage of total passages photographed.

Factors Likely to Affect Use of Monitored Underpasses

Underpass design, including dimensions and exclusion fencing, is likely to be a significant factor affecting fauna use. The factors influencing underpass usage are likely to be complex, however, and not simply related to obvious design features. Specific factors considered likely to exert a significant influence include:

Habitat in the region of the underpass.

The range of habitats and their condition within the region of the underpass will determine to a large extent the range of animal species and their abundance. A diverse range of habitats in good condition is likely to provide a greater 'pool' of species that could potentially utilise an underpass.

Habitat within the underpass approaches.

The type and condition of vegetation present in the immediate vicinity of the entrance to an underpass is also likely to influence the range and number of animal species using the structure. Such vegetation may provide habitat directly for a range of animals with limited home ranges, such as rats and small dasyurids or act as a corridor for more mobile species. The presence of a cleared area or pond, for example, immediately adjacent to an entrance could deter some species from entering the underpass.

Barriers to animal movement.

The presence of barriers such as fencing or steep freeway embankments is likely to influence animal behaviour in the vicinity of the underpass. Such barriers may force animals to move parallel to the road where they are more likely to encounter and use an underpass.

Flooding.

Many underpasses appear to be constructed along watercourses such as creeklines. The structures at Palmers Road and Sparks Road, for example, both serve dual functions as underpasses and drainage culverts. The extent to which these features flood is likely to influence animal usage considerably. It is considered that smaller animals, in particular, are unlikely to enter an underpass if there is water flowing through it.

Effectiveness of Remote Monitoring Technique

The system of automatic cameras employed in this study proved remarkably reliable and has a number of clear advantages over conventional trapping techniques. Subsequent to the initial outlay for monitoring equipment, the cost of maintenance, and film replacement and processing was relatively low compared to the cost of tending live traps over a similar period. Because of the low cost of maintenance it is possible to conduct monitoring continuously over a 24 hour period for many months.

Given the cost effectiveness of the method, accuracy was surprisingly high, with a very high proportion (as high as 80%) of photographs yielding positive identifications. In the remainder of cases the cause of false registration, that is animal not able to be seen in photograph, could either not be determined or was due to non-faunal agents such as wind blown debris triggering the beam, human interference or fogging of camera optics. In very few cases, where an animal was known to have triggered the camera, was it impossible to identify the subject individual to species or at least genus.

There are some pit-falls to the method, however, which should be acknowledged in the interpretation of the data and which should be considered prior to employing similar monitoring programs in the future.

It is not possible to determine to what extent animals exhibit learned response to the presence of the monitoring equipment. For example, to what extent, if at all, individuals are either attracted to or repelled by the sound of the equipment being triggered or the accompanying flash or both. Furthermore, in the process of maintaining the equipment it was necessary to visit the tunnels on a weekly basis. Whilst all sites would be visited periodically by, for example, RTA maintenance staff, bushwalkers, motorists and local land-owners, the level of human disturbance during this study was much higher than that which would normally occur. The impact of this disturbance on fauna using the underpasses is unknown. There were, however, no indications in the data that fauna usage either decreased or increased during the monitoring program in a pattern that would suggest a specific response either to the equipment or human presence.

The operation of monitoring equipment such as that used in this study is vulnerable to interference. Unattended electrical equipment is susceptible to vandalism or theft and a number of monitoring units were stolen during the monitoring period. The level of interference, however, was minimal over the period. In addition, the cost of lost equipment was not significant in comparison to the overall budget.

The photographs obtained during this study provided little biological data on animals using the underpasses. Only in occasional instances was it possible to obtain information on the sex, age or condition of the animals photographed. Whilst this is not considered to be a limitation within the scope of this study, which focussed on the identity and abundance of species using underpasses, it could hinder more detailed autecological investigations.

Management Options and Recommendations

Introduction

It is not possible to determine conclusively which of the differences between the three monitored underpasses account for the different observations of underpass use. However, it is clear that some features of the underpasses monitored could be improved to enhance animal usage. These are discussed below and summarised in Table 4. Underpass options are summarised in Appendix C.

Location/Placement of Underpass

Several factors appear to be important in deciding where to place underpasses including:

- adjoining habitat and land uses;
- topography;
- distance between underpasses; and,
- knowledge of movement patterns of animals.

Corridors of riparian forest such as creeklines appear in many cases to be the most appropriate locations for crossing structures. There is evidence that they provide corridors for the dispersal and movement of fauna and refuges in times of fire, logging and drought (Pressey et al. 1981; Recher et al. 1980; Dunning and Smith 1986; Smith et al. 1992). It should be noted, however, that underpasses located on creeklines may be prone to flooding.

Studies such as Foster and Humphrey (1995) have concluded that placement of underpasses based on knowledge of well-established, traditional migratory routes of species such as White-tailed Deer (*Odocoileus virginianus*) is more important in determining underpass use than other factors such as structural dimensions. It is difficult to assess the relevance of such findings to the Australian fauna, however, as such movement patterns have yet to be demonstrated with Australian species (Pressey et al. 1981).

Landscaping

Paradoxically, dense growth around the entrance to an underpass may at once disguise the opening preventing access and at the same time provide protective cover for smaller animals encouraging use of the structure.

Landscaping around an underpass will vary from site to site and may even be used to target a particular species. For example, Mansergh and Scotts (1989) restored habitat continuity for the rare Mountain Pygmy-possum (*Burramys parvus*) by constructing a corridor leading to two tunnels beneath a road that bisected the breeding area of the species. The corridor and tunnels were filled with rocks to mimic the natural scree habitat of the mountain pygmy-possum.

Roadside Planting

Pressey et al. (1981) state that the impact of highway construction on fauna can be lessened both by keeping clearance of natural vegetation before construction to a minimum, thereby maintaining the integrity of the vegetation as far as possible, and by replanting cleared areas with local plant species (using local gene pools) when construction is complete.

The use of local native plant species in roadside landscaping may provide habitat for a wide range of native fauna, particularly species common in farmland or forest 'edge' habitats. Rehabilitation of natural vegetation is particularly important in areas of cleared land, as the creation of strips of natural vegetation along highways can facilitate the movement of fauna between remnant stands of habitat (Pressey et al. 1981).

The use of native plants, rather than introduced species, in roadside landscaping has additional benefits such as:

- reducing or eliminating the need for herbicides and/or fertilisers, both of which are likely to impact upon nearby natural ecosystems such as creeks and wetlands; and,
- achieving reductions in maintenance costs such as mowing and weed control.
-

Attracting native fauna to roadside habitat may not be entirely beneficial. Providing habitat for native fauna adjacent to a busy road corridor, such as a highway, may significantly increase the risk of native animals being killed or injured by collisions with vehicles.

Macropod species were recorded as road-kills in the vicinity of all three underpasses. It appears that wallabies and kangaroos are crossing the highway, perhaps moving from one feeding area to another, without making an attempt to move through an underpass. Some observations suggest that macropods (wallabies and kangaroos) may be attracted to the edge of roadsides by cleared grassy areas which provide forage for these species.

Exclusion Fencing

Appropriately designed exclusion fencing should be used in association with underpasses to direct animals towards these crossing points. Various designs for exclusion fencing are described in Fanning (undated) and include:

- 'Floppy top fences' consisting of link-mesh fencing with the top 20 cm unsupported and fence posts angled away from the road at the top.
- Link-mesh fence with a 0.8 to 1.5 m strip of sheet metal or plastic attached to the upper portion of the fence.
- Electric fencing.
- Metal 'picket' style of fencing, similar to fencing around swimming pools.

Underpass Design

In many cases the structures that serve as fauna underpasses are structures originally designed for other purposes, for example, management of stormwater. This dual purpose may conflict, particularly during storms. Where an underpass serves a dual purpose, specific design features can be incorporated to allow for fauna movement, such as, for example, raising one cell or culvert higher than the others so as to main dry passage for animals.

Various underpass options, including traditional water management structures such as culverts and pipes, are presented in Appendix C along with brief discussion of the strengths and weaknesses of each.

Underpass Floors

The significance of floor type within underpasses is not clear. Animals will use underpasses with natural and artificial (e.g. concrete) floors, although some studies (e.g. Ward, 1982) have suggested some species may exhibit a preference for natural floor types.

Dimensions

The dimensions of an underpass will determine both its costs and its efficacy for a broad range of species. In general animals using an underpass should have an unobstructed view of the habitat or horizon of the far side of the underpass (Foster and Humphrey 1995; Beier 1995).

If an underpass is required for a variety of species, ranging from small to large, then it is recommended that a structure of size intermediate between that of the Mooney Mooney underpass and the Sparks Road underpass, eg between 3 and 5 m in radius or height and width, be used. Species recorded using underpasses of 3 to 5 m in height and width include White-tailed Deer (Pojar et al. 1975), Mule Deer (Ward 1982), Mountain Goat (*Oreamnos americanus*) (Singer and Doherty 1985), Common Brushtail Possum, Eastern Grey Kangaroo (Pieters 1992) and Swamp Wallaby (Hunt et al. 1987).

Underpasses of smaller dimensions, such as that at Palmers Road (1.5m), will restrict use by larger species such as wallabies and kangaroos. However, smaller underpasses may also be used to target small species, such as has been demonstrated with the Mountain Pygmy-possum (Mansergh and Scotts 1989) which used tunnels 0.9 m x 1.2 m in size. Results from monitoring the Palmers Road underpass also demonstrate how useful a smaller structure can be for one particular species, in this case the Long-nosed Bandicoot.

Skylights

The effectiveness of skylights in the NSW context is unknown. However, in a study of behavioural response of mule deer to a highway underpass in Colorado, USA a tunnel was lit to provide comparisons of use during periods of light and darkness. The study concluded that lighting the tunnel appeared unnecessary and that skylights allowed traffic noise inside (Reed et al. 1975).

In this study the Sparks Road underpass had a skylight, but was found to allow runoff from the freeway into the underpass. The floor of the culvert was rarely completely dry, as sunlight did not penetrate the underpass.

Internal Structures

Various structures or features that could be potentially incorporated into underpass design include hollow logs, refuge poles and ledges. The strengths and weaknesses of these structures are largely unproven.

Maintenance

A maintenance program for underpasses and associated fencing and landscaping should be incorporated into road planning. It is recommended that exclusion fencing be periodically checked for collapse, holes, etc to maintain integrity and effectiveness. Annual checks may be sufficient in most instances.

Table 4 - Summary of recommendations

Issue	Recommendation
Location/placement of underpasses	• *where habitat permits, the distances between underpasses should be such that animals do not have to travel far to find a crossing.* • *underpasses should be located where cover from adjoining habitat or topography comes close to a road on both sides.* • *underpasses should be located away from sources of disturbances such as dogs, houses, noise and pollutants.* • *several underpasses or tunnels should be included to provide options and loops for animals to avoid* • *disturbance, and to provide a more natural distribution of populations.*
Landscaping within an approach	*In general, vegetation within an approach to an underpass should:* • *be well-vegetated but not obstruct access to the underpass;* • *not obstruct view of, or disguise, the entrance to the underpass;* • *be representative of natural habitat of native species (eg shrubs and native grasses are usually appropriate; logs and rocks may also be appropriate); and,* • *attract native species to the underpass rather than onto the road corridor.*
Roadside planting	• *keep clearance of natural vegetation before construction to a minimum.* • *replant cleared areas with local plant species (using local gene pools) when construction is complete.*
Exclusion fencing	• *should be used in association with an underpass.* • *should be regularly checked to maintain effectiveness.* • *should enclose the road easement.*
Underpass design	• *size of 3 to 5 m in radius or width/height may be the most appropriate.* • *ensure dry passage for animals eg raise a cell or culvert, incorporate ledge, place culvert at an angle so water flows down one side.* • *ensure animals using an underpass have an unobstructed view of the habitat or horizon on the far side of the underpass.* • *design underpasses for the most sensitive species such as threatened species.*
Skylights	• *may be unnecessary or even detrimental eg may allow traffic noise or excess runoff from road corridor.*
Internal features	• *include internal features such as hollow logs, refuge poles and ledges where possible to provide refuge from predators and to encourage use by smaller species.*
Detritus/silt traps	• *design and location should be such that movement of fauna between the underpass and adjoining habitat is not impeded.*
Maintenance program	• *underpasses and associated fencing and landscaping should be included in road maintenance programs.*
Bridges	• *where a heavily used road crosses a defined movement corridor for terrestrial species, a bridged undercrossing is preferable to a culvert.*
Median strips	• *a wide median strip should be open rather than covered because a covered median is more costly and makes the underpass resemble a tunnel, but a narrow median should be covered to minimise noise, debris and traffic light.*
Noise	• *noise within an underpass should not be excessive, for example Mock et al.. (1992 cited in Beier (1995)) recommend a level of 60 db during expected time of use.*
Lighting	• *artificial lighting may be detrimental in underpasses and should therefore be avoided.*

Conclusions

The State government of NSW has a general commitment to the National Biodiversity Strategy and the State Strategy which is currently in draft form. Furthermore the Threatened Species Conservation Act (1995) (NSW) also imposes considerable responsibilities on any developer within the state, including state agencies. The NSW RTA is, therefore, committed to the conservation of biodiversity within the state. The outcomes of this study have provided important information in an ongoing process of improving wildlife protection measures.

This study has at the very least confirmed that the incorporation of fauna underpass structures within road developments is worthwhile and that they can make a significant contribution to the movement of wildlife. Furthermore it has confirmed that a wide range of structures can serve a useful function in this respect.

The information obtained during this study will be incorporated into RTA operations. In fact, the guidelines and recommendations formulated are already being incorporated into EIS documents prepared by RTA consultants. On the basis of the outcomes of this study the RTA is about to commission a related study which will extend investigations to overpass structures.

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Appendix A: Animal species recorded in or near underpasses during current study

Site (number of days equipment functional)		*Mooney Mooney (250)*		*Sparks Road (230)*		*Palmers Road (240)*	
Species Name	*Common Name*	*Underpass*	*Adjacent habitat*	*Under pass*	*Adjacent habitat*	*Under pass*	*Adjacen t habitat*
MAMMALS							
Antechinus sp.	*Dusky/Brown Antechinus*	*P(2), F*	*T*		*T*		*T*
Canis familiaris *	*Dog*	*P(3), F*	*F*			*P(3), F*	*F*
Cercartetus nanus	*Eastern Pygmy-possum*	*P(2), F*					
Dasyurus maculatus	***Tiger Quoll***	*P(1)*					
Felis catus *	*Domestic/Feral Cat*	*P(3), F*		*P(6), F*		*P(2), F*	
Isoodon macrourus	*Northern Brown Bandicoot*					*P(2), F*	*F, S, D*
Macropus giganteus	*Eastern Grey Kangaroo*		*S*		*S*		*S*
Parameles nasuta	*Long-nosed Bandicoot*	*P(38), F*	*D*			*P(212), F*	*F, S, D*
Petaurus breviceps	*Sugar Glider*						*T*
Rattus fuscipes	*Bush Rat*	*P(44), F*	*T*	*P(5), F*	*T*	*P(86), F*	*T*
Rattus lutreolus	*Swamp Rat*	*P(2)*	*T*	*P(10)*	*T*	*P(5)*	*T*
Rattus rattus *	*Black Rat*			*P(7)*	*T*		*T*
Tachyglossus aculeatus	*Short-beaked Echidna*	*P(4)*				*P(1)*	
Vombatus ursinus	*Wombat*	*P(14), F, S*	*S*	*P(1)*	*S*	*F*	*S*
Vulpes vulpes *	*Red Fox*	*P(2), F, S*	*F, S*		*F, S*		*F, S*
Wallabia bicolor	*Swamp Wallaby*	*P(14), F, S*	*S, R*		*S, F*		*S, F, R*
REPTILES							
Varanus varius	*Lace Monitor*	*P(8), F, S*					
Eulamprus quoyii	*Eastern Water Skink*			*P(3), F*		*F*	
Physignathus lesueurii	*Eastern Water Dragon*	*P(2)*				*P(1), F*	
Morelia sp.	*Python*	*P(1)*					
FROGS							
Limnodynastes peronii	*Brown-striped Frog*			*P(2)*			
Litoria lesueuri	*Leseur's Frog*					*P(1)*	
BIRDS							
Leucosarcia melanoleuca	*Wonga Pigeon*	*P(13), F*					
Total No. of native species photographed		*13*		*5*		*7*	
Total No. of introduced predator species photographed		*3*		*1*		*2*	

Key: *Underpass; - Photographed (figure in brackets refers to number of passages photographed);*
F - tracks/prints observed; *S - Scats, T - Trapped, D - Diggings; R - road-kill recorded within 100 m of underpass*
Bold text indicates species listed on Threatened Species Conservation Act 1995
** - Introduced species*

Appendix B: Road-kill Data

Wombat	*3*	*MM(1), PR(2)*
Swamp Wallaby	*15*	*MM(7), PR(8)*
Bandicoot	*4*	*MM(1), PR(3)*
Eastern Grey Kangaroo	*9*	*MM(2), SR(4), PR(3)*
Possum	*10*	*MM(3), SR(4), PR(3)*
Short-beaked Echidna	*2*	*SR(1), PR(1)*
Australian Magpie	*28*	*MM(1), SR(17), PR(10)*
Kookaburra	*6*	*MM(2), SR(2), PR(1)*
Galah	*1*	*PR(1)*
Magpie-lark	*1*	*PR(1)*
Kingfisher	*1*	*SR(1)*
Red-bellied Black Snake	*1*	*SR(1)*
Marsh Snake	*1*	*SR(1)*
Blue-tongued Lizard	*1*	*SR(1)*
*Dog**	*12*	*MM(7), SR(5)*
*Red Fox**	*17*	*MM(9), SR(4), PR(4)*
*Cat**	*14*	*MM(3), SR(6), PR(5)*
*Rabbit/Hare**	*14*	*SR(5), PR(9)*
TOTAL	***140***	

*Key: * indicates Introduced species; figure in brackets indicates number of road-kills recorded*

Appendix C: Options for fauna underpasses

Option	Strengths	Weaknesses
Box culvert	• *Allow unobstructed view of habitat on far side* • *Have been demonstrated to be used by a range of native species including wallabies, kangaroos and possums, where size of culverts is approx. 3 m high x 3 m wide (Pieters 1992)*	• *May be subject to inundation, thereby deterring some animals, if located in drainage line. Puddle or small pond formation and substrate washouts in tunnels suggest that greater effectiveness is attained for terrestrial wildlife if tunnels are not combined with a stream[8].* • *Smaller culverts - such as that included in monitoring program (1.5m x 3m) - too low for macropods* • *Concrete floor does not allow for vegetative growth, which may provide protective cover*
Arch tunnel (10 m diameter)	• *Utilised by a diverse range of native species* • *Potential for improvement, eg placement of rocks, logs, refuge poles* • *Openness allows adequate light* • *A wide underpass such as this provides greater view of habitat at each end[3]* • *Large open underpasses are more successful than tunnels[4,5]* • *Large open underpasses permit a range of species to pass through, rather than just target species[6], that is, species that the underpass was specifically designed for, such as threatened species* • *Maintaining underpass or tunnel width greater than height is generally much more effective[6]*	• *Size may be overwhelming for some animals - large area of open ground to be traversed without protective cover* • *Allows easy access to prey for feral predators*
Small pipes: around 130-150cm diameter	• *Regularly used by smaller mammals such as bandicoots, as demonstrated by monitoring undertaken at Palmers Road*	• *Too small for larger mammals such as wallabies, kangaroos and possibly wombats* • *Totally dark, even in daylight for almost entire length* • *Prone to flooding if located in drainage line* • *Small underpasses may magnify the sound of passing vehicles[7], although this was not found to be the case at the Palmers Road underpass*
Small prefab tunnels: 20cm wide x 40cm high	• *Suitable for amphibians, provided road-surface slits for light and air are included in design[9]*	• *Predation may be high[9]*
Lengthened bridges	• *Usually located along creek or gully line, therefore likely to coincide with existing animal movement corridor* • *Natural light not impeded* • *Sufficient moisture for plant growth.* • *Provides dry land route for crossing[1,2]*	• *Noise from traffic, particularly in heavily-used areas* • *Difficult to leave native vegetation intact during construction*

Footnotes:

1. *Harris and Gallagher (1989) cited in Forman (1995)*
2. *Noss (1993)*
3. *Pedevillano and Wright (1987)*
4. *Reed (1981)*
5. *Reed et al. (1975)*
6. *Forman (1995)*
7. *Pedevillano and Wright (1987)*
8. *J.E. Gates, University of Maryland, pers. comm. cited by Harris and Scheck (1991)*
9. *Forman (1995)*

NOTE: First three options (box culvert, arch tunnel and small pipe) formed the subject of this monitoring program.

Figure 1: Map showing location of monitored underpasses

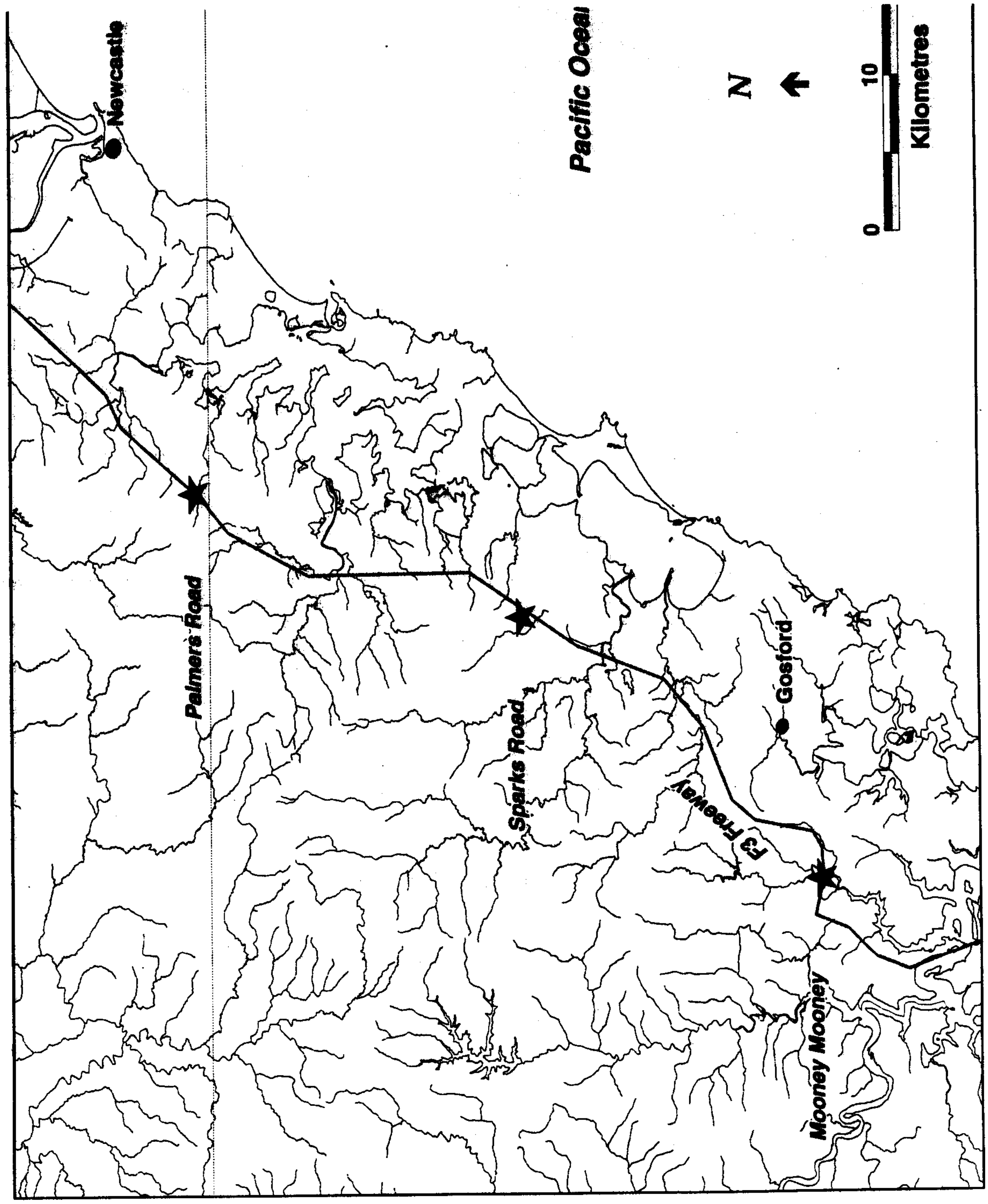

Figure 1.
Map showing location of monitored underpasses.