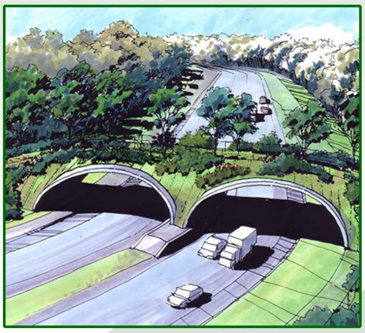
RESEARCH REPORT



Wildlife Surveillance Assessment Compton Road Upgrade 2005

Miriam Goosem

Rainforest CRC

WILDLIFE SURVEILLANCE ASSESSMENT
COMPTON ROAD UPGRADE 2005

REVIEW OF CONTEMPORARY REMOTE AND DIRECT SURVEILLANCE OPTIONS FOR MONITORING

Report to the Brisbane City Council,
Environment and Parks Branch

Miriam W. Goosem

School of Tropical Environment Studies and Geography, James Cook University, Cairns

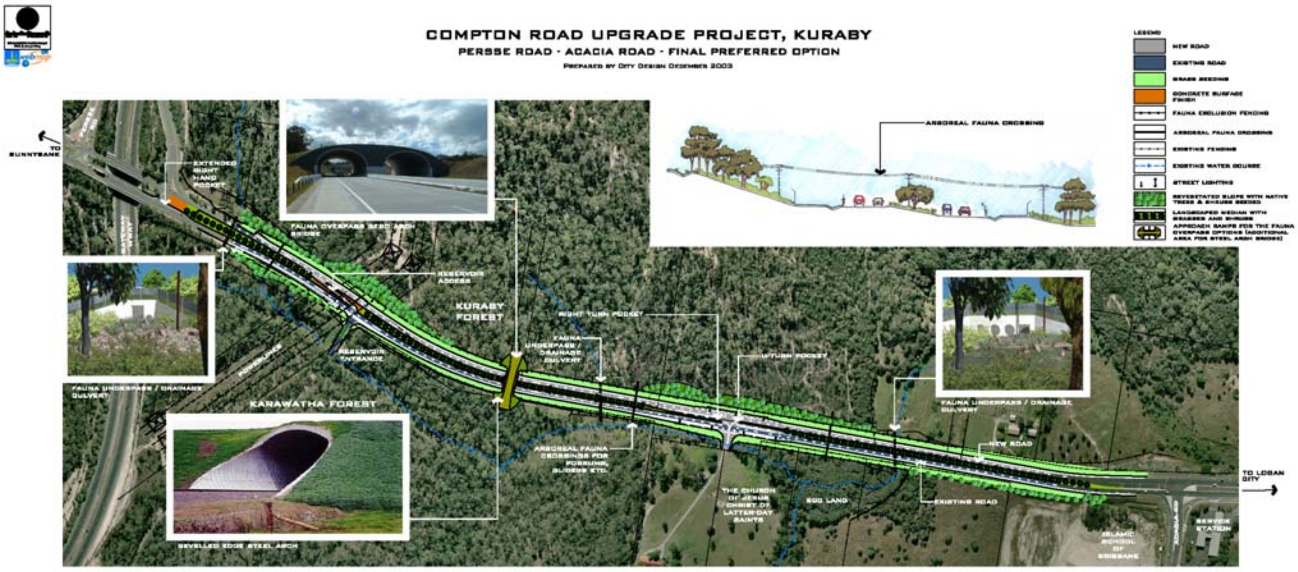


Diagram courtesy Brisbane City Council, 2003

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EXECUTIVE SUMMARY

In early 2005, the Brisbane City Council and the Rainforest CRC agreed to review potential remote and direct monitoring options for the wildlife crossing structures incorporated in the construction of the Compton Road upgrade. As part of the upgrade, a range of infrastructure was implemented to facilitate wildlife movement including a land bridge, two fauna underpasses with fauna ledge and "fauna furniture", three rope ladders for arboreal species, one set of 8 glider poles, fauna exclusion fencing and two wet culverts. Target species found or expected to be found in the area and for which the structures were hoped to provide connectivity include arboreal, gliding and terrestrial mammals, terrestrial birds, reptiles and frogs and fish in the stream.

A comprehensive literature review was undertaken encompassing all accessible recent literature in which wildlife crossing structures had been monitored. The review covered published scientific articles, publications from recent transport conferences, articles in the grey literature and web sites. In addition, all recognized experts in the field known to the author or identified by the literature review were consulted via email with replies received from many of these, describing their monitoring protocols, both direct and remotely sensed. Where the literature review and expert consultation identified successful monitoring strategies, suppliers of remote sensing equipment were contacted and asked for quotes or price lists and further information with respect to their products. Tables of equipment, features and indicative costs were compiled. A variety of direct and remotely sensed options for monitoring of the five types of structures incorporated into the Compton Road upgrade were compiled. Finally, recommendations with respect to the options were listed in order of preference, and where possible, indicative costings were provided.

The literature review pointed to the need to ensure that confounding variables are considered when examining the effectiveness of crossing structures. Factors such as variations in the amount of human activity near the structures and the accessibility of different structures to different species can produce spurious results if not included in models of crossing structure efficacy. A third factor that must be considered at least for representative target species is fluctuations in population density due to varying habitat variables in the vicinity of structures and from seasonal and yearly population fluctuations. Therefore population density must be monitored. A variety of indices such as density of scats and trails, visual and audio observations and more field-intensive mark-recapture methodologies have been used to provide an indication of populations near crossing structures. It is recommended that a group of species representative of different vertebrate groups should be monitored. Several of these are target species for the structures, others are more common species that have the advantage of providing more data for statistical validation. The establishment of a control area with similar habitat type, area and similar road factors must be considered a priority, as there was little opportunity to obtain population and movement data prior to construction.

Several areas of monitoring of the entire road upgrade should be continued. Roadkill monitoring provides an indication of the effectiveness of exclusion fencing. Traffic volume and speed as well as climatic variables can often affect the use of structures. Therefore traffic counters and environmental data-loggers may form part of the monitoring equipment or such data may be obtained from external sources. Presence of wildlife sign (e.g. scat) and trails can provide an index of population movements and density outside and within crossing structures. Other population density indices can be obtained using observational censuses of species e.g. spotlighting transects, active searches, bird and frog audio and visual census. Finally, more field-intensive trapping and mark-recapture methods can be used to provide indices of density and to follow movements of individual animals. Radio-tracking of target species could also be a useful addition for species of high conservation significance e.g.

gliders. Other methods such as hair analysis can point to population presence and with the incorporation of DNA analysis to population density.

Whether or not remotely sensed methods are incorporated into a monitoring scheme, direct methods must also be employed to provide a back-up should electronic failure occur. Options for direct monitoring of the crossing structures include many of the techniques mentioned above for population density indices. Noise may have profound effects on use of crossing structures by sensitive species and collection of noise data under varying conditions is necessary. Tracking beds form a very important and inexpensive means of monitoring – from wide strips of sand to narrow fine substrates or sooted track plates. Should animals be captured it may be possible to follow their movements from crossing structure to destination using a variety of tracking methods. Mark-recapture methods and radio-tracking also provide a means of discovering whether an individual has crossed from one side to the other, although not necessarily proving that the animal crossed via a crossing structure. Collection of hair and scat samples can identify species by hair analysis and individuals using the structure through DNA analysis.

For both direct and remotely sensed monitoring, through passage should be demonstrated. This can be done preferably by detecting the same animal at entrance, exit and in the middle of the crossing structure, or at both entrance and exit, or (not preferable but acceptable) by movement across the centre of the structure.

The advantages and disadvantages of a variety of remotely sensed monitoring methods and equipment are discussed. A combination of direct and remotely sensed methods have been suggested for each crossing structure as follows:

Faunal underpasses:

- Sand tracking on ledge level year round and on ground (wet) level when dry;
- Sooted plate tracking on shelf;
- Hair analysis data collection from rails of post and rail construction; and
- Digital still camera monitoring using dual sensors (passive infrared and microwave volume or passive IR volume and active infrared beams); or
- 35mm film still camera monitoring using 2 cameras to provide passive infrared volume monitoring and active infrared beam monitoring.

Land bridge:

- Sand on ground level year round when dry in 2 or 3 track beds;
- Fine substrate tracking during intensive monitoring periods;
- Hair analysis data collection during intensive monitoring periods;
- Small mammal and pit trapping, observational audio and visual bird and frog census, spotlighting, active searches during intensive monitoring period; and.
- Digital still camera monitoring using dual sensors (passive infrared and microwave volume or passive IR volume and active infrared beams); or
- 35mm film still camera monitoring using 2 cameras to provide passive infrared volume monitoring and active infrared beam monitoring.

Arboreal Rope Bridges:

- Spotlighting of arboreal overpass and surrounding forest edge and transects perpendicular to the road, increasing frequency with time elapsed for habituation;
- Scat collection and analysis using shade-cloth slings, if possible;
- Hair analysis data collection during intensive monitoring periods if possible; and
- Digital still camera monitoring using passive infrared sensor, solar power and cabling for ease of download; or
- 35mm film camera and passive or active infrared monitor mounted on rope bridge requiring climbing to download: or
- passive infrared video monitoring.

Glider Poles:

- Spotlighting of glider poles, increasing frequency with time elapsed for habituation;
- Scat collection and analysis using shade-cloth circles above pole guards;
- Hair analysis data collection during intensive monitoring periods: and
- Digital or still camera monitoring using passive infrared sensor.

Wet Culverts:

- Active searches, spotlighting and visual observations of movements;
- Trapping and netting where ethical; and
- Trials of digital still or video systems using passive infrared or microwave sensors.

Additional Monitoring:

In addition to the monitoring of crossing structures, the following needs have been discussed above:

- Roadkill monitoring at Compton Road and at an equivalent site with similar habitat and road features nearby;
- Population density monitoring of a variety of representative and/or target species by audio and visual census, active searches, spotlighting, wildlife sign indices, or mark-recapture methods;
- Traffic volume and speed data;
- Radio-tracking of selected target species; and
- Noise and other environmental (climatic) data.

Consideration should be given to monitoring of DNA variability in target species at longer time scales.

CONTENTS

1.0 BACKGROUND

In early 2005, Brisbane City Council entered into a partnership with the Cooperative Research Centre for Tropical Rainforest Ecology and Management (Rainforest CRC) to undertake a rapid review of contemporary remote and direct wildlife surveillance options for application to the monitoring phase of the Compton Road upgrade at Kuraby. The upgrade comprised widening of 1.3km of Compton Road between the Gateway Motorway and Acacia Road from a 2-lane carriageway to a 4-lane divided carriageway with centre median strip (BAAM 2004).

Drawing on previous experience of underpasses and arboreal overpasses in Far North Queensland, between October and December 2003 the Rainforest CRC (M. Goosem) had discussed with the Brisbane City Council (M. Grano) the types of wildlife movement structures and aspects of landscaping design that needed to be included. The final design included a comprehensive group of structures to enable road-crossing movements of fauna and prevent harvest through road kill. These included a land bridge (ecoduct) and several culvert-style underpasses for terrestrial fauna and a group of rope bridges and glider poles for arboreal fauna. To complement the underpasses, fauna exclusion fencing was constructed. This array of structures, in particular the inclusion of the land bridge, marks this project as at the forefront within Australia of mitigation against mortality and connectivity problems for fauna caused by road operations. The establishment of a sound monitoring program to assess the use of wildlife crossing structures is critical to determination of success of the design (Jones *et al*. 2004) and therefore to subsequent inclusion of successful structures in other upgrades. Monitoring of such structures requires an array of methodologies from direct observational techniques to the inclusion of remote technology. It is this combination of monitoring techniques which the Brisbane City Council has now requested the Rainforest CRC to recommend.

1.1 OBJECTIVES

The objectives of this project were to:

- undertake a review of options available for monitoring of the wildlife movement infrastructure citing successes and limitations of using remote and direct surveillance, including remote camera recording, infrared illumination and telemetric links with consideration of size, noise production, zoom facility, ability of equipment to be moved, power source, battery life, time and date recording, night vision capacity, sound recording, associated video link options and cable requirements;
- search for materials from various sources available to the Australian market including both Government (State and Local) and recognised research institutions.
- consult recognised experts for advice where required;
- collate the findings in an easily understandable way;
- identify appropriate surveillance techniques for long term installation at each wildlife crossing structure;
- recommend a preferred option and design of proposed surveillance technique for each structure; and
- provide an indicative cost where possible for requisition and/or construction of the proposed surveillance technique for each structure.

2.0 INTRODUCTION

Compton Road divides a significant remnant of urban bushland (Figure 1), with Karawatha Forest occurring to the south of the road and Kuraby Forest to the north (BAAM 2003). This bushland contains significant ecological values, particularly in the urban context. The area encompasses several remnant ecosystems (RE) classified as endangered or of concern. Corridor values have been identified for the area at strategic and local planning levels and Karawatha Forest forms part of the National Estate (Mack 2003). In terms of fauna, values include 2 species of wallaby, common ringtail possum, northern brown bandicoot, birds, snakes, dragon and scincid lizards and frogs, many of which have been recorded as victims of road mortality. Additionally, 3 species of flying fox, 2 possum and 2 glider species, koala and 72 species of birds were detected in comprehensive fauna surveys of the two areas of forest between February and June 2004 (Jones *et al*. 2004). A variety of other vertebrate fauna are also known or expected to occur including eastern grey kangaroo, short-beaked echidna, common dunnart, common planigale, feathertail glider, sugar glider, lace monitor, land rail, wallum froglet and green-thighed frog (Mack 2003; BAAM 2004).

Fragmentation of areas of natural habitat by roads has a number of impacts on fauna. These include habitat loss due to clearing and increased edge effects caused by the wide clearing, road mortality, disturbance from traffic movement, noise, headlights and pollutants and invasion along the clearing of weeds and feral animals (Goosem 2004). Together, these impacts can combine to cause the road to become a partial, substantial or complete barrier to movements of different wildlife. Animals may either attempt to cross and fail due to roadkill, or avoid the vicinity of the road because of disturbance and/or edge effects and therefore never attempt to cross. Failure of crossings can result in subdivision of animal populations. Population viability is lost due to smaller numbers and population decline can result from reproductive failure, disease or catastrophe as well as the long-term genetic problems of inbreeding.

The width of the clearing has a large impact on the degree of barrier effects – a wider 4-lane highway will restrict crossings far more than a 2-lane road (Goosem and Marsh 1997, Goosem 2001). This may have a positive effect on road kill, reducing the harvest of animals due to vehicles, but in the longer term barrier effects may cause problems for viability of the population (Goosem 2000). Either way, local extinction of the population could follow. Therefore, where road upgrades cannot be avoided, the inclusion of successful mitigation structures that improve connectivity is of great importance. However, not all structures are attractive to all species – for example, underpasses with a small openness ratio (height*width/length) are unlikely to be used by larger animals (Taylor and Goldingay 2003). The range of crossing structures included within the Compton Road upgrade provides good opportunities for the majority of target species listed above. Well-considered reports by Mack (2003) and Biodiversity Assessment and Management (2003) have aided in decisions on choice of structure and siting.

To establish the success of mitigatory strategies, sound monitoring experimental design and methodology must be incorporated into the pre-construction and post-construction phases of a road upgrade evaluation, or results remain observational at best (Clevenger and Waltho 2005). Additionally there is a need to incorporate long-term monitoring to address wildlife habituation to such large-scale landscape changes which may take periods of several years or more (Clevenger and Waltho 2005). Similarly effectiveness should be monitored for multiple species instead of focusing on just one target species of conservation concern because poor crossing structure design may form refuges for prey or for predators, altering ecosystem processes and the balance of the whole community. Thus, the system could be severely compromised but data extrapolated from one species may not necessarily show the problem.

Monitoring of road kill prior to and post- construction is a first requirement. A second necessity is long-term monitoring of the effectiveness of crossing structures in allowing movements of multiple species to occur. Thirdly, examination of long-term population dynamics on either side of the road within at least several representative species is needed. Such monitoring can demonstrate whether the combined population established by connecting the two sub-populations on either side of the road remains a functional entity able to conserve the species. Clevenger and Waltho (2005) suggest that once this data is available species performance indices for each crossing structure can be calculated as the ratio of observed through-passage use to expected through-passage use. This reduces the need for replication of crossing structures (generally impossible because of cost) in order to obtain statistically defensible results. Ideally, monitoring of genetic variability within the sub-populations would also be undertaken at intervals of several years.

Figure 1. Aerial photograph of Kuraby and Karawatha Forests divided by Compton Road and other infrastructure (Source: Brisbane City Council Environment Branch).

2.1 INFRASTRUCTURE TO FACILITATE WILDLIFE MOVEMENT

As part of the upgrade, a range of infrastructure was implemented to facilitate wildlife movement including:

- One Land Bridge (Figures 2 and 3);
- 2 fauna underpasses - modified Box Culverts with fauna ledge and "fauna furniture" (Figure 4);
- 3 Rope bridges/ladders (Figure 5);
- One set of 8 Glider poles (Figure 6);
- Fauna restrictive (exclusion) fencing (Figure 7);
- Two wet culverts (Figures 8 and 9).

All of these structures require surveillance options, both direct and remotely sensed where possible.

Figure 2. Land bridge concept design (courtesy of Brisbane City Council).

Figure 3. Land bridge following completion of construction (Photo: Pauline Fitzgibbon).

Figure 4. Modified box culverts with ledge to allow dry passage for fauna during low rainfall events.

Figure 5. Rope ladders for arboreal species (Photos: Pauline Fitzgibbon).

Figure 6. Glider poles situated on top of land bridge (Photos: Pauline Fitzgibbon).

Figure 7. Fauna exclusion fencing with mesh above to deter large species and solid plastic barrier buried into the soil to deter small mammals, amphibians, lizards and snakes.

Figure 8. Three-pipe wet culvert.
(Photo: Pauline Fitzgibbon)

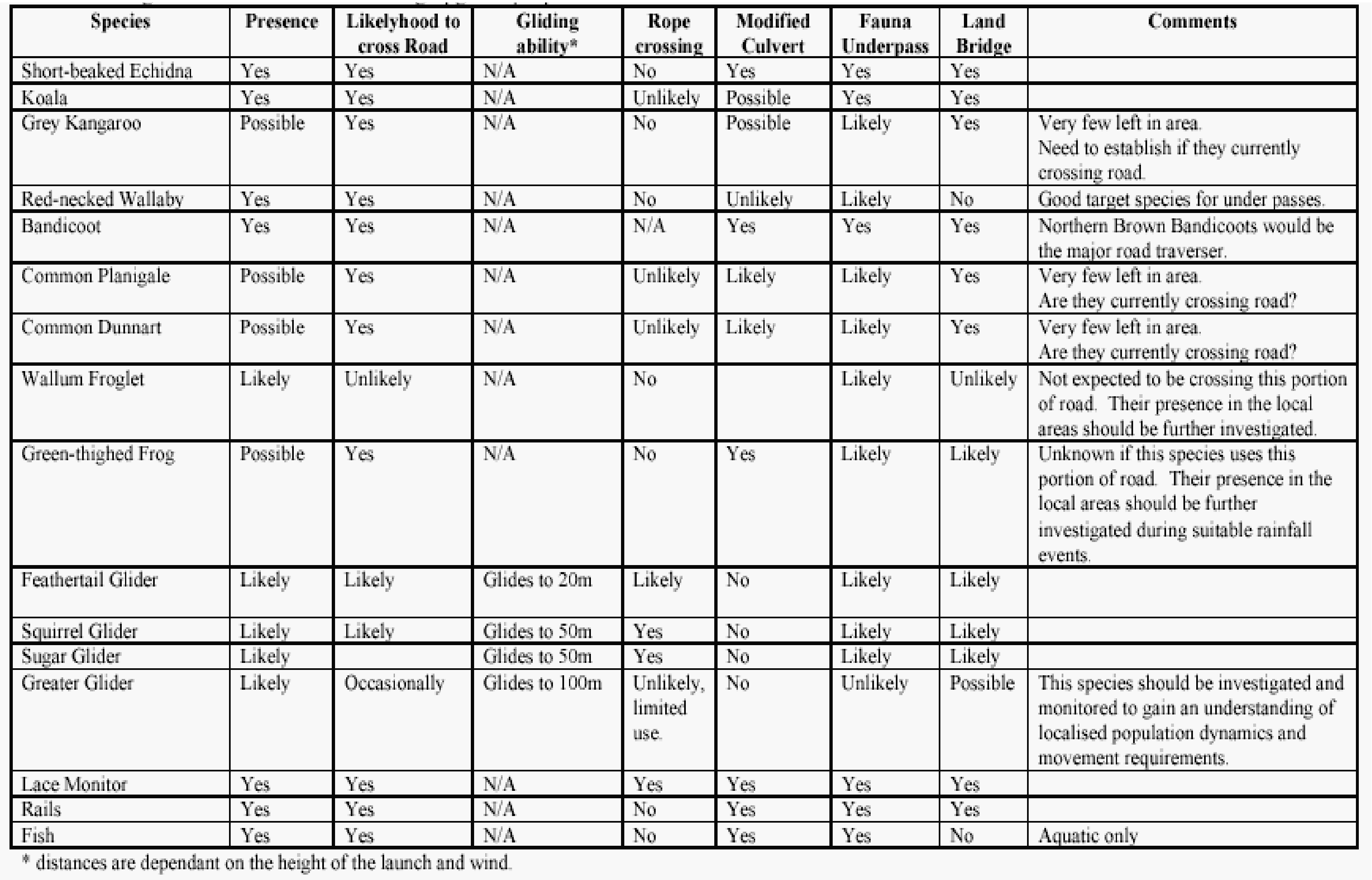
Figure 9. Three-box wet culvert.
(Photo: Pauline Fitzgibbon)

2.2 TARGET SPECIES

Mack (2003) suggested a list of target species for the area and suitable crossing types. As part of Biodiversity Assessment and Management's (November 2003) review and fauna management advice, a table of target species and their likelihood of use of crossing structures was prepared (Table 1).

The presence of many of these species has been confirmed in fauna surveys undertaken prior to and during construction (Jones *et al.* 2003). However, the current status of several target species in the vicinity of the upgrade remains to be confirmed. These include the eastern grey kangaroo, sugar and feathertail gliders, short-beaked echidna, common planigale and common dunnart, wallum froglet and green-thighed frog, lace monitors, rails and fish. Seasonal surveys for herpetofauna will be undertaken and terrestrial fauna surveys will continue to provide more certainty over the long term as to presence or absence of rare mammal and bird species. However, current fish surveys are also required to ascertain whether monitoring of fish species movement is necessary. The Rainforest CRC has been involved in the design and monitoring of fishways that will allow movements of native fish under roads (Kapitzke *et al*. 2003).

Table 1. Target species and likely use of crossing structures (BAAM 2003).



Species	Presence	Likelyhood to cross Road	Gliding ability*	Rope crossing	Modified Culvert	Fauna Underpass	Land Bridge	Comments
Short-beaked Echidna	Yes	Yes	N/A	No	Yes	Yes	Yes	
Koala	Yes	Yes	N/A	Unlikely	Possible	Yes	Yes	
Grey Kangaroo	Possible	Yes	N/A	No	Possible	Likely	Yes	Very few left in area. Need to establish if they currently crossing road.
Red-necked Wallaby	Yes	Yes	N/A	No	Unlikely	Likely	No	Good target species for under passes.
Bandicoot	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Northern Brown Bandicoots would be the major road traverser.
Common Planigale	Possible	Yes	N/A	Unlikely	Likely	Likely	Yes	Very few left in area. Are they currently crossing road?
Common Dunnart	Possible	Yes	N/A	Unlikely	Likely	Likely	Yes	Very few left in area. Are they currently crossing road?
Wallum Froglet	Likely	Unlikely	N/A	No		Likely	Unlikely	Not expected to be crossing this portion of road. Their presence in the local areas should be further investigated.
Green-thighed Frog	Possible	Yes	N/A	No	Yes	Likely	Likely	Unknown if this species uses this portion of road. Their presence in the local areas should be further investigated during suitable rainfall events.
Feathertail Glider	Likely	Likely	Glides to 20m	Likely	No	Likely	Likely	
Squirrel Glider	Likely	Likely	Glides to 50m	Yes	No	Likely	Likely	
Sugar Glider	Likely		Glides to 50m	Yes	No	Likely	Likely	
Greater Glider	Likely	Occasionally	Glides to 100m	Unlikely, limited use.	No	Unlikely	Possible	This species should be investigated and monitored to gain an understanding of localised population dynamics and movement requirements.
Lace Monitor	Yes	Yes	N/A	Yes	Yes	Yes	Yes	
Rails	Yes	Yes	N/A	No	Yes	Yes	Yes	
Fish	Yes	Yes	N/A	No	Yes	Yes	No	Aquatic only

* distances are dependant on the height of the launch and wind.

3.0 METHODS

The work for this project was undertaken in five stages:

1) A comprehensive literature review was compiled of recent (2002-present) journal articles, conference papers and web sites where monitoring of road crossing structures was undertaken.
2) From the literature review, researchers whose monitoring options were discussed but where insufficient detail was available, were contacted via email (Table 2) with questions about the successes and disadvantages of their methodology. Additionally, I emailed researchers in Australia that I know have monitored crossing structures and whose techniques needed further clarification. Questions examined both direct techniques and those using remote sensing. Applicability and reliability of remote sensing equipment to monitoring of different crossing structures was canvassed. Additional data was compiled from knowledge of the author of others who have monitored crossing structures. Appendix 1 shows a selection of sample questions that were modified to suit the current projects of individual researchers.
3) Where remote sensing options were found to have been successful, either through literature review or expert consultation, suppliers were contacted for more information about their equipment, together with indicative costings where possible.
4) Options for comprehensive monitoring of the various crossing structures constructed on the Compton Road upgrade were listed.
5) Decisions regarding recommended options were listed, together with potential equipment, and where possible, indicative costings for that equipment.

4.0 LITERATURE REVIEW

The literature review encompasses all accessible journal articles since 2002 where monitoring of road crossing structures was undertaken. Recent conference proceedings and web sites were also examined. The focus was remote sensing methods. Additionally, older articles that detailed direct methods of monitoring and recent articles with variations and improvements on the direct methods were also included. A total of 29 papers comprise the literature review (Table 3).

Clevenger and Waltho (2005) point out that assessment of the efficacy of wildlife crossing structures can lead to spurious results if confounding variables are not considered. Confounding variables include, but are not limited to, variations in the amount of human activity in the vicinity of the structure, whether there are alternative crossing routes nearby on the highway, and whether access to each crossing structure is equal for individuals and species. Although in the case of Compton Road it may not be possible to avoid variable human activity at crossing structures, the inclusion of remote sensing techniques within the monitoring program should at least provide data on how variable such activity is between structures.

Table 2. Researchers contacted with email questions about their monitoring methodology.

Researcher	Email Address	Reply[a]	Further consult	Reply
Dr Kelly Gordon	kgordon@uwyo.edu	-		
Dr Tony Clevenger	tony.clevenger@pc.gc.ca	Y	Y	Y
Dr Frank van Manen	vanmanen@utk.edu	Y	Y	
Dr Stanley Anderson	anderson@uwyo.edu			
Dr Kerry Foresman	foresman@selway.umt.edu	Y	YY	YY
Dr K Crooks	kcrooks@facstaff.wisc.edu kcrooks@wisc.edu	X X		
Dr Cristina Mata	Cristina.mata@uam.es	-		
Dr Chris Servheen	grizz@selway.umt.edu	Y		
Mr C. Brudin III	cbrudin@admarble.com	-		
Dr Larry Halverson	Larry.halverson@pc.gc.ca	Y		
Dr William Boarman	William_boarman@usgs.gov	-		
Dr Klemen Jerina	klemenjerina@hotmail.com	-		
Mr Antonio Righetti	a.righetti@bluewin.ch	-		
Dr Heinrick Reck	h.reck@pz-oekosys.uni-kiel.de h.reck@ecology.uni-kiel.de	X Y	Y	Y
Dr Verena Keller	Verena.keller@vogekwarte.ch	Y	Y	Y
Hans Molenaar	J.G.Demolenaar@alterra.wag-ur.nl	-		
Dr Marcel Huijser	M.P.Huijser@pv.agro.nl	-		
Hans Becker	g.j.bekker@dww.rws.minvenw.nl	-		
I. O. Lawrence	IOLawrence@msn.com			
Rebecca Shoemaker	okoshono@hotmail.com	Y	Y	Y
Dr C. Haas	cdhaas@prodigy.net	-		
L. M. Lyren	lmlyren@aol.com	-		
Dr Norris Dodd	doddnbenda@cybertrails.com	YYYY	Y	
Dr Raymond Sauvajot	ray_sauvajot@nps.gov	-		
Jean Carsignol	Jean.Carsignol@equipement.gouv.fr	-		
Mr Norman Scott	norman.b.scott@mainroads.qld.gov.au	-		
Australian Museum Business Services	jaynet@austmus.gov.au	Y	Y	
Dr Patty Cramer	Pcramer@cc.usu.edu	Y		
Ms Nancy Newhouse	sylcon@telus.net	Y	Y	
Ms Lisa Simpson	lsimpson@umwelt.com.au	Y	Y	

[a] (X) not valid email address; (Y) reply received; (-) no reply received.

To examine the third question requires population density or relative abundance data in the vicinity of the structures for a variety of 'representative species' (as far as any species can be representative of others). A possible selection of species could include several of the target species for the project e.g. gliders, bandicoot, wallabies, koala and lace monitor, as well as more common species such as possums, rodents, frogs, skinks and fish, for which relative abundance data may be easier to obtain. Relative abundance estimates for habitat in the vicinity of each crossing structure can then be used to derive species-specific, performance indices that can be compared between structures i.e. observed crossings vs expected crossings (Clevenger *et al.* 2001).

4.1 EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES

Hardy *et al.* (2003) outline a series of steps that need to be considered when planning an evaluation of the effectiveness of wildlife crossing structure installations.

4.1.1 Identifying Clear and Concise Evaluation Questions and Definitions of Effectiveness

The most basic evaluation of crossing structures would concurrently address the issues:

- Do the structures reduce wildlife mortality (and concomitant danger to drivers)?
- Do the structures allow animals to move safely across the road?

The monitoring proposed for the Compton Road structures should address these questions, however a longer time frame may be required than is currently proposed. It may take many months for animals to habituate to the presence of the structures. For example a 15 m long arboreal overpass (rope bridge) across a tourist road in the Wet Tropics was not observed to be used within the first 6 months of erection (Weston 2003). Due to the greater length of the rope bridges at Compton Road and lack of any cover from predators nearby, habituation may be expected to take at least several months and probably far longer, even though the species targeted for the crossing are likely to be less affected by open spaces than the shy rainforest ringtails targeted in the Wet Tropics monitoring. Conversely, monitoring of use of faunal underpasses by rainforest species at East Evelyn, also in the Wet Tropics, found that coppery brushtail possums and rodents were recorded using underpasses within a month of completion of construction works (Goosem 2003). The shyer target species, however, including the tree-kangaroo and cassowary have demonstrated that periods of habituation may take years (pers. obs.).

It should be emphasized that effectiveness of structures does not mean 100% reduction in road kill as no exclusion fence can be an absolute barrier. A realistic decision on the level of reduction in road kill that is an acceptable target is required. Similarly, it is extremely unlikely that the crossing structures will be viewed by fauna as an extension of habitat. Instead, they are likely to be used when dispersing or for more large-scale movements in the landscape, such as for accessing a seasonal food resource. Therefore expecting crossing structures to be used equally as often as movements in natural habitat is not realistic. A more realistic target might be that movements across the road of the target species are increased, relative to the situation pre-construction. Unfortunately, the monitoring period available prior to construction did not allow evaluation of movements (Jones *et al.* 2005), so the Compton Road monitoring will need to rely on the observation of movements of the target species post-construction in comparison to movements across an equivalent road in similar habitat nearby.

More complex research questions could also be important to understanding the long-term and large-scale effectiveness of the structures in terms of populations, communities, biodiversity, ecosystem processes and landscape ecology (Hardy *et al.* 2003). More complex research would consider how crossing structures affect populations of species in terms of survivorship, recruitment and dispersal of juveniles, physical condition, short-term and long-term reproductive rates, sex ratios and genetic exchange. These questions obviously require more expensive long-term monitoring of target species, possibly requiring many years before preliminary results are obtained. Effective crossing structures must ensure subadults can disperse and that recolonisation of areas after long absences or local extinctions can occur (Beier and Noss 1998).

To examine whether ecosystem processes can be maintained is difficult in an urban context where processes may already be severely curtailed by surrounding human influences. However, corridors for faunal movements form important landscape scale processes in the Compton Road context. Again species populations and critical resources in terms of access to seasonal habitat requirements would need to be monitored, together with the ability of dispersers to use the landscape-scale corridors conserved within Karawatha and Kuraby Forests.

4.1.2 Identification of Methods to Measure Effectiveness

It is important here to consider the possibility of confounding variables as discussed in Section 4.0. For example, a statistically significant reduction in road kill may be due to the mitigation works, or it might be because traffic levels, abundance of animals or traffic speed has decreased, or because the wider road and likely higher traffic volume is causing an increased barrier effect. Having population data prior to and post-construction can solve the problem of annual and seasonal population fluctuations (Hardy *et al*. 2003). In the case of Compton Road, control areas without upgrade and with similar habitat type and area and similar road factors need to be monitored concurrently, but such sites may be difficult to find.

4.2 DIRECT MONITORING OF CROSSING STRUCTURES

Whether or not remotely sensed methodology is to be incorporated into a monitoring scheme for road crossing structures, direct methods must also be employed. Although remote sensing methods generally supply a large quantity of good quality data, when electronic failure occurs, the direct monitoring methods provide continuous data collection. Most researchers maintain a back-up of less technologically complicated techniques, or use these as the main source of data with electronic measures used to solve identification problems or to investigate questions of behaviour. Direct monitoring is also required for a variety of other reasons. For example, roadkill monitoring is necessary to confirm the effectiveness of exclusion fencing. Monitoring of population densities prior to and post-construction is also required to ensure that the crossing structures are performing the function of maintaining population viability.

The literature review identified a variety of direct monitoring methods from easily undertaken to more difficult to achieve:

- anecdotal and incidental observations;
- road kill monitoring;
- monitoring of animal tracks within crossing structures e.g. sand and/or loam track stations, marble dust beds or gypsum powder track stations, sooted track plates;
- tracking of animal movements;
- population indices using wildlife sign e.g. trails, snowtracks, scat collection;
- observation censuses of species e.g. spotlighting, active searches, bird observations on transects, audio recordings of birds and frogs;

- trap, mark recapture methods for estimation of population densities;
- radio-tracking of animal movements;
- hair sampling for species identification and DNA analysis of individuals.

4.2.1 Anecdotal and Incidental Observations

Anecdotal information from scattered observations of animals moving in and around crossing structures can be useful as supplementary data (Abson and Lawrence 2003, Hardy *et al.* 2003), although such data must be treated differently from formally-collected data (Chruszcz *et al.* 2003). Particularly for rare species that are seldom encountered, they give an indication that a structure may be used (Beier and Noss 1998), although not necessarily determining that the structure is always effective for the species.

4.2.2 Road Kill Monitoring

A statistically significant reduction in level of road kill indicates some level of effectiveness of a mitigation structure. However, confounding variables such as traffic volume, traffic speed and abundance of animal populations need to be considered. Many papers discuss monitoring of road mortality (Goosem 2000, 2003; Cain *et al.* 2003; Taylor and Goldingay 2003; Abson and Lawrence 2003; Pukey and Vogel 2003; Servheen *et al.* 2003; Dodd *et al.* 2004; Singleton and Lehmkuhl 2000). One of the most important aspects of road kill monitoring is to consider the species being monitored – if multiple species of different sizes are to be monitored, driving and observing road kill from a moving vehicle will not allow smaller species to be observed (Goosem 2000). It is necessary to walk along both sides of the road for the complete transect distance to achieve satisfactory monitoring of all vertebrates killed. Similarly timing of road kill monitoring is important. Commencing at dawn on a Sunday morning was the best strategy when examining road kill on the Kuranda Range road near Cairns, as many small animals were not be able to be identified once many vehicles had traveled over them. On a Sunday traffic levels did not increase to high levels as early in the morning as other days of the week (Goosem 2000). To obtain quantitative results, it is also necessary to incorporate an identifiability index for each group of vertebrates, as small animals such as frogs will normally only last one night on the road, while others such as cane toads may last several days (Goosem 2000). Removal of animals by predators and by humans for reasons of safety is another source of error in road kill monitoring which can be reduced by commencing monitoring early in the morning. However, there are few options for correction of data where animals are hit on the road but die later away from the road surface.

Table 3. Literature techniques for monitoring of wildlife crossing structures.

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
Brudin, C.	2003	Pennsylvania	bridges (18)	tracks, trails, scat	rodents - large mammals
			culverts (28)	tracks, trails, scat	smaller mammals
			culverts (9) – variety of sizes	infrared cameras - TM550 Passive infrared Trail Master Monitors (Goodson and Assoc, Widmer, Lenex - body heat and motion sensors - Trail Master TM35-1 camera kit with Yashica T4 Super D camera, 25ft cable, shield and tree pod for mounting, 35mm film, mounted at 30in height, sensitivity high/medium for small to large mammals, delay 6 sec; monitor in metal container bolted to culvert wall, camera mounted on top, Fuji Super HG, 1600-ASA 36 exposure colour film, 2ft x 3ft area adjacent to camera flash painted with no-gloss flat black spray paint, Mon-Fri to reduce vandalism, 2 weeks separated by 1 month	deer, bear, raccoon, opossum, weasel, feral cat, heron, fox, skunk, humans
			box culverts (20) - large	infrared cameras - TM550 Passive infrared Trail Master Monitors (Goodson and Assoc, Widmer, Lenex - body heat and motion sensors - Trail Master TM35-1 camera kit with Yashica T4 Super D camera, 25ft cable, shield and tree pod for mounting, 35mm film, mount	bear, deer, raccoons, duck, muskrat, opossums, dogs, humans
Bank, F., Irwin, C.L., Evink, G., Gray, M., Hagood, S., Kinar, J., Levy, A., Paulson, D., Ruediger, W., Sauvajot, R., Scott, D., White, P.	2002	Switzerland	vegetated ecoduct	infrared video camera, tracks, infrared still photos	large wildlife, butterflies
			ecoducts	infrared video technology	badger, fox, marten, chamois, roe deer, red deer
Bank, F. *et al.*	2002	Slovenia	bridge underpass	infrared camera in protective case	bear, large mammals
Bank, F. *et al*.	2002	Germany, Netherlands, France, Switzerland	ecoducts	infrared video cameras	large mammals, small mammals, flightless insects e.g. ground beetles, grasshoppers and spiders, butterflies
Bank, F. *et al.*	2002	Europe	crossing structures in general	sand tracking, snow tracking, counters, infrared cameras	multispecies

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
Lyren, L., Crooks, K.	2003	California	wildlife underpasses (3)	radio-tracking, remotely triggered cameras	bobcat, coyote
			culverts (20)	radio-tracking, remotely triggered cameras	bobcat, coyote
Mata, C., Hervas, I., Herranz, J., Suarez, F., and Malo, J.	2003	Spain, NW	culverts 1.8m diam (33)	Marble dust beds, infrared beam digital cameras	frogs, lizards, snakes, small mammals, rats, weasel, cat, fox
			culvert 2-3mW, 2mH (10)	active infrared sensors at ground level, Sanyo VPC R1 digital camera and electronic control connecting both	frogs, lizards, snakes, small mammals, rats, badger, weasel, cat
			traffic underpasses 4-9mW, 4-6mH (14)		hare, rabbit, frogs, rats, hedgehog, cat, fox, dog
			wildlife underpasses 20mW, 5-7mH (7)		rabbit, frogs, lizards, rats, hedgehog, badger, cat, fox
			traffic overpasses 7-8mW (16)		hare, small mammals, cat, dog
			grass and shrub covered ecoducts 16mW (2)		hare, lizards
Haas, C., Crooks, K.	2003	California	large underpasses	tracks, remotely triggered cameras	coyote, bobcat, mule deer, fox, raccoon, skunk
			small underpasses (43 two sizes)	tracks, remotely triggered cameras	fox, raccoon, skunk
Foresman, K.	2003	Montana	culverts 1-1.2m diameter with ledges (3)	TrailMaster passive infrared cameras, mounted in roof of culvert, 15m from entrance, cameras outside entrances to 2 culverts, film replaced weekly, small mammal census - 25 traps in line transect 10m from culvert entrance temperature, light, humidity dataloggers	deer mice, weasels, cat
	2001		culverts 1-1.2m diam, no ledges (3)	TrailMaster passive infrared cameras, mounted in roof of culvert, 15m from entrance, cameras outside entrances to 2 culverts, film replaced weekly, small mammal census - 25 traps in line transect 10m from culvert entrance	deer mice, weasels, cat, raccoon, skunk, muskrat, not vole, dog, coyote
Tigas, L., van Vuren, D., Sauvajot, R.	2002	Los Angeles, California	culverts, mean diameter 4.1m	radio tracking, motion sensitive collars, 2 yr transmitting life	bobcat, coyote

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
van Manen, F., Jones, M., Kundall, J., Thompson, L., Scheick, B.	2001	North Carolina	open span bridge 37mW, 2.4mH	Trailmaster active infrared (TM1500) and passive infrared (TM550) camera systems with Yashica T-4 Super D weatherproof automatic flash cameras (Goodson and Associates, Inc., Lenexa, Kansas, USA), monitors set 56cm above ground, continuously operable	black bear
				radiotracking	black bear
Clevenger, A., Waltho, N.	2003 2000	Canadian Rockies	open span underpasses (11)	tracking sections (2 x 4m) at both ends of underpass, dry, loamy mix of sand, silt and clay 3-4cm deep, checked every 3-4 days, noise	bear - black, grizzly, cougar, wolf, deer, elk, bighorn sheep, moose
			underpasses, metal culvert (2)	tracks, noise	bear - black, grizzly, cougar, wolf, deer, elk, bighorn sheep, moose
			overpasses 50mW (2)	Trailmaster camera systems, track stations installed in centre of overpass between the 2 arches	bear - grizzly, wolf, deer, elk
			creek bridge underpasses 11mW, 3mH (2)	tracks, noise	grizzly, wolf, deer, elk
			metal culvert 7mW, 4mH (5)	tracks, noise	bear - black, grizzly, cougar, wolf, deer, elk, bighorn sheep, moose
			box underpasses 3mW, 2.5mH (4)	tracks, noise	bear - black, cougar
Clevenger, A., Chruszcz, B., Gunson, K.	2001	Banff, Canadian Rockies	culverts, variable (36)	sooted track plates, noise, traffic volume, tracks external to culverts- population density	coyote, marten, weasel, snowshoe hare, red squirrel
McDonald, W. and Cassady St Clair, C.	2004	Banff, Canadian Rockies	arch culvert, 3m diam (9) overpass 15mW metal pipe, 0.3m diam	tracks, fluorescent powder (Radiant fluorescent pigment, Radiant Color Inc, Richmond) trail able to be followed 4-5 days, trapped animals translocated across road	deer mice, meadow voles, red-backed voles
Puky, M., Vogel, Z.	2003	Hungary	amphibian tunnels, usually fencing	road transects - live and dead amphibians counted, adjacent population sizes estimated using visual, call playback, netting and torching transects for newts	frogs, newts, toads, salamanders

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
Gordon, K., Anderson, S.	2003	Wyoming	box cattle culvert (4)	Trailmaster TM1500 active infrared system, Yashica 35mm still camera, 2-weekly, 13 months, both underpass entrances, tracks	mule deer
			open span road underpass (2)	Trailmaster TM1500 active infrared system, Yashica 35mm still camera, 2-weekly, 13 months, both underpass entrances, tracks	mule deer
			box underpass 6mW, 3.5mH (1), height, width modified	videocamera system, 4 infrared lenses at entrance, exit and approach areas fed to a VHS videocassette recorder, activated by four sets of infrared scopes, 2 on either approach, one at outermost extremity of fence and one halfway along fence, LED lights, visible to infrared lenses but not to deer installed to improve quality of night images	mule deer
Servheen, C, Shoemaker, R., Lawrence, L.	2003	western Montana	culvert 2-4.6m diam (3)	Trailmaster TM550 and TM35-1 infrared motion and heat sensor cameras	cat, skunk, raccoon, fox
			underpass (7)	Trailmaster units and DeerCam Scouting Cameras (Lenexa, KS and Park Falls, WI)	deer, elk, cat, skunk, raccoon, coyote, black bear
LaPoint, S., Kays, R., Ray, J.	2003	Adirondacks, NY	culverts, 0.6-1.5mW, 0.6-1.5mH (7)	CamTrak motion sensing cameras, snow tracking	Raccoon
			culverts, 2.25mW, 1.6mH (9)	CamTrak motion sensing cameras, snow tracking	raccoon, weasel
			underpass, 3-3.6mW, 3.75-4.8mH (2)	CamTrak motion sensing cameras, snow tracking	
			bridge, 36.9mW, 0.9-4.5mH (1)	CamTrak motion sensing cameras, snow tracking	fox
Taylor, B., Goldingay, R.	2003	northern NSW	culvert 2.4mW, 1.2m H (12)	sand tracking 1mW, 2-3cm deep, fine-grain, raked smooth every 2nd day, Elliot trapping, hair tubes, scat, spotlighting, frog searches	bandicoot, rat, wallaby, mouse, koala, cat, fox, toad, frog, birds, possum, lizard, snake
Bennett, G.	2003	Netherlands	ecoduct, 140m long, 50mW	sand-tracking, visual observations twice a week	deer, boar, badger

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
Ng, S., Dole, J., Sauvajot, R., Riley, S., Valone, T.	2004	Los Angeles, California	culverts, mean 4.2mW, 3.7mH (6)	gypsum powder track stations, 3mm thick 1mW at entrance, middle and exit (4), passive infrared Trailmaster TM550, triggered by body heat and motion of animal passing within 20m within a horizontal arc of 20^o and vertical arc of 4^o of the IR sensor, one photo/min (1)	coyote, bobcat, raccoon, skunk, cat, dog, opossum
			pipe culverts, mean diameter 2.7m (5)	gypsum powder track stations, 3mm thick 1mW at entrance, middle and exit (3), passive infrared Trailmaster TM550, triggered by body heat and motion of animal passing within 20m within a horizontal arc of 20^o and vertical arc of 4^o of the IR sensor, one photo/min (3)	coyote, raccoon, skunk, cat, dog, bobcat
			underpasses, mean 42mW, 5.2mH (4)	gypsum powder track stations, 3mm thick 1mW at entrance, middle and exit (4), passive infrared Trailmaster TM550, triggered by body heat and motion of animal passing within 20m within a horizontal arc of 20^o and vertical arc of 4^o of the IR sensor, one photo/min (1)	opossum, cat, dog, deer, coyote, bobcat, skunk, raccoon
Cain, A., Tuovila, V., Hewitt, D., Tewes, M.	2003	Texas	ledge culverts (5)	radio-tracking - 120g radiocollars + mortality switches (Advanced Telemetry Systems, Minnesota), located 12-15 times/month for 2yrs, bearing sites located using GPS, accuracy checked by placing transmitters at known locations and triangulating, Locate and calhome estimates of home ranges	bobcat, felids
			culverts (9)	Trailmaster active infrared beam system, placed at both entrances of 7 crossing structures, tracking in soil or white lime	
			bridges (4)		
Goosem, M.	2003	north Qld	underpasses, 3.4mW, 2.4mH (3)	sand-tracking, active IR beam-triggered digital camera system from Faunatech, mounted on pole with cage for security, 2 beams, one set radio signal sensor and one set cable attached sensors	brushtail possum, pademelon, scrubfowl, scrub turkey, rodents, bandicoots, cat, dog/dingo

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
Kinley, T., Page, H., Newhouse, N.	2003	British Columbia	surface crossing behaviour	2 QWIP IR camera mounted on 6m poles, facing on-coming traffic, trailer with generator, computer with tracking software, 2 radar guns, radio controls, conventional digital video camera, continuous IR (digital) and conventional (VHS) video footage recorded, 5 mins footage sampled each half hour	deer, elk
Dodd, C.K., Barichivich, W., Smith, L.	2004	Florida	wet culverts 2.4mW, 2.4mH (2)	wire screen-mesh funnel traps, 10 floating screen funnel traps	frogs
			culverts 1.8mW, 1.8mH (2)	wire screen-mesh funnel traps, 10 square hardware-cloth funnel traps, sand track station 1.8mL, 1.0mW, Trailmaster TM1500 active IR system beam at 30cm height	frogs, rodents, armadillo, otter, opossum, raccoon, rabbit, alligator, snakes,
			pipe culverts 0.9mD (4)	2 crayfish traps in light boxes of ROW	rodents, fish, frogs, reptiles
Weston, N.	2003	north Qld	arboreal overpasses, rope tunnel and rope bridge (3)	Foresite Buckshot 35A, 35mm 800 ASA colour or 400 ASA BW film, passive IR, 8AA batteries, red filter to mask flash Foresite Buckshot RTV, low sensitivity, 2 min delay between photos, 400ASA BW 35mm film, passive infrared, red filter to mask flash; hair sampling using self-adhesive double-sided tape on rope of bridge or on curtain of a circular wire frame 55cm diameter draped with double-sided tape slipped over bridge, scat collection using nets underneath bridges or funnels of wire mesh and PVC pipe hung under bridge	ringtail possums, brushtail, striped possum, Melomys
Abson, R., Lawrence, R.	2003	Victoria	open span underpass 70mW, 12mH (1)	active search, Anabat, birdsong recording, frog call recording, bird observations, trapping, hair funnels, harp trap, incidentals, nest boxes, pitfalls, roadkill, sandtray, scat, spotlighting	multispecies
Boarman, W.	2005	Mojave Desert	storm drain culverts 1-3.6m diam (3)	Passive integrated transponder system tags, Automated reader systems	desert tortoise

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
Swann, D., Hass, C., Dalton, D., Wolf, S.	2004	Arizona	Laboratory	Trailmaster 1500 active IR 35mm film narrow vertical detection zone 3-7 degrees, narrow horizontal detection band <10 degrees, best at lower ambient temps, not highest for detections, performed well for large animals, poorly for small animals at either 120cm or 20cm height, beam needs to be set lower for smaller animals, very durable, multiple sensitivity settings and timing options, complicated to use, requires programming each time batteries are changed (not for TM1550), 4 separate parts provide flexibility in camera placement, false triggers from moving vegetation, rain	animal models of 3 sizes
			Laboratory	Trailmaster 500 passive IR narrow vertical detection zone 3-7 degrees, horizontal detection band >10 degrees, best at lower ambient temps, performed well at default and high sensitivities, not highest for detections, sensitive at 20cm but not 120cm height, loses sensitivity at temperatures >26 degrees, durable, false triggers may occur when animal is outside camera field of view, complicated to use but flexible	animal models of 3 sizes
			Laboratory	Buckshot Scout passive IR - narrow vertical detection zone 3-7 degrees, narrow horizontal detection band <10 degrees, best at lower ambient temps, most detections (high sensitivity)	animal models of 3 sizes
			Laboratory	Buckshot RTV passive IR narrow vertical detection zone 3-7 degrees, narrow horizontal detection band <10 degrees, higher ambient temps OK, most detections (high sensitivity) except when close to sensor at 120cm height, durable housing, large detection zone, false triggers due to heated ground, one of better cameras for animals <5kg,	animal models of 3 sizes

Authors	Year	Study Area	Wildlife Passage	Monitoring Method	Species
			Laboratory	CamTrakker passive IR narrow vertical detection zone 3-7 degrees, narrow horizontal detection band <10 degrees, best at lower ambient temps, most detections (high sensitivity), detected all size models at 20cm, and large animals at 120cm and all animal sizes at distances of 10m, sensitivity declined at higher ambient temperatures, easy to use, housed in one box, better suited for large animals than those <5kg	animal models of 3 sizes
			Laboratory	DeerCam passive IR narrow vertical detection zone 3-7 degrees, narrow horizontal detection band <10 degrees, best at lower ambient temps, missed small and medium animals at 129cm height, easy to use, sensitive reducing false triggers but requiring careful aiming, cheap	animal models of 3 sizes
Singleton, P., Lehmkuhl, J.	2000	Washington State	culverts > 0.5m diameter (24)	Trailmaster TM500 passive IR monitors and TM 35-1 35mm cameras, sooted track plates	mice, chipmunks, squirrels, skunks, others
			bridges (6)	Trailmaster camera systems, raked tracking beds	as above, humans, others
Dodd, N., Gagnon, J., Schweinsburg, R.	2004	Arizona	underpasses 10-16mW, 6.8-11.5mH (2)	4 0.01 lux, high resolution B&W video cameras linked to 12v VCR with B&W quad-screen splitter, 60 IR LED illuminators to cover camera field of view, turn on at night by internal photocells, 5 IR photo-beam triggers, operating on 120v AC power converted to 12v DC, distributed via buried wiring. 2 cameras on trees in approach 30-25m from entrance, 1 camera on pole within underpass, 1 camera towards highway and underpass entrance, all components operated continuously and switched on for 2 mins when triggered, small 12v DC blowers and heaters included	elk, deer, coyote, fox, raccoon, puma, bear, dog, cat
				1 video camera, 2 IR illuminators, 3 IR beam triggers, VCR, 6v battery bank	deer, elk

4.2.3 Monitoring of Animal Tracks

Mammal tracks can be used to document presence and movements relative to road and crossing structures, and in some cases, population trends (Beier and Cunningham 1996; Clevenger *et al.* 2005). However, track data alone cannot identify absolute numbers of individual animals or distinguish between different individuals passing through a crossing structure, but tracks can be used as an index of relative abundance (Huijser and Bergers 2000) and an index of relative rates of crossings. An advantage of tracking is that it is a non-intrusive procedure without the disturbance elements of flash and camera noise, or the need to capture the animal. The technique is relatively low cost and low tech, but reading and interpreting tracks requires a fair amount of skill (Hardy *et al*. 2003).

Tracks are identified when left by animals crossing a track bed, or soft surface. For larger mammals such as wallabies, a track bed wider than the stride of the animal is needed. The hopping stride of large kangaroos ranges between 1.2 and 2.5m, whereas for wallabies this length ranges between 0.9 and 1.1m (Triggs 1988). If eastern grey kangaroos are expected in the vicinity of Compton Road a track bed of at least 2.5m in width will be necessary within the structures that these species are likely to use (particularly the land bridge and possibly the fauna underpasses). Should eastern grey kangaroos not currently be found in the area (Jones *et al.* 2004), a track bed of 2m in width will be ample for wallabies and other smaller species. Materials of track beds should be at the same level as the floor of the crossing structure, so the animal does not have to change its normal motion to cross the track bed. Enclosure of the track bed in a metal tray or frame could be preferable in culverts to avoid the need to replace the complete track bed when material is washed away each time the culvert carries water.

Materials used in track beds include fine sand about 2-5cm deep that can be raked or smoothed after tracks have been identified (Goosem *et al.* 2001; Abson and Lawrence 2003; LaPoint *et al.* 2003; Taylor and Goldingay 2003; Dodd *et al*. 2004). A width of 1-2m for the track bed and fine sand are most commonly used in Australia. Sand can have the disadvantage of difficulty in track identification for small species and even for larger species if allowed to dry out completely. In the Netherlands, Bennett (2003) found that a strip of loose soil across the centre of a land bridge had been successfully monitored for several years. A similar technique of ploughing logging tracks was used by van Manen *et al.* 2001 and Gordon and Anderson (2003) in the United States. Another material that has been used for tracking beds is sieved agricultural gypsum powder 3mm thick and 1m wide in tracking strips across the crossing structure in the middle and at both entrances (Ng *et al.* 2004), giving results for both large and medium-sized mammals and rodents. Austin white lime has also been used for medium-sized mammals (Cain *et al.* 2003). Marble dust at 3-10mm depth and 1m wide completely across the middle of a structure is recommended for track beds by Mata *et al*. (2003), due to lack of odour and high quality of footprints it renders due to its density (Yanes *et al.* 1995).

In Canada, Clevenger and Waltho (2003; 2005) use a dry loamy mixture of sand, silt and clay 3-4cm deep and 2m wide to get satisfactory tracks of large animals, whereas for smaller animals, Clevenger *et al.* (2001) used sooted track plates (75x30cm) with multiple plates to cover the bottom of the culvert. A sooted track plate is prepared by sooting a 0.1cm aluminium plate with an acetylene torch or similar apparatus that uses kerosene as an alternative (Canadian Ministry for Environment Parks and Wildlife 1999). Tracks show up on the sooty surface much more readily than in soil (Herzog 2003). After the plate is sooted, a piece of Con-Tact® is wrapped around the centre of the plate with the sticky side up and taped to back of plate. Soot is transferred by the feet to the Con-Tact where it is deposited in the form of highly detailed tracks. Sooted track plates were found by Singleton and Lehmkuhl (2000) to be preferable for smaller culverts (<0.75m diameter) compared with remotely triggered Trailmaster cameras with passive infrared monitors which, due to the size of the culvert, had to be mounted outside the structure and therefore only triggered when an animal entered or exited. The tracks can be `lifted' from the track plate using wide, transparent tape to transfer the image to a sheet of white paper. Unlike tracks left in snow or sand, these impressions provide a permanent record and permit consultations with experts on difficult identifications. In addition to providing permanent and consistent track impressions, track-plate stations are inexpensive and easily transported, and involve no potential injury to focal animals. Because a permanent record of tracks can be kept, it is possible to study difficult-to-identify tracks at one's leisure and to send photo-copies (even by fax) to authorities for verification. The permanent record also permits detailed measurements and the application of discriminant analyses in making identifications. Disadvantages of track plate stations include the difficulty of accurately distinguishing among tracks of related species of similar size.

It is important to make an informed decision on whether an observed track can be considered a through-passage. With tracking beds set at both ends of a structure, Clevenger and Waltho (2005) recorded a through-passage if tracks moving in the same direction were present on both track beds. Through-passages for smaller animals were recorded across a track bed across the middle of an underpass when the track continued straight through the track bed from one side to the other (Goosem 2003). Taylor and Goldingay (2003) took a similar approach. Ng *et al.* (2004) distinguished three types of passage across their three track beds – one at each entrance and one in the middle of the crossing structure:

1. a verified crossing when tracks were present at both ends and in the middle;
2. a probable crossing when tracks were found at both ends but not in the middle or at one end and the middle and moving in the same direction; and
3. an assessment of the entrance when tracks were found only at one end.

4.2.4 Tracking Animal Movements After Leaving Crossing Structures

Snow tracking at entrances and exits allows the path of animals to be followed before entering and after leaving a crossing structure (Clevenger and Waltho 2003; 2005) and has also been used by La Point *et al.* (2003) and Servheen *et al.* (2003). McDonald and Cassady St Clair (2004) applied a small quantity of fluorescent powder (Radiant fluorescent pigment, Radiant Color Inc., Richmond, CA) to animals trapped near crossing structures. The powder gradually fell off as the animals moved over the ground, permitting fine-scale monitoring of movement paths that were able to be followed the next day with a hand-held ultraviolet light and which lasted for 4-5 days. Burnett (1992) and Byrnes (2004) used cotton spools attached with glue to the fur of rodents and small marsupials so that a trail of cotton was left by the animals when they moved. It was possible then to examine whether animals crossed roads via culverts. Individuals of target species were trapped and fitted with two cotton spools for tracking by super-gluing to the rump of each animal following trimming of the guard hair layer. The two cotton spools were joined, providing a total length of 550m of cotton, and the loose end fixed to a tree or stake near the point of capture. The animal was then released to continue on its daily activities (Byrnes 2003). The following day, the cotton was followed to create a map of home range of the individual after several recaptures. Once empty, the spools fell off the animal after several days.

4.2.5 Presence, Movement Relative to Roads and Population Indices Using Wildlife Sign e.g. Trails, Snowtracks, Scat Collection and Identification

Besides mammal sign being useful to document presence in the vicinity and in the case of trails, movements relative to roads and mitigation measures, tracks and other sign can be used as an index of relative population density and relative movement rates. Indices can be set up related to the number of snow tracks that cross a transect (Clevenger *et al.* 2001;

Singleton and Lehmkuhl 2000) and the density of scats and other sign found in a defined area of concentrated searching (Abson and Lawrence 2003; Brudin 2003; Taylor and Goldingay 2003). Scats collected underneath the centre of arboreal overpasses using nets or a funnel system indicated the range of possum species that used the structures (Weston 2003), although such data cannot be used to identify the number of different individuals crossing.

4.2.6 Observational Censuses of Species e.g. Spotlighting, Active Searches, Bird Observations on Transects, Audio Recordings of Birds and Frogs

Estimates of population densities are very important, at least for target species, when documenting the effectiveness of mitigation measures. Annual and seasonal population fluctuations must be incorporated into the analysis of movements. Point sightings, call-counts and audio recordings are all techniques that can determine presence/absence, relative abundance and distributions of species. Each technique has unique considerations, advantages, disadvantages and biases (Williams *et al.* 1996; Price *et al*. 2005). Reviews concerning monitoring methodology are available with respect to target species such as the gliders (Goldingay and Sharpe 2004). Many reviews consider monitoring that incorporates valid statistics and the monitoring of a variety of species (Price *et al.* 2004; Wintle *et al.* 2004), so this technical area will not be discussed further.

Spotlighting and audio techniques were used by Taylor and Goldingay (2003) to examine mammals and frogs within and near their series of culverts in northern New South Wales. Abson and Lawrence (2003) also used spotlighting, audio recordings for frogs and birds, visual bird observations, Anabat bat detection and active searches for herpetofauna at their Victorian underpass. Puky and Vogel (2003) used a combination of visual, acoustic and spotlighting techniques to obtain population indices for amphibians near amphibian tunnels in Hungary. Weston (2003) also used spotlighting to identify arboreal species near arboreal overpasses in tropical north Queensland rainforest and to watch individuals cross (Weston 2000; Goosem and Weston 2002). Bushnell (2005) combined audio and visual bird surveys to look at birds using corridors planted to provide connectivity up to the entrances of the East Evelyn underpasses in far North Queensland.

4.2.7 Trapping for Species Presence/Absence and Mark-recapture Methods

Mark and recapture methods are commonly used to provide estimates of relative densities of species that can then be used to determine expected crossing rates. As with observational census, a large amount of literature is available critiquing such methodologies**.** Mark-recapture is commonly used in the case of small and medium-sized mammals (Goosem 2001, 2002; Goosem *et al.* 2001; Foresman 2003) as an indicator of relative population abundance and to determine whether movements across roads are occurring. Trapping and recapture may also be used when animal translocations are undertaken to determine whether animals will cross a road to return to their usual home range (Burnett 1992; McDonald and Cassady St Clair 2004). However, without associated tracking methods, photography, or total exclusion fencing, it is impossible to be sure that the crossing route used was via a crossing structure. If photography is included in a monitoring program with trapping, consideration should be given to individual marks that can be identified from a photograph.

Pit, box, harp and cage trapping for small mammals, bats and herpetofauna will also aid in detection of cryptic and nocturnal species not normally detectable by spotlighting and other visual census methods (Abson and Lawrence 2003; Larsson 2003; Taylor and Goldingay 2003). In wet and dry culverts, Dodd *et al.* (2004) used a variety of trapping techniques to sample faunal usage, although usage was unable to be quantified with these methods. Wire screen-mesh funnel traps (Karns 1986) were used to sample amphibians, reptiles and small mammals. Square hardware-cloth funnel traps were placed flush with the sides of the culverts. Floating screen funnel traps were also installed in the centre of culverts and commercial crayfish traps were placed in light boxes located in the right of way. Abson and Lawrence (2003) also used a variety of trapping methods to sample the fauna within the bridge underpass and compare diversity and species present with forest nearby.

4.2.8 Radio-tracking of Animal Movements

Radio-tracking is commonly used to determine whether animals have crossed a road. Comparative data on animal movements is produced in relation to roads, wildlife fencing and crossing structures (Chruszcz *et al.* 2003). However, unless the animal is being monitored visually at the time of crossing, it again is impossible to determine whether the individual has used a crossing structure or crossed over the surface of the road, unless a total exclusion fence completely prohibits this option (Clevenger and Waltho 2005). Depending on the species and battery life, individuals can be followed both pre- and post-construction (Hardy *et al.* 2003). Mech and Barber (2002) provide a critique of wildlife radio-tracking methodology and its effects. Issues that require consideration in the use of radio-telemetry is the high expense in terms of equipment and researcher time, the intrusiveness of the technique in terms of the need to capture the individual and possibly sedate them to attach the radio-tracking device and then the need to follow in the field. However, for species of conservation concern, radio-tracking appears to remain as the best option for determination of movements over time (Mech and Barber 2002).

Calculation of performance indices for crossing structures relies on determination of expected crossing frequencies, in turn reliant on either radio telemetry or trapping location data, relative abundance indices as described above and habitat suitability indices or a combination thereof. The effectiveness of crossing structures for a variety of large mammals has been determined using this combination of techniques (Clevenger and Waltho 2003). In target species studies, Lyren and Crooks (2003) followed usage of wildlife culverts and water culverts by radio-tracking of coyotes and bobcats, which was augmented by remotely triggered cameras in the culverts. To achieve individual recognition, radio-collars should include marks for photographic identification. Alternatively, Tigas *et al.* (2002) applied uniquely coloured ear tags at the same time as radio-transmitter collars were fitted. This allowed individual bobcats and coyotes to be visually monitored when crossing either above or below roads. The telemetry data was used to map home ranges and movements using GIS technology. Cain *et al.* (2003) also combined remote photographic monitoring of crossing structures with radio-telemetry of bobcats. Motion-sensitive radio-collars were used on black bears to examine habitat use near and away from roads and crossing structures (van Manen *et al*. 2001). Similar examinations of grizzly bear movements have also been undertaken using radio-tracking (Chruszcz *et al.* 2003).

4.2.9 Hair Analysis for Species Detection and Individual Determination via DNA Analysis

Hair tubes are quite commonly used to detect cryptic mammals (Taylor and Goldingay 2003; Abson and Lawrence 2003). Hair tube or other hair collection methods (e.g. double-sided tape, barbed wire baited enclosures for large mammals) can be used for the identification of numbers of individuals through DNA analysis using microsatellite markers (van Manen *et al*. 2001). Such data can detect genetic problems at different spatial scales and correlate these with environmental barriers such as roads and also can identify whether mitigation measures are aiding animal movements, dispersal rates and connectivity across a highway barrier. However, these are complex and time-consuming procedures requiring a great deal of development and therefore expense and are unlikely to be employed in the majority of crossing structure monitoring programs except for species of conservation concern. Hairs found attached to droppings (scat) can also be used for identification of animals within the vicinity, a technique which is particularly useful for herbivores (Weston 2003).

4.3 REMOTE MONITORING OF CROSSING STRUCTURES

Remote sensing methods generally supply a large quantity of good quality data but electronic failure can occur. Emphasis should be placed on at least one form of direct monitoring to provide a backup for such eventualities. However, many researchers do rely on remote sensing as their main data source. As mentioned in 4.2.7 and 4.2.8, if animals are to be captured for other reasons, the attachment of tags that can identify an individual in a photograph can greatly increase the usefulness of remotely-collected photographic data.

The literature review identified a variety of remote monitoring techniques:

- environmental data collection using dataloggers – temperature, light, humidity:
- monitoring of traffic levels and speed;
- monitoring of levels of human activity; and
- remotely-triggered camera systems – still or video.

4.3.1 Environmental Data Collection

Environmental data inside and outside crossing structures may be collected in the field using data loggers. Foresman (2003) found that temperature, light and humidity data collected at 30 second intervals 24 hours per day were useful in describing use by small mammals of wet and dry culverts. Weather and other seasonal variables and stochastic events such as fires and floods can affect road kill and road crossing by altering wildlife populations or habitat and should always be incorporated into models of crossing structure effectiveness. Generally, weather data available from the closest Bureau of Meteorology weather station may be sufficient for this purpose, unless very fine scale monitoring is required.

4.3.2 Traffic Levels, Speed and Noise

Traffic levels and speed can influence animal movements and mortality (Goosem 2000; Hardy *et al.* 2003; Chruszcz *et al.* 2003). Generally, as traffic volumes increase, animals tend to avoid road crossing more (Goosem 2000; Clevenger *et al.* 2001; Chruszcz *et al.* 2003). This may be a function of high noise levels, as was the case for five species that avoided crossing via culverts (Clevenger *et al.* 2001), or simply due to disturbance from greater levels of traffic movement, as was the case for coyote. Clevenger *et al.* (2001) found that greater traffic volumes encouraged the use of culverts rather than the road surface for crossings by red squirrel, marten and snowshoe hare. Goosem *et al.* (2004) found that noise levels under bridges and at the entrances to underpasses were extremely high where these had no noise abatement structures.

Therefore monitoring of traffic volume and speed, as well as noise levels is very useful in determining the reasons for effectiveness (or lack thereof) of crossing structures. Traffic volume and speed can easily be monitored using standard traffic monitoring equipment e.g. Metrocount^{TM} counters with pressure-sensitive hose detectors that require only monthly downloads or with more expensive devices built into the road surface. Such data are often already being collected by relevant road authorities. Monitoring of noise levels either requires sophisticated technology that can be left in place together with other environmental data collection devices or requires expensive researcher sampling time replicated to provide data on diurnal and seasonal variability. Noise data should be collected both within crossing structures and outside the entrances to structures as entrance areas usually have the greatest noise levels. High noise levels near structure entrances may result in animals turning away from attempts to cross via the structure. Such monitoring may determine a need for noise abatement devices near crossing structures. Dawe (2005) used a Svantek sound level meter (SLM), Svan model 949 type 1, coupled via a 20 metre 50 ohm co-axial cable to a BSWA TECH Model SV 22 ½” pre-polarized condenser microphone and pre-amplifier fitted with a 90 mm diameter foam windscreen to examine noise levels at the edge of a rainforest highway.

4.3.3 Levels of Human Activity

Levels of human activity near and within crossing structures need to be quantified as the amount of human (and domestic animal) activity can have a large effect on use of crossing structures by wildlife. Human activity includes those on foot (including researchers monitoring the crossing structures) and those on bikes, motorbikes etc. Wildlife will avoid crossing structures which are subject to a great deal of human use (Clevenger and Waltho 2003; 2005). Human use can be monitored directly using tracks in track beds and by using remotely sensed photography. In larger landscapes indices of human activity include proximity to structures and recreational areas (Hardy *et al*. 2003).

4.3.4 Remotely-triggered Camera Systems

Many researchers have used remotely-triggered camera systems to monitor wildlife activity within and adjacent to crossing structures (Table 3). The two main alternatives are still cameras – either film or digital, and video systems.

4.3.4.1 Remote Still Camera Systems

Infrared-triggered cameras have been used to remotely examine wildlife activity for many years, but did not become popular with researchers until commercial systems such as the Trailmaster™ (Goodson and Associates, Inc., Lenexa, Kansas) were developed mainly for the American hunting fraternity. Infrared-triggered camera systems are now widely used in vertebrate ecology and have been applied to the monitoring of underpasses and overpasses such as green bridges for more than 10 years (Foster and Humphrey 1995). In Australia in 1993, culverts under a rainforest highway in North Queensland were monitored by Goosem (2000) using a home-constructed system with a 35mm film camera and infrared beam (Figure 10).

Figure 10. *Rattus leucopus* (Cape York rat) using culvert under Kennedy Highway near Cairns, 1993 (Photo: Miriam Goosem).

The majority of remote camera systems available today have features including weatherproof housing, automatic focus and flash, and the ability to attach to trees or other structures that allow them to work under field conditions (Swann *et al.* 2004). However, as many of them are designed for use along wildlife trails away from normal human interference, rather than in fixed structures like underpasses and overpasses, they often do not have a high level of vandal-proofing and anti-theft devices. Sometimes security devices may be purchased as optional extras from the system manufacturer, but alternatively such items such as the cages and poles used in the East Evelyn underpasses (Goosem 2003) are designed especially for the site and must be factored in to cost (~$325 each). Thirty-five mm film cameras range in price from <$380 to >$760 (Swann *et al.* 2004).

4.3.4.1.1 Trigger Systems for Remote Still Cameras

Although some systems have been purpose-designed to be triggered by pressure plates (York *et al.* 2001; Moruzzi *et al*. 2002), the majority of remote still cameras use one of two sensor types (Swann *et al*. 2004).

Active Infrared Beam Sensors:

The first of these are active infrared photobeam triggers such as found in the TrailMaster^{TM}1500 and 1550 (www.trailmaster.com). Such systems are also found in several digital camera systems including the Faunatech Digicam DC110 (www.faunatech.com). The single beam operates in the near infrared band (800-1,000nm), which is invisible to the human eye, and is sent to a separate infrared receiver. The receiver is set up on the other side of the area where the animal will pass (in the case of underpasses, the transmitter is on one side of the underpass and the receiver on the other). The beam is generally very narrow (about 1 cm for Trailmaster^{TM} systems). When a passing animal interrupts the beam, the receiver sends a signal to the camera to take a photograph. By setting the beam at chest height of the target species, and controlling the length of time the beam must be blocked to trigger a response, only the target species can be monitored. Most beam-type triggers have sensitivity settings such as these to filter out responses to small non-target animals and save battery power and film (or memory in the case of digital cameras) and to reduce multiple photographs of the same animal using a wait function before allowing another photograph to be taken.

Passive Infrared Sensors:

The majority of still camera systems use passive sensors that detect differences between ambient background temperature and the rapid change in heat energy (temperature differential) caused by a moving animal (Swann *et al*. 2004). Passive systems operate in the thermal infrared band (3,000 – 10,000nm). In this case the sensor emits no energy, it simply detects the radiation from warm-bodied targets which must be moving across the detection area to trigger the sensor. A very slow-moving target will generally not be detected. Similarly, if the body temperature of the target is similar to its surroundings like those of cold-blooded reptiles and amphibians, it will remain undetected. A very small target, cold- or warm-blooded, is also hard to detect unless it is very close to the sensor. However, a large animal such as a human or a wallaby will generally still be detected even when ambient temperature is similar to body temperature. Detection occurs because body temperature is almost never uniform across the entire body of a large animal so that the change in temperature as the animal moves can still be recognized by the sensor. Because some background 'noise' is caused by thermal radiation from non-target objects, such as branches and leaves warmed by sunlight and waving in the breeze, passive infrared sensors usually have a preset threshold that prevents false triggers. Passive infrared detectors monitor an area and almost any animal activity in the area will trigger a photograph.

Active Infrared vs Passive Infrared detectors:

1. ***Active infrared*** systems are well suited for almost all fauna. Animal size can be selected as they consist of a narrow, accurate beam. Trailmaster^{TM} boasts that their active infrared monitors are used by researchers to monitor everything from mice to elephants. However, once set for one size of animal, detection of species that are much smaller or larger is unlikely. Faunatech^{TM} can overcome this problem by the inclusion of two pairs of sensors. However, it may be difficult to align a beam close enough to the ground to detect very small species such as skinks and frogs. ***Passive infrared*** monitors cannot differentiate between sizes of animals and will not detect cold-blooded species.
2. For specific areas, such as underpasses, where animals must pass through a particular narrow section of space, ***active infrared monitors*** are useful because it is easy to be specific about sensitivity. For a large, open area such as an overpass or ecoduct where it is uncertain exactly where an animal will be, ***passive infrared sensors*** will detect warm-blooded animals, although the smallest may not be detected when at a distance. However, in such an area, it is likely that there will be many more false triggers with no animal present. ***Passive*** camera systems have wider zones of detection than ***active*** systems, with the size and shape of the zone dependent on the configuration of the sensor and the focusing lens (Swann *et al*. 2004).
3. ***Advantages*** of ***passive infrared sensors*** include their
   - very low power usage;
   - ease of deployment;
   - wide area coverage; and
   - they will not be affected by debris breaking the beam.

   Disadvantages include:
   - their susceptibility to false triggers from environmental conditions or improper set-up;
   - the loss of sensitivity when ambient temperature is similar to the temperature of the target animal (a very likely situation in the sub-tropics and tropics); and
   - detection of slow-moving, very small or cold-blooded animals is very unlikely.
4. ***Advantages*** of ***active infrared beam sensors*** are:
   - the very accurate detection area;
   - their immunity to temperature changes and the ability to detect any animal – large, small or cold-bodied.

   Disadvantages include:
   - much higher power consumption;
   - difficulty in setting up the multi-part system; and
   - the possibility of debris blocking the beam and disabling the system causing false triggers.

Microwave Sensors

Microwave sensors have been occasionally used for wildlife monitoring in the United States but are generally paired with a passive infrared sensor (Ministry for Environment Lands and Parks 1998). Dual-sensor systems operate best in cool temperatures. In normal operations of the Trailmaster design, both the microwave sensor that detects motion and the passive infrared (PIR) sensor that detects changes in ambient temperature are triggered simultaneously and operate the camera (Zielinski and Kucera 1995). If either sensor malfunctions (e.g. the microwave sensor loses its signal, or if ambient temperature approaches the body temperature of a target animal), the other sensor will take priority and will work like a single-sensor system. Both sensors send out a field to approximately 11m. The camera is triggered when an animal enters the field, which can be restricted to several metres wide by obstructing the PIR sensor window. The sensors draw 35mA from the 12-v gel cell, deep-cycle battery used to power the system. This rechargeable battery should last for 20 days between charges. However, Foresman (2004) notes that the dual sensor system of the Trailmaster TM550 comprising the infrared detector responding to heat and the microwave detector responding to motion resulted in photographs of only warm-blooded animals using underpasses, other than one turtle. Therefore it seems that cold-blooded species are unlikely to be detected by such dual sensor systems.

Faunatech Pty Ltd have a single microwave sensor system that can be used with their digital cameras. They state (pers. comm.) that “the microwave sensor has many of the plusses and few of the minuses of other sensors. Firstly it monitors a "volume" (like a Passive InfraRed) yet it is not affected by moving shadows/ heat changes like the PIR is. It uses less power than an active infrared beam. Another difference is that the microwave is better at sensing movement towards it, rather than across the field of view. It uses an electromagnetic bounce and return beam to detect things moving towards it, using the doppler shift principle. As it is not looking at heat changes, it is just as effective at detecting cold-blooded animals as an active infrared beam. It does detect fairly small targets, but being a new product they lack field feedback on size.” The sensor is slightly more expensive than an active infrared beam and needs to be trialed for the ability to detect small and cold-blooded species.

4.3.4.1.2 Digital vs 35mm Film Camera Systems

Although by far the majority of researchers using infrared-triggered still camera systems continue to use 35mm film designs, digital cameras have become more common in recent years. Systems are available from Faunatech in Victoria, and from Reconyx in Wisconsin and Crow Systems also from the US. However, some of the major manufacturers do not supply them. For example, the Trailmaster web site states “We have been evaluating digital cameras since they first appeared on the market but have not yet found one that we feel is acceptable”. They state high power use and the inability to keep powered and ready to take a picture continuously as one reason - even large external batteries are unable to supply the power necessary for more than one day. Secondly, normal flash on digital cameras are often weak. Thirdly, they believe the delay of up to 5 seconds to capture a photo is far too long because for their film cameras 0.75 seconds is often too long. Fourthly, they cite the need for a weatherproof housing for a digital camera as a disadvantage. Nonetheless, other manufacturers have surmounted most of these problems.

Advantages of ***digital still*** cameras include:

- the larger number of images that can be captured;
- less records missed with no film to run out;
- reviewing of images in the field;
- easy reproduction and distribution of images without loss of quality;
- enlargement of images of small animals for identification;
- movie mode is available on some cameras for a short look at animal behaviour;
- lower lifetime operational costs due to no developing; and
- information about the image including time and date is stored in a header attached to the file.

Disadvantages include:

- high power usage;
- delay to capture a photo;
- greater potential for electronic failure; and
- poor flash capabilities.

However all of these problems have been surmounted by various manufacturers of wildlife monitoring equipment.

4.3.4.2 Use of Remote Triggered Still Camera Systems for Monitoring of Crossing Structures

The majority of researchers listed in Table 3 have used relatively simple 35mm film camera systems for their crossing structure monitoring. Trailmaster TM550 passive infrared monitors with the associated camera kits are the most popular system in use in North America, where the majority of this type of research is being undertaken. Eight researchers were recorded as using this system, with 5 using active infrared beam sensors. Other systems used include cheaper passive infrared hunting cameras from Camtrakker (2 researchers), DeerCam (2 researchers) and Buckshot (2 researchers). Mata *et al.* (2003) used a digital system with active infrared beam, as did Goosem (2003). The Faunatech system Goosem (2003) used included a pair of active infrared sensors placed at ground level, and connected to the camera housing via a cable to reduce delays suffered by the alternative radio-signalled trigger from a second pair of sensors that were angled at 45 degrees to record larger animals. The use of passive infrared sensors by many researchers has resulted in satisfactory recording levels for mammals, particularly large ones. The majority of the projects in this review have targeted large mammals such as deer, bear and other carnivores. However, smaller species are not normally detected by such techniques. Active infrared systems do detect smaller species to the size of 20-50g mammals (Foresman 2003; Goosem 2003) and the microwave sensors from Faunatech also should pick up small species, although it is unknown how small the targets would be. Small, cold-blooded species appear to be a problem for all systems, although a home-constructed active infrared beam system was able to detect large huntsman spiders (Goosem 2000). However, that system did not incorporate infrared flash that reduces animal disturbance and therefore avoidance.

Figure 11. Small rodent (deer mouse) in U.S. underpass using passive infrared sensor and Trailmaster 35mm film camera (Photo: Professor Kerry Foresman).

Figure 12. Red-necked pademelon in north Queensland underpass, using Faunatech Digicam 110, and active infrared beam sensors (Photo: Miriam Goosem).

4.3.4.3 Remote Video Camera Systems

Relatively few researchers have used remote video camera systems to monitor crossing structures (Table 3). Video surveillance has an advantage over other techniques aimed at detecting through passage because animal behaviour can be assessed, especially when crossing resistance or failed crossings occur (Hardy *et al.* 2003). Video can also aid in identification and classification (sex, age) of individual animals. In Europe, researchers have used infrared video camera technology to look at the use of land bridges (ecoducts or overpasses) by large mammals, small mammals, and flightless insects such as ground beetles, grasshoppers and ground spiders, along with diurnal butterflies (Bank *et al.* 2002). Swiss researchers have also used infrared video to look at wildlife behaviour on a land bridge and concluded that the alarmed behaviour of roe deer, one of the target species showed that a 23m wide land bridge was too narrow (Bank *et al.* 2002). On wider overpasses, infrared video showed that animals were actually feeding on vegetated land bridges. Verena Keller (pers. comm.) used conventional VHS systems when monitoring overpasses in Switzerland and was very happy with the behaviour attributes able to be monitored.

Examination of wildlife behaviour appears to be the main application of video technology with respect to crossing structure use. Gordon and Anderson (2003) used a video camera system to monitor mule deer movement through an underpass in Wyoming, USA. The system consisted of four infrared lenses that fed images of the underpass to a VHS videocassette recorder. Lenses monitored the entrance, exit and approach areas of the underpass. The camera system was activated by four sets of infrared scopes, two each located on either side of the underpass. LED lights, visible to the infrared lenses but not to deer were installed to improve quality of night-time images. A variety of data were extracted from the video including time entering and exiting the underpass, the type of gait, several alarm responses and those animals that attempted to use the structure but were repelled.

In Arizona, Dodd *et al*. (2005) employed integrated 4-camera video systems to compare wildlife use of two bridged wildlife underpasses and to monitor passage rates and behavioural responses of elk approaching and crossing via the underpasses. The system consisted of 4 low-lux/high resolution black and white video cameras linked to a 12v videocassette recorder with a quad-screen splitter. To illuminate the area covered by the cameras, 60 infrared LED illuminators were installed. Five infrared photobeam triggers were installed to detect approaching and crossing animals. Systems operated on mains power converted to 12v by buried wiring or by a bank of 6v deep cycle batteries. Cameras were mounted on top of a 5m pole in the underpass, with 2 cameras on trees near the underpass approaches and one that could also determine whether traffic was passing as an animal approached. All components were operated continuously so that there was no delay in VCR recording once an animal passed an IR trigger. Data on sex, age, time, time spent in the area, animal behaviour, direction of travel and traffic on the highway were extracted from the video recordings. Advantages of the system included the triggers that avoid hours of empty tape to review later and the mains power inverted to 12v that avoided the requirement for equivalent banks of 6 batteries weighing more than 60kg that lasted only 2-3 weeks. Norris Dodd (pers. comm.) has also used solar power very successfully even in rainy conditions. He states that a reliable power source and good IR lighting is critical. His entire system costs about $10,000US for mains power and for solar power is about $13,000US. This price range means that such systems are only likely to be used for very specialized monitoring tasks.

Tony Clevenger (pers. comm.) has used an analog Trailmaster video system with infrared cameras to look at behaviour and approaches at underpasses, although he says that lighting at night was a problem. Other disadvantages are the cost and the requirements for large amounts of battery power. Kerry Foresman (pers. comm..) has Trailmaster passive infrared video monitors with video cameras, weather housing and light source. They are relatively expensive systems in comparison to still ($3,000US) but work well. However, battery life can be a problem, particularly in cold environments. Foresman is very keen on the ability to record movement and stress behaviours of small mammals in relation to culverts and wildlife bridges which has enabled them to design ledges for culverts that the animals appear to be very comfortable with.

Although not examining crossing structure usage, Kinley *et al*. (2003) used infrared and conventional video camera footage to monitor the behaviour of deer when crossing the surface of a highway through a National Park in Canada. Nancy Newhouse (pers. comm.) states that they “found the cameras to be very valuable in recording animal behaviour”. The computer processing equipment was housed in a trailer and the infrared camera in protective housing on a 6m pole. The system was sensitive enough to see smaller carnivores the size of a cat, and regularly recorded birds. She states that the advantages of video are that it is possible to see behaviour of animals and that there is no concern about missing a detection as can be the case with digital still cameras. The FLIR camera they used could record behaviour over very long distances of over 1km. Disadvantages include the time consuming task of reviewing the tape and the extremely high cost of the total equipment package.

4.4 REMOTE MONITORING SYSTEMS AVAILABLE

Table 4 provides a summary of remote sensing camera systems readily available on the United States and Australian markets.

4.4.1 Application to Compton Road

4.4.1.1 Passive Infrared Still Film Systems

The cheapest remote camera models tend to be 35mm still film cameras with passive infrared sensors that are marketed towards the lucrative American hunting fraternity. The majority of these do not have a research focus. They are fully capable of detecting deer and elk moving along forest trails, but would probably not be a success for smaller animals of the species targeted at Compton Road.

However, as noted above, the Trailmaster passive infrared systems are commonly used by North American researchers to detect large mammals such as deer, bear and carnivores, and are capable of detecting smaller mammals in the more enclosed spaces of culverts (Prof Kerry Foresman pers. comm.). Prof Foresman states that “in smaller culverts animals are often moving quickly and by the time the camera fires after an active sensor beam detection, they are often already out of the field of view, whereas the passive systems detect them as they approach and photos are obtained easily”. This would be certainly be the case if the web site claim of 0.75sec delay for the Trailmaster active sensor remains the case. Newer designs such as those from Faunatech have much faster reaction times. The most useful application of passive infrared still film systems in terms of Compton Road situations could be inside the faunal underpasses and mounted on the land bridge, if the major consideration is cost, rather than features and comprehensive data collection. While film lasted, such a camera could certainly aid in identification of large, medium-sized and hopefully smaller mammals and probably birds on the ground that were unable to be distinguished using track bed data and other wildlife sign. If the camera and sensor were mounted in the roof of the culvert (Figure 13), good coverage over the entire underpass should be possible for warm-blooded animals. The problem of loss of data due to film running out could be overcome by the use of digital models with passive infrared sensors.

Figure 13. Trailmaster camera with passive infrared sensor mounted on roof of culvert (Photo: Professor Kerry Foresman)

4.4.1.2 Active Infrared Still Film Systems

The active infrared sensor systems present greater possibilities in terms of detection of small species. However the sensors tend to be difficult to align very close to the ground – the ground needs to be almost level to achieve a satisfactory outcome. On the ledge within the fauna underpasses at Compton Road this may be possible to achieve, so it may be possible to detect some of the targeted small lizards and frogs, as well as small mammals. At East Evelyn, where of necessity our beams need to be set about 5-10cm above ground level to avoid underpass furniture, we have found that we do not detect the smallest cold-blooded species, although we do regularly detect small rodents. In the Compton Road faunal underpasses with ledges, post and rails and shelves, a beam set at ground level would miss animals using the above ground structures, as well as larger species that walked or hopped over it and failed to break it.

At East Evelyn we have overcome the problems of larger species missing low sensor beams by using the feature of the Faunatech Digicam that allows more than one sensor to be connected. We use 2 beams, one horizontal and one angled at about 45 degrees so that we can detect larger species such as pademelons that may hop over the lower beam. However, the problems of inability to detect small skinks and frogs remain. The likelihood of vandalism means that all equipment must be housed securely, also limiting how close to the ground the beam can be positioned. However, Faunatech sensors are rated as waterproof to several metres, so the potential flooding of culverts and underpasses is not a problem. Both film and digital cameras are available with active beam sensors (Trailmaster or Faunatech/Reconyx). Still film systems do not appear to offer any options to use more than one active beam sensor. However, dual systems are available with Faunatech and Reconyx digital systems, although Reconyx have an external supplier to build active infrared sensors. Dr Frank van Manen (pers. comm.) says that the Trailmaster active sensor system has been successful recording crossings and that he has also used it in Sri Lanka under tropical conditions, although operating success appeared to be fairly dependent on weather.

4.4.1.3 Digital Camera Systems

Although the Trailmaster products are cheap, the advantages of digital cameras are manifold. The ability to store hundreds of images is of prime importance – there is never likely to be loss of data due to lack of storage as there is with 36 photograph film. We have not found the delay to take a photograph to be a problem – the Faunatech Digicam 110 delay is 0.2 seconds with radio-linked wireless sensors. The wired sensors have much less of a delay. Certainly the delay is nowhere near the 0.75-5.0 seconds that the Trailmaster web site quotes. We have achieved satisfactory results at East Evelyn with the radio-linked sensors, with no appreciable increase in photo capture with wired sensors. There is also no indication from track data that we are missing animals.

Figure 14. Faunatech Digicam 110 (similar to newer budget Digicam 120 cameras)

A number of researchers in North America have now turned to digital cameras, particularly mentioning Reconyx as a manufacturer. Dr Tony Clevenger (pers. comm.) was concerned that the flash might be a weak point of the system, although he has no first-hand experience. Prof Kerry Foresman (pers. comm.) has recently switched from Trailmaster passive infrared film systems (approx $500US) to Reconyx Silent Image Professional Edition digital cameras (approx $1,200US) and is very satisfied with the results. The silent photography has resulted in photos of species he has never seen before, he can store up to 5,000 images and the expense of film is eliminated.

Figure 15. Reconyx Silent Image Professional Edition (http://www.reconyx.com/features.php)

4.4.1.4 Microwave Sensors

Although few manufacturers mention microwave sensors, Faunatech have suggested a trial of this type of sensor to determine whether it will detect the movement of the smallest cold-blooded species. It certainly should detect small mammals. The most sensible option for this type of sensor might be to trial it in tandem with a passive infrared sensor within underpasses, as passive infrared sensors have proved successful in culverts for Prof Foresman.

4.4.1.5 Video Monitoring Systems

In view of the high expense associated with these systems, it is difficult to justify their use at Compton Road, unless a species of conservation significance is to be targeted. The majority of systems either are very expensive (e.g. $10-13,000US for the home-constructed large system of Norris Dodd which is less than one third of the price of professional quotes, and even more for the digital trailer system used by Nancy Newhouse to monitor road surface crossings of deer in Canada) or they do not incorporate a trigger facility, resulting in the need for an expensive technical officer to view endless tedious hours of blank video to obtain the information required. In fact, this requirement also applies to some of the expensive systems, although not to Norris Dodd's home design.

However, for obtaining behavioural data, there are few other options. Faunatech attempted to construct a 4 camera system with a quad screen viewer in digital format for a project with cassowaries that I have tried to commence. Eventually they found that the technology was not currently up to the task. This design would have given the capability of fast scroll through images from 4 cameras until a target was observed, and would have been able to save a week's data on a large hard drive. They hope to revive the idea once technology becomes available. Faunatech have ceased production of the non-digital VHS version of their video system.

Trailmaster make a video system that cost Prof Kerry Foresman a much more reasonable $3,000US which he has commenced to use in monitoring underpasses. It uses a passive infrared sensor to turn the video on when a warm-blooded animal enters the sensor area. This eliminates the problem of endless hours of footage to view, although false triggers and battery life can still be a problem. Dr Tony Clevenger has also used this system with success. However, cold-blooded species are missed, and very small mammals may also remain undetected. There is an option for use with an active infrared sensor beam, which may make detection of smaller animals possible.

Rebecca Shoemaker suggested an alternative to video in the form of digital cameras that have 'video' options and take still pictures every second for time periods of 15-60secs. Several of the 'hunting camera' suppliers produce cameras with this option, relying on passive infrared sensors.

Figure 16. Trailmaster TM700v Passive Infrared Video Trail Monitor with remote sensor (Photo: Professor Kerry Foresman).

5.0 OPTIONS FOR COMPTON ROAD CROSSING STRUCTURE MONITORING

The following discussion considers the literature review in terms of the crossing structures now constructed at Compton Road.

5.1 FAUNAL UNDERPASSES WITH LEDGES AND UNDERPASS ‘FURNITURE’

Optimal monitoring of the faunal underpasses would include both direct and remotely sensed options. The following are the options more generally used in Australia, North America and Europe. As the faunal furniture occurs on several levels (Figure 17) the direct and remotely sensed options required are more complex than would otherwise be the case.

Figure 17. Faunal underpasses with faunal furniture installed at Compton Road.

5.1.1 Direct Monitoring Options

5.1.1.1 Sand Tracking

In both faunal underpasses, two or three sand track beds in trays should be installed on ledges. Very fine sand is required, and should be kept damp but not wet for best results. Sand trays should be positioned about 1m inside the culvert entrance at either end and protected from rain. A third tray in the centre of the underpass would be an advantage. Sand should be 2.5-5cm deep. Using a tray may help protect against sand being washed away when culvert is flooded. If trays are used a short ramp of sand should cover the tray edges on either side so that animals do not have a sudden change in height of floor. Track beds should be 2m wide, or 2.5m, should investigation find eastern grey kangaroo in the vicinity of Compton Road (see section 4.2.3).

In both faunal underpasses 2-3 matching strips of sand should also be placed on the floor of the culvert where water flows in the wet season. Again a sand tray would be an advantage, but use must depend on engineering advice regarding requirements to keep drainage section clear. The strips of sand would be similar to those described above and would need to be replaced after each wet period if they had been washed away. These strips would record animal tracks using the base floor of the culvert during dry periods.

Figure 18. Tracks in sand at East Evelyn underpasses.

5.1.1.2 Sooted Plate Tracking or Fine Substrate Tracking

In both faunal underpasses, sooted track plates should be prepared and placed to fit the whole width of the shelves attached to underpass sides. They would match the position of the 2-3 sand track beds. The technique for preparation of these tracking plates is described in section 4.2.3 above. A width of 1m should be sufficient – 0.25m of soot, 0.5m of Con-Tact sticky side up attached to the plate by taping on the back and another 0.25m of soot. Track plates should be prepared at the commencement of monitoring periods (Jones *et al.* 2005) and be removed at the end of the period, unless the amount of use dictates replacement more often.

Alternatively, fine substrate such as gypsum or marble dust could be placed in 0.5m wide trays that stretch the whole width of the ledge.

5.1.1.3 Hair Sample Collection

Two to three hair funnel traps modified to allow through passage should be attached to the post and rail fence structures within the faunal underpasses in similar locations to the sand and sooted plate tracking stations. Hair funnel traps are available from a number of sources including Faunatech. Should these prove too difficult to modify to allow through passage, a simple circular wire construction with a double-sided tape curtain could be attached above the rails, similar to that used by Weston (2003). The circle would need to be large enough to allow a koala through passage, but the double-sided tape curtain would need to cover sizes down to rodent size. Hair samples would be collected at commencement of monitoring period and removed at its completion with hair samples sent to an expert such as Barbara Triggs for analysis to species. If using home-made curtains, care must be taken not to contaminate the samples with human or domestic animal hair present in vehicles etc.

5.1.2 Remote Sensing Monitoring Options

To achieve optimal remotely sensed monitoring of the faunal underpasses, a dual sensor monitoring system is required. This is because there are three or four levels at which animals might be moving (Figure 18), the wet section of the culvert, the ledge section, the rails on top of posts and the shelf. Therefore to detect mammals moving through the underpass at all levels, a passive infrared sensor system is required. It will not be possible to detect cold-blooded animals moving at all levels with active infrared sensor beams, but a beam sensor (active infrared) can be used in a dual system to trigger when animals move at one level. The most appropriate level for a beam sensor appears to be either on top of the ledge or on the ground (wet) level when there is no flow. It should be reasonably easy to align a sensor beam at ledge level in the field. Aligning a sensor at ground level is more difficult. It may be possible to align beam sensors attached to a piece of wood or metal the width of the wet section of the underpass and similar to those used by myself in culverts under the Kuranda Range Road (Figure 10). This would ensure that the beam did not get out of alignment when being installed in the underpass, as they become very difficult to align very close to the ground in the field. However, should a microwave sensor prove to be sensitive enough to detect small cold-blooded species moving, it would be more appropriate, as it monitors a volume similar to a passive infrared sensor, rather than needing to align a beam. Microwave sensors from Faunatech need to be trialed urgently to determine their sensitivity.

5.1.2.1 Faunatech Digital Cameras with Dual Sensors

A Faunatech monitoring system would include a Digicam 120 with passive infrared sensor and either an active infrared sensor beam mounted as low above ledge level as possible or a microwave motion sensor. The camera would be suspended from the ceiling of the underpass and placed within a security cage similar to the one constructed by Ingal for East Evelyn cameras (Figure 14). It would be preferable to install two systems, one at either end of the underpass about 2m in from the entrances. However, an alternative option would be to include only one camera and rely on the tracking beds with centre-mounted camera to determine through passage. A quote from Faunatech is shown in Appendix 2.

Costs for a one camera system with dual sensors (passive infrared monitor and active infrared sensor beam) is	$2,430	for 2 underpasses	$4,720
Costs for a two camera system dual sensor system with passive IR and active IR beam is	$4,720	for 2 underpasses	$9,300
Costs for a one camera system with dual sensors (passive IR and microwave motion detector) is	$2,540	for 2 underpasses	$4,950
Costs for a two camera system with dual sensor (passive IR and microwave) is	$4,950	for 2 underpasses	$9,760
Cages cost approximately per system	$320	for 2 systems	$ 640
		for 4 systems	$1,280

Advantages:

- Supplier in Australia
- Easy access to repairs
- Reasonable cost
- Supplier always helpful in making adjustments to suit a situation
- Digital cameras with large photo memory capability, ease of download and export
- Sensors are waterproof to several metres, so should not need removal in culvert floods.

Disadvantages:

- Supplier not known for prompt delivery
- Need to remove from underpass if downpours are expected to completely flood the culvert.

5.1.2.2 Reconyx Digital Cameras with Dual Sensors

Reconyx Silent Image Professional cameras with dual sensors would be mounted similarly and would also require security cages.

Cost for a one camera dual sensor system (passive IR and active IR beam)			
is	$2,000US or $2,600A	for 2 underpasses	$5,000A
Cost for a two camera dual sensor system (passive IR and active IR beam)			
is	$4,600A	for 2 underpasses	$9,800A
Cages cost approximately per system	$320	for 2 systems	$ 640
		for 4 systems	$1,280

Advantages:

- May expect reasonable delivery times
- Digital cameras with large photo memory capability, ease of download and export

Disadvantages:

- Limited access to repairs
- Active IR sensor beam made by external supplier so may be delay there.
- Need to remove from underpass if downpours are expected to completely flood the culvert.
- No potential for microwave ‘volume’ sensor
- Unsure of waterproof capability of sensors

5.1.2.3 Trailmaster 35mm Film Camera Systems

Trailmaster TM1550 active infrared sensor monitor + camera, paired with Trailmaster TM550 passive infrared monitor + camera would be mounted from the ceiling of the underpass with a new design of security cage to fit the camera in question.

Cost for an active IR sensor beam system is	$760US or $960A		
Cost for a passive IR sensor system is	$470US or $600A		
Cost for accessories (data collector, software)	$400US or $510A		
Cost for a two camera system (one with passive IR sensor, and one with active IR sensor beam) for placement in centre of underpass is	$2,070A	for 2 underpasses	$3,630
Cost for a four camera system (two with passive IR sensors, and two with active IR sensor beams) for placement at either entrance is	$3,630	for 2 underpasses	$6,740
Cost for cage (approx) per system	$ 640	for 2 systems	$1,280
		For 4 systems	$2,480

Advantages:

- Less expensive

Disadvantages:

- Possibly not as reliable in high humidity tropical situations
- Film may run out
- Need to attend the cameras daily to ensure film hasn't run out
- Not able to use dual sensors, so therefore require 4 cameras instead of 2
- Unsure of waterproof capability of active IR sensors
- Limited access to repairs from overseas supplier
- More difficult to provide secure cages
- Need to remove from underpass if downpour completely floods culvert
- No potential for microwave 'volume' sensor.

5.2 LAND BRIDGE

For land bridges, both direct and remotely sensed monitoring options are required to achieve coverage at all times. Because tracking systems are open to the weather, tracks can become obliterated during rain, so that backup remote sensing is required to maintain coverage for large and medium-sized mammals (Dr Tony Clevenger, pers. comm.). The remotely sensed options will not always be effective, however, particularly due to seasonal angles of the sun when passive infrared sensor cameras may be set off by the sun's rays entering directly into the system. Thus both options are required.

5.2.1 Direct Monitoring Options

5.2.1.1 Sand Tracking

Flush with the surface of the land bridge soil cover, two or three sand track beds in trays should be installed to cover the whole width of the overpass. Requirements for sand are similar to those described for underpasses. The use of trays is again recommended to prevent contamination of sand by soil and growth of vegetation. Protection from rain would be preferable, but, provided remote sensing options are also included for monitoring of the land bridge, rain protection is not vital, as the remote sensing equipment can cover times when rain obliterates tracks in the sand. A third tray in the centre of the land bridge is again considered an advantage, to demonstrate that tracks complete a crossing. Sand should be 2.5-5cm deep. Track beds should be 2m wide, or 2.5m, should investigation find eastern grey kangaroo in the vicinity of Compton Road (see section 4.2.3).

5.2.1.2 Fine Substrate Tracking

Sooted track plates are not practical for areas unprotected from rain. However, fine substrate such as gypsum or marble dust could be included in a tracking protocol to increase detectability of small species. In such a case a low drift fence similar to that used at the base of the exclusion fencing could be erected during intensive monitoring periods to guide small species toward the centre of the land bridge where a sub-tray containing gypsum would be placed within the sand tray covering either the whole width of the sand, or at least a 0.5m wide section of it. Stakes for drift fence erection could be left in place at all times.

5.2.1.3 Trapping, Observations and Hair Sample Collection

In the future, once vegetation has become established, small mammal trapping on the land bridge itself may become a viable option. Species captured could be spool and line-tracked or fluorescent powder-tracked to determine their destination upon leaving the land bridge.

However, before vegetation has established trapping is not recommended, due to problems with lack of cover to prevent overheating of animals in traps and release of animals in areas where there is no cover from aerial predators.

Similarly to detect rare or shy species, once vegetation has become established, it should be possible to include baited hair funnel traps to obtain hair samples identifiable by experts.

A series of covered pit traps should also be established on the land bridge to detect small species. Drift fence stakes could remain *in situ* for easy attachment of plastic or shadecloth drift fences prior to opening of pits during intensive monitoring periods (possibly for a week every 3 months, or more often if possible).

Periodical visual and audio census of birds and frogs is also recommended, together with active searches, searches for sign e.g. scats and spotlighting, once vegetation has established on the land bridge.

5.2.2 Remote Sensing Monitoring Options

To achieve optimal remotely sensed monitoring of the land bridge, two alternatives are available. One would use two still camera systems mounted at either entrance/exit of the land bridge, each incorporating dual sensor monitoring. One passive infrared sensor would be used to capture any large and medium-sized mammals. The second sensor would be similar to those used in the underpasses – either a microwave ‘volume’ sensor (dependent on success in the underpasses) or an active infrared beam. Dr Tony Clevenger uses two active infrared beam systems in monitoring 45m wide Canadian overpasses. A ‘volume’ sensor is likely to be more efficient than a beam unless ground level is kept extremely flat. Photographs do not indicate that the ground level on the final construction of the land bridge is flat, so the microwave sensor is likely to be the best alternative. As the usable width of the overpass at Compton Road is limited to approximately 10m, one system at either end should be sufficient, provided either that the infrared lighting used can fully illuminate this distance, or that the infrared flash has that coverage. Camera systems should be mounted to incorporate the tracking beds within the field of view, as these will be open areas without vegetation that might obstruct the field of view and prevent identification of animals from photos.

The second alternative is to incorporate two video camera systems. However, due to unavailability within Australia, video coverage is currently recommended to be limited to examination of animal behaviour at entrances to all terrestrial crossing structures, after a suitable period of habituation to the structures (I would suggest at least 6 months, and probably 12 months or more).

5.2.2.1 Faunatech Digital Cameras with Dual Sensors

A Faunatech monitoring system would include a Digicam 120 with passive infrared sensor and either an active infrared sensor beam mounted as low above ground level as possible or a microwave motion sensor. The camera would be mounted on a metal pole and placed within a security cage similar to the one constructed by Ingal for East Evelyn cameras (Figure 19). It would be preferable to install two systems, one at either end of the land bridge about 2m in from the entrances. However, an alternative option would be to include only one camera that has a field-of-view incorporating a tracking bed in the centre of the land bridge and then to rely on the tracking beds together with the centre-mounted camera to determine through passage.

Figure 19. Faunatech Digicam 110 mounted in Ingal cage on pole in East Evelyn underpass.

Costs for a one camera system with dual sensors (passive infrared monitor and active infrared sensor beam) is	$2,430
Costs for a two camera system dual sensor system with passive IR and active IR beam is	$4,720
Costs for a one camera system with dual sensors (passive IR and microwave motion detector) is	$2,540
Costs for a two camera system with dual sensor (passive IR and microwave) is	$4,950
Cages cost approximately per system	$ 320
for 2 systems	$ 640

Advantages:

- Supplier in Australia
- Easy access to repairs
- Reasonable cost
- Supplier always helpful in making adjustments to suit a situation
- Digital cameras with large photo memory capability, ease of download and export
- Sensors are waterproof to several metres, so should not need removal in culvert floods.

Disadvantages:

- Supplier not known for prompt delivery

5.2.2.2 Reconyx Digital Cameras with Dual Sensors

Reconyx Silent Image Professional cameras with dual sensors would be mounted similarly and would also require a pole and security cages.

Cost for a one camera dual sensor system (passive IR and active IR beam) is	$2,000US	or	$2,600A
Cost for a two camera dual sensor system (passive IR and active IR beam) is			$4,600A
Cages cost approximately per system			$ 320
for 2 systems			$ 640

Advantages:

- May expect reasonable delivery times
- Digital cameras with large photo memory capability, ease of download and export

Disadvantages:

- Limited access to repairs
- Active IR sensor beam made by external supplier so may be delay there.
- No potential for microwave sensor beam
- Unsure of waterproof capability of sensors

5.2.2.3 Trailmaster 35mm Film Still Camera Systems

Trailmaster TM1550 active infrared sensor monitor + camera, paired with Trailmaster TM550 passive infrared monitor + camera would be mounted from the ceiling of the underpass with a new design of security cage to fit the camera in question.

Cost for an active IR sensor beam system is	$760US	or	$960A
Cost for a passive IR sensor system is	$470US	or	$600A
Cost for accessories (data collector, software)	$400US	or	$510A
Cost for a two camera system (one with passive IR sensor, and one with active IR sensor beam) for placement in centre of land bridge is			$2,070A
Cost for a four camera system (two with passive IR sensors, and two with active IR sensor beams) is for placement at either entrance is			$3,630
Cost for cage (approx) per system			$ 640
for 2 systems			$1,280

Advantages:

- Less expensive

Disadvantages:

- Possibly not as reliable in high humidity tropical situations
- Film may run out
- Need to attend the cameras daily to ensure film hasn’t run out
- Not able to use dual sensors, so therefore require 4 cameras instead of 2

- Unsure of waterproof capability of active IR sensors
- Limited access to repairs from overseas supplier
- More difficult to provide secure cages
- No potential for microwave 'volume' sensor

5.3 ARBOREAL OVERPASSES (ROPE LADDERS)

For rope ladders, both direct and remotely sensed monitoring options will be necessary. Direct monitoring is required to determine which species are in habitat in the vicinity as well as to examine which use the rope ladders. Remote sensing should be able to monitor continuously over long periods of time but may not always be successful due to sun angles triggering the cameras similarly to the problem expected for the land bridge.

5.3.1 Direct Monitoring Options

5.3.1.1 Scat Collection

Scat collection from below the rope bridge provides good data on use. However, the height of the Compton Road rope bridges makes this type of monitoring very difficult. By installing 2 slings of shade cloth below the rope ladder it may be possible to collect and analyse scat. Each sling would need to be suspended taut on a downward slope from the centre of the road towards the road verge that would allow scat to run down the sling to a collector bottle situated above the road verge. However, given the height of the rope ladders, it would be very difficult to access the shade cloth sling to collect the scat, other than with a cherry picker. Extension ladders may be an alternative although safety of the monitoring team must be the first priority. Weston (2003) also used a sampling system where funnels with collecting bottles at the base were suspended every few metres below the rope ladder, but such an option is too dangerous for the Compton Road bridges.

5.3.1.2 Hair Sample Collection

Weston (2003) also created a circle of wire from which was draped a 'curtain' of double-sided tape. This he wired above the rope ladder. Again this appears to be a difficult option for monitoring given the height of the rope bridges and the need to change the curtain of tape regularly so that samples can be analysed. However, such a system could be trialed on the sections of rope leading from the trees to the bridge, as the trees provide greater stability. I would certainly recommend that the ropes attached to the trees from the poles for the rope bridges be made into rope bridges rather than single ropes. These ropes rather than rope ladder connecting trees to the main bridge are a weak link in the current system (Figure 20).

Figure 20. Rope bridge as currently constructed at Compton Road (Photo: Pauline Fitzgibbon). It is strongly recommended that the 4 ropes connecting the trees with the pole on which the rope bridge is mounted at either end of the bridge be converted to lengths of rope bridge as the bridge structure should be actually touching the trees to encourage animals to use it.

5.3.1.3 Spotlighting

Of all the direct monitoring options available for the rope bridges, direct spotlighting appears the most feasible. After the first few months, several hours a month should be spent spotlighting the rope bridges to examine whether any use is occurring. If unsuccessful, this monitoring should be increased after 6 months and if still unsuccessful, increased again after 9 months, as the 6-9 month period of time is the habituation time observed for use of a 15m rope ladder by shy rainforest species (Weston 2003). Less shy open forest species may be expected to use the crossings more quickly, however, the longer overall distance that is required to be crossed in the case of Compton Road is likely to mean an increased length of time for habituation.

5.3.2 Remote Sensing Monitoring Options

To achieve optimal remotely sensed monitoring of the arboreal rope bridges, two options are possible. The first would use still camera systems mounted at entrance/exit of the rope bridge, incorporating passive infrared sensor monitoring. The second alternative is to incorporate video monitoring from ground level together with infrared illumination at rope bridge level. I would recommend that the remote sensing options be mounted 6 months after completion of construction, as prior to a reasonable habituation period, it is unlikely that there will be much use of the rope bridges.

5.3.2.1 Faunatech Digital Cameras Designed for Rope Bridges

A Faunatech monitoring system would include a Digicam 120 with passive infrared sensor. The camera would be mounted on top of the rope bridge adjacent to the telegraph pole to which the rope bridge is attached. Faunatech has recently designed a system for a rope tunnel erected in NSW (Figure 21) that is currently under trial. It consists of a frame (Figure 22) that allows an active infrared beam to wrap around the tunnel so that both the internal base and the top of the tunnel is monitored concurrently. As the Compton Road structure is only a bridge rather than a tunnel, there is only one surface required to be monitored and this complexity is unnecessary. However, there are two very useful features of the system in the Compton Road context. The first is the provision of a solar panel (Figure 23) to power the device that can be mounted on top of the pole above the camera. The second is that although the camera is mounted on the top of the pole to take photographs of anything using the bridge, a cable follows down the pole to a secure metal box (Figure 24) in which all the computer equipment that controls the camera and sensor is mounted and from which the data can be downloaded. If this box is attached to the pole 3 metres or more above the ground, it will only be accessible by ladder for downloading, maintaining a reasonable degree of security from vandalism and theft. Faunatech are always comfortable with altering systems to suit the situation so the frame complexity can be removed to reduce costs.

Figure 21. Rope tunnel erected in New South Wales.

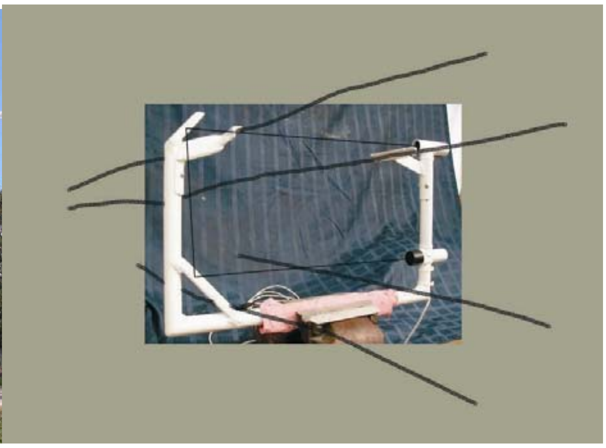


Figure 22. Frame – rope tunnel monitoring system.

Figure 23. Faunatech solar panel.

Figure 24. Faunatech control security box.

A quote for the rope bridge monitoring system can be found in Appendix 3. However, it should be remembered that the rope bridge system that this quote is based upon and which the costings below are based on, is more complex than is required for the Compton Road rope ladder system.

Costs for a one camera system with active infrared sensor beam and solar panel is	$3,225
Costs for a two camera system for one rope bridge	$6,450
Costs for a one camera system for 3 rope bridges is	$9,675
Costs for a two camera system for 3 rope bridges	$19,350

Advantages:

- Supplier in Australia
- Easy access to repairs
- Supplier always helpful in making adjustments to suit a situation
- Digital cameras with large photo memory capability, ease of download and export
- No need to climb high extension ladders for downloading
- Solar powered

Disadvantages:

- Supplier not known for prompt delivery

5.3.2.2 Trailmaster 35mm Film Still Camera Systems

Trailmaster TM550 passive infrared sensor monitor + camera mounted on the rope bridge adjacent to the telegraph pole to which the rope bridge is attached. This would require cherrypicker or extension ladder access very often (preferably weekly) for replacement of film and batteries so is certainly not recommended unless cost of installation is the main consideration rather than ease of operation and cost of maintenance.

Cost for a passive IR sensor system is	$470US	or	$600A
Cost for accessories (data collector, software)	$400US	or	$510A
Cost for a one camera system for placement at one end of rope bridge is	$1,110		
Cost for a two camera system for placement at either entrance of structure is			$1,710
Cost for a one camera system for three rope bridges is			$2,310
Cost for a two camera system for three rope bridges is			$4,110

Advantages:

- Less expensive
- As the monitoring personnel would be climbing rope bridges to replace film and batteries regularly, probably weekly, it may be possible to shift two systems and reinstall in the second and third rope bridges, thus requiring only 2 systems

Disadvantages:

- Possibly not as reliable in high humidity tropical situations
- Film may run out
- Need to attend the cameras regularly to ensure film hasn’t run out
- Unsure of waterproof capability of active IR sensors
- Limited access to repairs from overseas supplier

- Dangerous enterprise of climbing to access camera system for monitoring personnel or requirement for expensive cherry picker

5.3.2.3 Trailmaster Video Camera Systems

Trailmaster TM700v with passive infrared sensor monitor aimed at the rope bridge from ground level (or preferably mounted for security on pole several metres above the ground). A time-saving alternative is to have an active infrared remote sensor (TM700v – RT) mounted on the rope bridge which triggers the video to start recording. However this would require access to the bridge reasonably often for battery replacement.

Cost for a passive IR sensor system is	$3,000US	or	$4,000A	
Cost for accessories (data collector, software)	$400US	or	$510A	
Cost for accessories (active IR sensor beam)	$260US	or	$330A	
Cost for a one camera system for placement at one end of rope bridge is				$ 4,840
Cost for a two camera system for placement at either entrance of structure is				$ 9,170
Cost for a one camera system for three rope bridges is				$13,500
Cost for a two camera system for three rope bridges is				$26,490

Advantages:

- Can record behaviour of possums approaching rope bridge
- No need to climb up to rope bridge, unless using active IR sensor to commence recording
- If using active IR sensor to commence recording, monitoring personnel would be climbing rope bridges to replace tape and batteries regularly, probably weekly, so it may be possible to shift two systems and reinstall for the second and third rope bridges, thus requiring only 2 systems

Disadvantages:

- Possibly not as reliable in high humidity tropical situations
- If not using active IR sensor beam triggering, monitoring personnel have a large amount of empty video to look through and VHS cassettes must be replaced daily
- If using active IR sensor beam triggering, monitoring personnel have dangerous climb to replace batteries etc or require the expensive services of cherry picker
- Unsure of waterproof capability of active IR sensors
- Limited access to repairs from overseas supplier

5.4 GLIDER POLES

For glider poles on the land bridge, direct monitoring methods are recommended. Remote sensing methods may be feasible if concentrated on one or two poles, preferably two near either end of the land bridge but monitoring of 8 separate poles appears overly expensive and monitoring of only two may fail to capture proof of potential glider movements.

5.4.1 Direct Monitoring Options

5.4.1.1 Scat Collection

Checking for scat caught in or near the circular guard around each pole is recommended. A wire circle larger than the circular guard covered with shade cloth and fitted around the pole above the circular guard is recommended to be attached and checked using ladders during intensive monitoring periods.

5.4.1.2 Hair Sample Collection

Double sided tape should be wrapped around the perpendicular arms of the glider poles during intensive monitoring periods. Hair samples collected should be treated as described in Section 4.2.9.

5.4.1.3 Spotlighting

Of all the direct monitoring options available for the glider poles, direct spotlighting appears the most likely to achieve the desired results. The acknowledged experts in glider behaviour are engaged to undertake this monitoring and their advice with regards to best options should be accepted. I suggest that spotlighting test use after the first few months and repeat as the experts advise until habituation is (or is not) established.

5.4.2 Remote Sensing Monitoring Options

To achieve optimal remotely sensed monitoring of the glider poles could be difficult. A passive infrared sensor system could concentrate on activity at selected poles, rather than attempting to monitor all poles. A suggestion might be two camera systems concentrating on the second pole from each entrance to the land bridge. However, the expert monitoring data should be used as the guide to position remote systems. There is always the possibility that monitoring only a selection of poles may miss any action, however monitoring of 8 poles would be expensive particularly when the possibility of failure is considered. An alternative would be to install security cages for monitoring equipment adjacent or attached to all poles and cycle the equipment between them. It is recommended that the remote sensing options be trialed 6 months, 9 months and 12 months after completion of construction, as prior to a reasonable habituation period, it is unlikely that there will be much use of the poles. Remote sensing should not be rejected if unsuccessful in the first 12 months, unless there is direct monitoring proof that the poles are being used, and the remote sensing option fails to record any use.

5.4.2.1 Faunatech Digital Cameras

A Faunatech monitoring system would include a Digicam 120 with passive infrared sensor. It may be possible to mount the camera in a security cage on a third arm bolted to the telegraph pole at right angles and below the other two arms with the camera’s field-of-view incorporating the main two arms. Alternatively a 3 metre high metal pole with security cage for the camera that was bolted to the floor of the land bridge 1-2 metres from the glider pole with the camera aimed towards the centre of the structure should provide a similar field of view. The system could incorporate a solar panel or battery power. Battery power is probably preferable so that the solar panel did not form an alternative landing point for gliders, detracting from results.

Costs for a one camera system with passive infrared sensor beam is		$1,925
Costs for a two camera system for 2 glider poles is		$3,770
Cages cost approximately per system		$ 320
	for 2 systems	$ 640
	for 8 cages	$2,560

Advantages:

- Supplier in Australia
- Easy access to repairs
- Supplier always helpful in making adjustments to suit a situation
- Digital cameras with large photo memory capability, ease of download and export
- If 8 cages are installed 2 camera systems can be cycled between all poles

Disadvantages:

- Supplier not known for prompt delivery

5.4.2.2 Reconyx Digital Cameras

Reconyx Silent Image Professional cameras with passive infrared sensors would be mounted similarly to 5.4.2.1.

Costs for a one camera system with passive infrared sensor beam is		$2,190
Costs for a two camera system for 2 glider poles is		$4,270
Cages cost approximately per system		$ 320
	for 2 systems	$ 640
	for 8 cages	$2,560

Advantages:

- May expect reasonable delivery times
- Digital cameras with large photo memory capability, ease of download and export

Disadvantages:

- Limited access to repairs
- Unsure of waterproof capability of sensors

5.4.2.3 Trailmaster 35mm Film Still Camera Systems

Trailmaster TM550 passive infrared sensor monitor + camera mounted on a third upright perpendicular to the other glider pole arms, or in a security cage on a 3 metre metal pole bolted to the land bridge 2-3 metres from the pole (see Section 5.4.2.1).

Cost for a passive IR sensor system is	$470US	or	$600A	
Cost for accessories (data collector, software)	$400US	or	$510A	
Cost for a one camera system for monitoring of only one pole at a time is				$1,110
Cost for a two camera system for monitoring of 2 poles, one pole at either entrance of land bridge is				$1,710
Cages cost approximately per system				$320
	for 2 systems			$640
	for 8 cages			$2,560

Advantages:

- Less expensive
- Cycling around a series of security cages associated with each pole would be relatively simple using ladders to access

Disadvantages:

- Possibly not as reliable in high humidity tropical situations
- Film may run out
- Need to attend the cameras regularly to ensure film hasn’t run out
- Unsure of waterproof capability of active IR sensors
- Limited access to repairs from overseas supplier

5.5 WET CULVERTS

Unfortunately there are few easily achievable monitoring methods for use of wet culverts by cold-blooded vertebrates such as amphibians and fish. Direct monitoring methods are recommended as far as possible. Remote sensing methods should be trialed using equipment purchased for other crossing structures, in particular the Faunatech microwave motion sensor cameras. It is unknown firstly, how successful these may be in detecting small cold-blooded species and secondly in detecting such vertebrates in the presence of moving water.

5.5.1 Direct Monitoring Options

5.5.1.1 Active Searches and Spotlighting for Amphibians and Reptiles

Generalised searches and spotlighting in and around culvert entrances for amphibians, reptiles and fish are recommended as having the most potential for establishing whether animals are entering wet culverts. However establishment of movement through the passage is very difficult. Visual observation of movements may be the safest and easiest way of determining passage. Some form of marking or tagging of larger fish may be possible to determine movement. At present there are few ethical forms of marking for amphibians that will allow examination of movements. Non-toxic fluorescent dyes may be considered, provided these fade quickly (within a night) or are outside normal predator visual wavelengths and have no adverse effects on sensitive skin. Toe removal, although a procedure used for many years, is not an ethical marking procedure, resulting in reduced survivorship (McCarthy and Parris 2004). Certain pigmented latex derivatives have been suggested for injection under the skin near the limbs, but this procedure is extremely intrusive, and only could be considered for common larger species.

5.5.1.2 Trapping and Netting

In wet and dry culverts, Dodd *et al.* (2004) used a variety of trapping techniques to sample faunal usage, although usage was unable to be quantified with these methods. Wire screen-mesh funnel traps (Karns 1986) were used to sample amphibians, reptiles and small mammals. Square hardware-cloth funnel traps were placed flush with the sides of the culverts. Floating screen funnel traps were also installed in the centre of culverts and commercial crayfish traps were also used. Seine netting across the culvert may allow fish capture but should not be used should sensitive amphibians be present.

5.5.2 Remote Sensing Monitoring Options

There are few options for remote sensing of the wet culverts. Microwave motion sensors should be trialed when purchased with equipment for the monitoring of other structures. Video monitoring of both entrances to the wet culvert may possibly establish passage but could be an expensive procedure with low likelihood of success. Again this could be trialed if video equipment is purchased for other structures.

6.0 RECOMMENDATIONS FOR COMPTON ROAD CROSSING STRUCTURE MONITORING

6.1 FAUNAL UNDERPASSES WITH LEDGES AND UNDERPASS 'FURNITURE'

6.1.1 Direct Monitoring Recommendations

Direct monitoring of the faunal underpasses should include all three systems described in Section 5.1.

1) Sand tracking on ledge level year round and on ground (wet) level when dry;
2) Sooted plate tracking on shelf; and
3) Hair analysis data collection from rails of post and rail construction.

6.1.2 Remotely Sensed Monitoring Recommendations

For remote sensing of the faunal underpasses, it would be preferable to install camera monitoring equipment at both entrances to the underpasses. If cost precludes this option, mounting of remote monitoring equipment in the centre of the underpass is recommended. I recommend systems described in Section 5.2 in the following order of preference:

1) Faunatech Digicam 120 with dual sensor modification for passive infrared and microwave sensors mounted in security cage
   4 systems **$11,040**
2) Faunatech Digicam 120 with dual sensor modification for passive infrared and active infrared beam sensors mounted in security cage
   4 systems **$10,580**
3) Reconyx Silent Image Professional Edition with dual sensor system (passive IR and active IR beam) mounted in security cage
   4 systems **$11,080**
4) Trailmaster TM1550-16k active infrared beam monitor + TM35-1 camera kit together with Trailmaster TM550 passive infrared monitor + TM35-1 camera kit + accessories mounted in security cages
   4 systems comprising 2 cameras and 2 sensors and 2 cages each **$ 9,220**
5) Faunatech Digicam 120 with dual sensor modification for passive infrared and microwave sensors mounted in security cage
   2 systems **$ 5,590**
6) Faunatech Digicam 120 with dual sensor modification for passive infrared and active infrared beam sensors mounted in security cage
   2 systems **$ 5,360**
7) Reconyx Silent Image Professional Edition with dual sensor system (passive IR and active IR beam) mounted in security cage **$ 5,640**
8) Trailmaster TM1550-16k active infrared beam monitor + TM35-1 camera kit together with Trailmaster TM550 passive infrared monitor + TM35-1 camera kit + accessories mounted in security cages
   2 systems comprising 2 cameras and 2 sensors and 2 cages each **$ 4,910**

6.2 LAND BRIDGE

6.2.1 Direct Monitoring Recommendations

Direct monitoring of the faunal underpasses should include all four systems described in Section 5.2.

1) Sand on ground level year round when dry in 2 or 3 track beds;
2) Fine substrate tracking during intensive monitoring periods;
3) Hair analysis data collection during intensive monitoring periods; and
4) Small mammal and pit trapping, observational audio and visual bird and frog census, spotlighting, active searches during intensive monitoring periods.

6.2.2 Remotely Sensed Monitoring Recommendations

For remote sensing of the land bridge, it would be preferable to install camera monitoring equipment at both entrances to the bridge. If cost precludes this option, mounting of remote monitoring equipment in the centre of the land bridge is recommended. I recommend systems described in Section 5.2 in the following order of preference:

1) Faunatech Digicam 120 with dual sensor modification for passive infrared and microwave sensors mounted on pole in security cage
   2 systems **$5,590**
2) Faunatech Digicam 120 with dual sensor modification for passive infrared and active infrared beam sensors mounted in security cage
   2 systems **$5,360**
3) Reconyx Silent Image Professional Edition with dual sensor system (passive IR and active IR beam) mounted in security cage
   2 systems **$5,240**
4) Trailmaster TM1550-16k active infrared beam monitor + TM35-1 camera kit together with Trailmaster TM550 passive infrared monitor + TM35-1 camera kit + accessories mounted in security cages
   2 systems comprising 2 cameras and 2 sensors and 2 cages each **$4,910**
5) Faunatech Digicam 120 with dual sensor modification for passive infrared and microwave sensors mounted in security cage
   1 system **$2,860**
6) Faunatech Digicam 120 with dual sensor modification for passive infrared and active infrared beam sensors mounted in security cage
   1 system **$2,750**
7) Reconyx Silent Image Professional Edition with dual sensor system (passive IR and active IR beam) mounted in security cage
   1 system **$2,920**
8) Trailmaster TM1550-16k active infrared beam monitor + TM35-1 camera kit together with Trailmaster TM550 passive infrared monitor + TM35-1 camera kit + accessories mounted in security cages
   2 systems comprising 2 cameras and 2 sensors and 2 cages each **$ 2,710**

6.3 ARBOREAL ROPE BRIDGES

6.3.1 Direct Monitoring Recommendations

Direct monitoring of the faunal underpasses should include all three systems described in Section 5.3.

1) Spotlighting of arboreal overpass and surrounding forest edge and transects perpendicular to the road, increasing frequency with time elapsed for habituation;
2) Scat collection and analysis using shadecloth slings, if possible: and
3) Hair analysis data collection during intensive monitoring periods if possible.

6.3.2 Remotely Sensed Monitoring Recommendations

For remote sensing of the rope bridges, it would be preferable to install camera monitoring equipment at both entrances to each bridge. If cost precludes this option, mounting of remote monitoring equipment at one end or the centre of each rope bridge is recommended. I recommend systems described in Section 5.3 in the following order of preference:

1) Faunatech Digicam 120 with passive infrared or active IR sensor beam with solar panel mounted on pole and security box near ground level
   2 systems for each rope bridge less than **$19,350**
2) Faunatech Digicam 120 with passive infrared or active infrared beam with solar panel mounted on pole and security box near ground level
   1 system for each rope bridge less than **$ 9,675**
3) Trailmaster TM1550-16k passive or active infrared beam monitor + TM35-1 camera kit mounted on rope bridge adjacent to telegraph pole
   2 systems for each rope bridge **$ 4,110**
4) Trailmaster TM1550-16k passive or active infrared beam monitor + TM35-1 camera kit mounted on rope bridge adjacent to telegraph pole
   1 system for each rope bridge **$ 2,310**
5) Trailmaster TM700v – RT passive infrared video monitor with active beam remote trigger input mounted on pole a few metres above ground level
   3 systems, 1 for each rope bridge **$13,500**
5) Trailmaster TM700v – RT passive infrared video monitor with active beam remote trigger input mounted on pole a few metres above ground level with 3 remote active beam sensors on separate rope bridges
   1 system + 3 remote active IR beam systems **$ 5,500**

6.4 GLIDER POLES

6.4.1 Direct Monitoring Recommendations

Direct monitoring of the glider poles should include all three systems described in Section 5.4.

1) Spotlighting of glider poles, increasing frequency with time allowed for habituation;
2) Scat collection and analysis using shadecloth circles above pole guards; and
3) Hair analysis data collection during intensive monitoring periods.

6.4.2 Remotely Sensed Monitoring Recommendations

For remote sensing of the glider poles, it would be preferable to install camera monitoring equipment at poles near both entrances to the land bridge. Costs of monitoring equipment for all poles can be reduced by inclusion of cages at all poles and then cycling the equipment between poles. I recommend systems described in Section 5.4 in the following order of preference:

a) Faunatech Digicam 120 with passive infrared sensor in security cage mounted on pole arm at right angles to main arms or on metal pole bolted to the land bridge
   2 systems for 2 glider poles + 8 cages **$6,330**
b) Reconyx Silent Image Professional Edition with passive infrared sensor system mounted in security cage as per a) above
   2 systems for 2 glider poles + 8 cages **$6,830**
c) Trailmaster TM550 passive infrared monitor + TM35-1 camera kit mounted in security cage as per a) above
   2 systems for 2 glider poles + 8 cages **$4,270**

6.5 WET CULVERTS

6.5.1 Direct Monitoring Recommendations

Direct monitoring of the faunal underpasses should include the two systems described in Section 5.5.

1) Active searches, spotlighting and visual observations of movements; and
2) Trapping and netting where ethical.

6.5.2 Remotely Sensed Monitoring Recommendations

Because of the likelihood of failure, no purchase of expensive monitoring equipment specifically for the wet culverts is recommended. Instead, trials of two systems with potential purchased for monitoring of other structures is recommended.

1) Trials of Faunatech Digicam 120 with microwave motion sensor in security cage mounted on metal poles adjacent to entrances of wet culverts
2) Trials of Trailmaster TM700v Video Monitoring systems in security cages mounted on metal poles adjacent to entrances of wet culverts

Camera	Type	Flash Distance	Photo Storage	Resoluation	Trigger Available	Housing	Field View	Delay	Power Source	Features	Cost USD	Cost AUD
Vigil P-box Olympus D-380	digital	9m	8MB - 50 32MB - 180 64MB - 360 128MB - 720	2Mpixels	passive IR to 50ft	weatherproof impact resistant external on/off	Y	2sec - flash 6sec +flash	4AA batteries 300-400 photos up to 3 months	6 time delays 3 sensitivities nylon strap or cable, chain & lock	$600Ca	$620
Penn's Woods Digital-Scout Sony Cybershot Minolta X-20	digital		16MB -100s 16MB -100s	3.2Mpixels 2.0Mpixels	passive IR to 80ft	waterproof camouflage		<2sec	4C-cell batteries up to 3 months 4AA batteries	sensitivity adjustment detection range limited to flash range time delays day, night or 24hr 15sec video clip	$700 $600	$900 $770
Leaf River Digital Trail Scan	digital	oversized flash	50 flash cards	2.0Mpixels		camouflage gasket seal mounting bracket				3-90sec video clips sensitivity adjustment adjustable delay	$350	$450
Stealth Cam DIGRC-X	digital	30ft	16MB - 150 256MB	1.3Mpixels		weatherproof			6 AA batteries	10 sec video clips time delays time, date recording	$250	$320
StealthCam DIGRC-XTR	digital	30ft	16MB 256MB	3Mpixels	passive IR				solar panel	10sec video clips time, date recording time delay	$400	$510
Penn's Woods Video Scout Sony NightShot other video camcorder	video digital				passive IR to 80ft	waterproof camouflage cable lock			up to 6 months	sensitivity adjustment prevents false triggers detection range limited at night set times, day, night	$370 $1300Ca	$480 $1,340
Hunter's Specialties Rack Tracker	digital		32MB - 100s	0.3/1.3 Mpixel	3-beam IR - 180^{o}	weatherproof camouflage lockable			up to 6 months solar panel	time, date recording day, night, 24hr 8 time delay settings	$450	$575

Camera	Type	Flash Distance	Photo Storage	Resoluation	Trigger Available	Housing	Field View	Delay	Power Source	Features	Cost USD	Cost AUD
Faunatech Digicam 120 Olympus Camedia	digital digital	up to 25m IR flash	122 - 489		active IR to 15m or passive IR or both other external triggers	weatherproof sensors floodproof to few metres	Y		4 AA NiH batteries	could include short video in camera high sensitivity- covert night photography - fox-size fauna at 10m cable or radio-linked sensors single or 4 shots per trigger		$1600 +$250 extra sensor
										adjustable sensitivity adjustable delays		
Faunatech DC120 for arboreal overpasses	digital	1-2m			2 active IR beams top & bottom tunnel surfaces passive IR also	bracket design can swing with bridge st/st security box pole 15m above hwy	Y		solar panel	pre-focussed at 1m, IR floodlight 1sec delay USB lead from camera to control box		$1,600 ~$350 ~$200
Reconyx silent image	digital	15-20m	batteries - 15,000 64MB - 1,200 256MB - 5,000 1GB - 20,000		passive IR - 40° IR illuminator - 40° camera - 40° can use external active IR both passive & active IR	waterproof tripod or bungee mounting cable lock	Y		8 AA batteries 1-2 wks C-cell batteries 4-8 wks	nearVideo capability 2frames/sec time lapse capability time, date, temperature recording 2 daily schedules infrared illuminator inbuilt dessicant packets sensitivity adjustment adjustable delays	$1,250 $300	$1,600 $385
DeerCam Scouting camera Olympus 35mm	35mm film	no flash washout				weatherproof camouflage				delay 2 sensitivity levels	$200	$260

Camera	Type	Flash Distance	Photo Storage	Resoluation	Trigger Available	Housing	Field View	Delay	Power Source	Features	Cost USD	Cost AUD
						cable				date, time imprint		
Sentinel video surveillance	video											
1. Sanyo time-lapse VCR	mono-chrome		tape-8,24,40hr			waterproof				IR illumination to 2m		
PicoMount camera	VHS					PicoMount				time lapse video		
									12v DC	Sanyo SRT-4400 DC timelapse VCR		
3. Ultra low light zoom	VHS tape		tape-8,24,40hr			waterproof				24/7 activity over large or distant areas		
ULL zoom picoCam	mono-chrome					sturdy tripod mount				hi-res images from full sun to bright moonlight		
										8-46^{o} horizontal field of view		
										Sanyo SRT-4400 DC timelapse VCR		
										optional hipower IR spotlight to 10m		
5. miniature digital X-100	digital video		40/80GB hard drive							miniature		
AutoColor AC 2002-3.7 PicoCam	day color		one month							low power requirements		
	night monochrome									5 frame/sec - can use 1-4 cameras IR illumination to 2m adjustable image compression, recording rate, period video lab playback to extract data optional hipower IR spotlight to 10m optional day or night only recording		
TrailMaster monitors TM1550					active IR beam	weatherproof			8C-cell batteries	adjustable sensitivity	$260	$330
						nylon strap to tree			8-12 months	time, date recording		

Camera	Type	Flash Distance	Photo Storage	Resoluation	Trigger Available	Housing	Field View	Delay	Power Source	Features	Cost USD	Cost AUD
TrailMaster monitor TM550					passive IR to 65ft	weatherproof			4C-cell batteries	time, date recording	$180	$230
						nylon strap to tree			12 months	adjustable delay		
Trailmaster TM 35-1 camera kit	35mm film	built-in flash or IR filter & IR film				weatherproof			4-6 wks	used with TM1500 or TM550 monitors	$290	$370
						tree-pod, shield				autofocus 0.35m to infinity		
						velcro strap to tree				time, date recording		
										24hr or specific time zone monitoring		
										adjustable delay 6sec - 98 min		
Trailmaster TM 700v video monitor					passive IR to 100ft	weatherproof			4C-cell batteries	adjustable recording length	$595	$760
Sony Handycam Nightshot	2hr tape -wks								12 months	time, date recording	$1,200	$1,530
Trailmaster TM70vRT video monitor					active IR beam TM1500	nylon strap			camera 6v	2lux sensitivity for low light recording	$695	$890
Trailmaster video housing						weatherproof				auto exposure	$950	$1,200
						adjustable bracket				sharp focus from ultra close up to telephoto		
Trailmaster video IR light											$250	$320
Crow Systems	35mm film	10m			passive IR to 15m	waterproof				multiple external inputs		
Canon Owl PF Dateback					external triggers	camouflage				environmental logger		
						tamper resist lock				24hr, day, night, twilight		
										field of view matched to camera		
										20 step delay		
Crow systems										low power setting		
Trail-camera video systems	video				passive IR to 45ft					adjustable detection range		

Camera	Type	Flash Distance	Photo Storage	Resoluation	Trigger Available	Housing	Field View	Delay	Power Source	Features	Cost USD	Cost AUD
Sony Night-Shot	analog or digital				optional external triggers	Pelican watertight unbreakable windows rugged mounting camouflage security locks				24hr, day, night, twilight field of view matched to camera 20 step delay fully adjustable record duration automatic nightshot activation/deactivation low power for extended use date, time recording built-in IR spotlight for NightShot		$1,350
Camtrakker Original Yashica T4 zoom	35mm film	30ft optional strobe to 60ft			passive IR	camouflage weatherproof cable lock			4C batteries alkaline	simple operation optional delays time, date recording 24hr, day, night quiet camera	$445 $250	
Camtrakker Ranger Olympus AF50	35mm film					camouflage			lead acid 2AA batteries	6 time delays stable electronics	$245	
Camtrakker Digital Sony Cyber-shot	digital	60ft strobe	batteries - 500 16MB - 44 >MB option	3.2Mpixels	passive IR	camouflage weatherproof cable lock			2 lead acid gel cells	ultrastable electronics	$775	

7.0 REFERENCES

Abson, R.N. and Lawrence, R.E. (2003). Monitoring the use of the Slaty Creek wildlife underpass, Calder Freeway, Black Forest, Macedon, Victoria, Australia. . In “2003 Proceedings of the International Conference on Ecology and Transportation”. Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. pp303-308.

Bank, F. (2002). The scan of the wild. Public Roads 66 (3). http://www.tfhrc.gov/pubrds/02nov/01.htm

Bank, F., Irwin, C.L., Evink, G., Gray, M., Hagood, S., Kinar, J., Levy, A., Paulson, D., Ruediger, W., Sauvajot, R., Scott, D. and White, P. (2002). Wildlife habitat connectivity across European highways Publication No FHWA-PL-02-011 Office of International Programs, Federal Highway Administration, US Department of Transportation. 64pp.

Beier, P. and Cunningham, S.C. (1996). Power of track surveys to detect changes in cougar populations. *Wildlife Society Bulletin* **24**: 434-440.

Beier, P. and Noss, R. (1998). Do habitat corridors provide connectivity? *Conservation Biology* **12**: 1241-1252.

Bennett, G. (2003). Linkages in Practice. A review of their conservation value. Report to IUCN. 28pp.

Biodiversity Assessment and Management (2003). Review and Fauna Management Advice. Compton Road Upgrade, Kuraby. Report for Brisbane City Council. 16pp + Appendix.

Boarman, W. (accessed 2005). Mojave Desert Tortoise Retrofitted Culverts and Barrier Fence**.** In “ Wildlife Crossings Toolkit http://www.cnr.usu.edu/crossings/pubdetail.cfm?projname=&locstate=&Submit=Search&offset=41&pID=758

Boarman, W. I. et al. 1998. A passive integrated transponder system for tracking animal movements. Wildlife Society Bulletin Vol. 6, Number 4

Brudin, C. (2003). Wildlife use of existing culverts and bridges in north central Pennsylvania. . In “2003 Proceedings of the International Conference on Ecology and Transportation”. Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. pp344-352.

Burnett, S.E. (1992). Effects of a rainforest road on movements of small mammals: mechanisms and implications. *Wildlife Research* **19:** 95-104.

Bushnell, S. (2005). Investigation into the effectiveness of revegetation corridors and faunal underpasses: Mitigating the effects of a road through fragmented highland rainforest. MSc project thesis, TESAG, James Cook University.

Byrnes, P. (2003). Impact of Roads on Medium-sized, Ground-dwelling Rainforest Mammals in the Wet Tropics World Heritage Area. Proposal for funding to the Rainforest CRC.

Byrnes, P. (2004). Why did the musky cross the road? James Cook University School of Tropical Environment Studies and Geography Postgraduate conference, June 2004.

Cain, A.T., Tuovila, V.R., Hewitt, D.G. and Tewes, M.E. (2003). Effects of a highway and mitigation projects on bobcats in Southern Texas. *Biological Conservation* **114**: 189-197.

Canadian Ministry for Environment, Parks and Wildlife (1998). Inventory Methods for Marten & Weasel. Standards for Components of British Columbia's Biodiversity No. 24. .

Canadian Ministry for Environment, Parks and Wildlife (1999). Inventory Methods for Medium-sized Territorial Carnivores: Coyote, Red Fox, Lynx, Bobcat, Wolverine, Fisher & Badger. Standards for Components of British Columbia's Biodiversity No. 25. 72pp.

Chruszcz, B., Clevenger, A. Gunson, K. and Gibeau, M. (2003). Relationships among grizzly bears, highways and habitat in the Bow Valley, Alberta, Canada. *Canadian Journal of Zoology* **81**: 1378-1391.

Clevenger, A.P., Chruszcz, B. and Gunston, K. (2001). Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* **38**: 1340-1349.

Clevenger, A.P. and Waltho, N. (2000). Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Canada. *Conservation Biology* **14**: 1-11.

Clevenger, A.P. and Waltho, N. (2003). Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. . In "2003 Proceedings of the International Conference on Ecology and Transportation". Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. Pp293-302.

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

Dawe, G. (2005). Traffic noise and its influence on the song of tropical rainforest birds. Hons. Thesis, TESAG, James Cook University. 94pp.

Dennis, A.J. (1997). Musky Rat-kangaroos, *Hypsiprymnodon moschatus*: Cursorial Frugivores in Australia's Wet-Tropical Rain Forests. PhD Thesis, James Cook University of North Queensland, Townsville.

Dodd, C.K., Barichivich, W.J. and Smith, L.L. (2004). Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. *Biological Conservation* **118:** 619-631.

Dodd, N.L. (2005). Video surveillance to assess wildlife highway underpass use in Arizona. *Wildlife Society Bulletin* (in press).

Faunatech (2002). Digicam surveillance camera. Product Information Series. April 2002. 2pp. www.faunatech.com

Foresman, K.R. (2001). Small mammal use of modified culverts on the Lolo South project of Western Montana. In " Proceedings of the International Conference on Ecology and Transportation, Keystone, Colorado, September 24-28, 2001". Pp581-582.

Foresman, K. R. (2003). Small mammal use of modified culverts on the Lolo South project of Western Montana – an update. In “2003 Proceedings of the International Conference on Ecology and Transportation”. Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC.pp342-343.

Foresman, K.R. (2004). The effects of highways on fragmentation of small mammal populations and modifications of crossing structures to mitigate such impacts. Report to Montana Department of Transportation. 45pp.

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

Goosem, M. (2004). Linear infrastructure in tropical rainforests: mitigating impacts on fauna of roads and powerline clearings. In “Conservation of Australia’s forest fauna”. (Ed. Lunney, D.), Royal Zoological Society of NSW, Mosman, NSW pp 418-434.

Goosem, M. (2003). Effectiveness of East Evelyn faunal underpasses. In “Proceedings of the National Environment Conference, 2003” (Eds. Brown, R. and Hanahan, C.) pp 200-205.

Goosem, M. (2002). Effects of tropical rainforest roads on small mammals: fragmentation, edge effects and traffic disturbance. *Wildlife Research* **29,**1-13.

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

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

Goosem, M., Harriss, C., Chester, G. and Tucker, N. (2004). Kuranda Range: Applying research to planning and design review. Report to Queensland Department of Main Roads. 66pp.

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

Goosem, M. W. and Marsh, H. (1997). Fragmentation of a small mammal community by a powerline corridor through tropical rainforest. *Wildlife Research* **24,** 613-629.

Goosem, M. and Weston, N. (2002). Under and over. *Wildlife Australia* **39(3):** 34-37.

Gordon, K.M. and Anderson, S.H. (2003). Mule deer use of underpasses in western and southeastern Wyoming. In “2003 Proceedings of the International Conference on Ecology and Transportation”. Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. pp309-318.

Haas, C.D. and Crooks, K.R. (2003). Responses of mammals to roadway underpasses across an urban wildlife corridor, the Puente-Chino Hills, California. . In “2003 Proceedings of the International Conference on Ecology and Transportation”. Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. p580.

Hardy, A., Clevenger, A.P., Huijser, M. and Neale, G. (2003). An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: emphasizing the science in applied science. In "2003 Proceedings of the International Conference on Ecology and Transportation". Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. pp319-330.

Herzog, C. The use of track plates to identify individual free-ranging fishers. MA (Wildlife Ecology) thesis. Prescott College, New York State, USA. 59pp.

Huijser, M.P. and Bergers, P.J.M. (2000). The effect of roads and traffic on hedgehog populations. *Biological Conservation* **95:** 111-116.

Jones, D., Appleby, R., Edgar, J. and Breen, B. (2004). Compton Road Wildlife Movement Monitoring Program: Preliminary results of Phase 1. Report for Environment and Parks, Brisbane City Council. Griffith University Surburban Wildife Research Group. 8pp.

Kapitzke, R. (2003). Outline of R & D for remediation of fish migration barriers at road-stream crossings: featuring prototype culvert fishways on University Creek, Townsville. Rainforest CRC. 18 pp. http://www.rainforest-crc.jcu.edu.au/research/CulvertFishwaysProject.pdf

Karns, D.R. (1986). Field Herpetology. Methods for the study of amphibians and reptiles in Minnesota. James Ford Bell Museum of Natural History. Occasional paper 18. 90pp. http://files.dnr.state.mn.us/ecological_services/nongame/projects/consgrant_reports/1986_karns.pdf

Kinley, T. A., H. Page, N. J. Newhouse (2003). *Use of Infrared Camera Video Footage from a Wildlife Protection System to Assess Collision-Risk Behaviour by Deer in Kootenay National Park, British Columbia*. Report prepared for the Insurance Corporation of British Columbia. 12pp.

LaPoint, S.D., Kays, R.L. and Ray, J.C. (2003). Animals crossing the northway: are existing culverts useful? *Adirondack Journal of Environmental Studies* **Spring/Summer 2003:** 11-17.

Larsson, U. (2003). Functionality of revegetated corridors across linear clearings in reducing edge and linear barrier effects on rainforest fauna. Hons thesis, TESAG, James Cook University.87pp.

Lyren, L.M. and Crooks, K.R. (2003). Factors influencing the movement, spatial patterns, and wildlife underpass use of coyotes and bobcats along State Route 71 in southern California. . In "2003 Proceedings of the International Conference on Ecology and Transportation". Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. p490.

Mack, P. (2003). Proposed Road Widening Compton Road, Kuraby. Report on Ecological/ Fauna Movement Issues. Brisbane City Council. 18pp.

Mata, C., Hervas, I., Herranz, J., Suarez, F. and Malo, J.E. (2003). Effectiveness of wildlife crossing structures in a highway in northwest Spain. . In "2003 Proceedings of the International Conference on Ecology and Transportation". Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC.pp265-275.

McCarthy, M. A. and Parris, K. M. (2004) Clarifying the effect of toe clipping on frogs with Bayesian statistics. *Journal of Applied Ecology* 41: 780-786.

McDonald, W. and Cassady St Clair, C. (2004). Elements that promote highway crossing structure use by small mammals in Banff National Park. *Journal of Applied Ecology* **41**: 82-93.

Mech, L. and Barber, S. (2002). A critique of wildlife radio-tracking and its use in national parks. : A report to the U.S. National Park Service. 81 pp. (Reprint Number 1164.)

Moruzzi, T.L., Fuller, T.K., DeGraaf, R.M., Brooks, R.T. and Li, W. (2002). Assessing remotely triggered cameras for surveying carnivore distribution. *Wildlife Society Bulletin* **30**: 380-386.

Ng, S.J., Dole, J.W., Sauvajot, R.M., Riley, S.P.D. and Valone, T.J. (2004). Use of highway undercrossings by wildlife in southern California. *Biological Conservation* **115:** 499-507.

Puky, M. and Vogel, Z. (2003). Amphibian mitigation measures on Hungarian roads: design, efficiency, problems and possible improvement, need for a co-ordinated European environmental education strategy. In ‘Habitat Fragmentation due to Transportation Infrastructure – IENE 2003). 13pp.

Servheen, C. Shoemaker, R. and Lawrence, L. (2003). A sampling of wildlife use in relation to structure variables for bridges and culverts under I-90 between Alberton and St Regis, Montana. . In “2003 Proceedings of the International Conference on Ecology and Transportation”. Eds. Irwin, C.L., Garrett, P., McDermott, K.P. North Carolina State University, Raleigh, NC. pp331-341.

Singleton, P. and Lehmkuhl, J.F. (2000). I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment. Final Report. US Department of Agriculture Forest Service. http://www.wsdot.wa.gov/ppsc/research/CompleteReports/I-90WildLIfe.html

Swann, D.E., Hass, C.C., Dalton, D.C., and Wolf, S.A. (2004). Infrared-triggered cameras for detecting wildlife: an evaluation and review. *Wildlife Society Bulletin* **32,** 357-365.

Taylor, B.D. and Goldingay, R.L. (2003). Cutting the carnage: wildlife usage of road culverts in north-eastern New South Wales. *Wildlife Research* **30**, 529-537.

Tigas, L.A., van Vuren, D.H. and Sauvajot, R.M. (2002). Behavioural responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation* **108**: 299-306.

Trailmaster (2004). Trailmaster infrared trail monitors. TM1550 active infrared trail monitor, TM multi-camera trigger II, TM statpack software/cable, TM550 passive infrared trail monitor, TM700v passive infrared video trail monitor, TM intervalometer, TM multi-camera trigger, TM35-1 camera kit, TM data collector, TM weather proof housing. 11pp. www.trailmaster.com

Triggs, B. (1988). Mammal tracks and signs: a field guide for south eastern Australia. Oxford University Press, Melbourne.

Van Manen, F.T., Jones, M.D., Kindall, J.K., Thompson, L.M. and Scheick, B.K. (2001). Determining the potential mitigation effects of wildlife passageways on black bears. In “Proceedings of the International Conference on Ecology and Transportation, Keystone, Colorado, September 24-28, 2001.” Pp435-446.

Weston, N. (2000). Bridging the rainforest gap. *Wildlife Australia* **37(4):** 16-19.

Weston, N. (2003). The provision of canopy bridges for arboreal mammals: a technique for reducing the adverse effects of linear barriers, with case studies from the Wet Tropics region of north-eastern Queensland. MSc thesis. 179pp + Appendices

Williams, S.E., Vernes, K. and Coughlan, J. (1996). Vertebrate fauna of Cannabullen plateau: a mid-altitude rainforest in the Australian Wet Tropics. *Memoirs of the Queensland Museum* **43**: 849-858.

Wintle B. A., M. A. McCarthy, K. P. Parris, & M. A. Burgman. 2004. Precision and bias of methods for estimating point survey detection probabilities*. Ecological Applications*. **14**: 703-712.

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

York, E.C., Moruzzi, T.L., Fuller, T.K., Organ, J.F., Sauvajot, R.M., and DeGraaf, R.M. (2001). Description and evaluation of a remote camera and triggering system to monitor carnivores. *Wildlife Society Bulletin* **29**: 1228-1237.

Zielinski, W. and Kucera, T.E. (1995). American marten, fisher, lynx, and wolverine: Survey methods for their detection. USDA Forest Service General Technical Report PSW GTR-157.

8.0 APPENDICES

8.1 APPENDIX 1

Sample of questions asked of researchers with regards advantages and disadvantages of monitoring techniques and equipment.

Questions were modified to suit the research of the individual ie. type of project undertaken and type of monitoring technique and equipment used.

- Faunal use of an ecoduct or green bridge is to be monitored for several years. I notice from your paper in ICOET Proceedings 2003 that you have used a video camera system for monitoring. I would appreciate your comments as to whether video or still camera monitoring may be more efficient.
- The project also includes underpasses and arboreal overpasses that will be monitored using infrared triggered cameras. Any comments concerning camera systems that you have found effective and their approximate cost would also be very much appreciated.
- An ecoduct or green bridge is to be monitored in this project. I had thought that a video camera system may be useful for this, but notice from your paper in the ICOET 2003 proceedings that you used a still camera system as well as tracking. I would appreciate your comments as to whether video or still camera monitoring may be more efficient.
- All of the crossing structures (other than glider poles) will be monitored using tracking methods as well as the remote sensing apparatus, to provide continuous data in the case of breakdown of the more sophisticated techniques. Hair analysis techniques may be available for glider poles, although it is unlikely that DNA analysis for individuals could be included in the costing.
- I notice from your abstract in the ICOET 2003 proceedings that you used a passive infrared triggered system mounted on the roof of each culvert to monitor culverts which may often contain water. I would appreciate your comments regarding the effectiveness of this system in comparison with an infrared beam active system.
- I notice from your papers in the ICOET 2003 proceedings that you have been monitoring multispecies use of a large number of culverts. Any comments concerning camera systems that you have found effective and their approximate cost would also be very much appreciated. Sand-tracking at underpasses will also be used to allow continuous data collection, even when there are equipment failures. Hair and scat analyses will provide backup data for arboreal overpasses and glider poles.
- A second project requires an ecoduct or green bridge to be monitored. I had thought the video camera system may be useful for this also. I would appreciate your comments as to whether your PIT tag monitoring system may be a useful addition to video or still camera monitoring for any trapped species. If possible it would be useful to understand the range that such a system can detect the marked species.
- This new project also includes underpasses and arboreal overpasses and glider poles that will be monitored using infrared triggered film or digital cameras. Any comments concerning PIT tag monitoring in these situations would also be appreciated, together with any camera systems that you have found effective and their approximate cost. All of the crossing structures (other than glider poles) will be monitored using tracking methods as well as the remote sensing apparatus, to provide continuous data in the case of breakdown of the more sophisticated techniques. Hair analysis techniques may be available for glider poles, although it is unlikely that DNA analysis for individuals could be included in the costing.

- For the monitoring of ecoducts or green bridges I notice from references to your work in a paper compiled by the US Scan of the Wild team that visited Europe in 2003 that you have used a variety of less complicated techniques. I would appreciate your comments as to whether video or still camera monitoring or other methods may be more efficient.
- A second project requires an ecoduct or green bridge to be monitored. I had thought the video camera system may be useful for this also, and noticed from references to your work in a paper compiled by the US Scan of the Wild team that visited Europe in 2003 that researchers in Germany and Switzerland used such a system as well as tracking. I would appreciate your comments as to whether video or still camera monitoring may be more efficient.
- For monitoring of ecoducts or green bridges I had thought to use a video camera system, but notice from various reports of work in the Netherlands that still camera systems and tracking tend to be used. I would appreciate your comments as to whether video or still camera monitoring may be more efficient, or whether other monitoring protocols are more reliable.
- I have also tried a combined system of 2 infrared beams one low and horizontal to the culvert floor and another angled at about 45 degrees to ensure capture of larger species. But the idea of a passive sensor that can be fixed to the culvert roof is very appealing, provided the range of the sensor is sufficient to detect a small mammal (or preferably a small scincid lizard) from about 3.5m height.
- I had thought to use a digital videocamera monitoring system for monitoring of an ecoduct (green bridge). I was hoping you may be able to give me an idea of a supplier in North America. Tony Clevenger says that you have constructed your own system with lighting. Would it be possible to give me some information concerning that. Is such a thing available commercially or are the parts able to be put together without too much difficulty? Any comments concerning it would be appreciated.
- I notice in your recent papers in Biological Conservation that you have been involved in monitoring underpasses and would greatly appreciate any comments on still infrared beam and passive IR systems and also any video systems that you may have experience with, as well as their approximate cost.
- I noticed from references to work in France in a paper compiled by the US Scan of the Wild team that visited Europe in 2003 that researchers in France used a variety of techniques for monitoring of overpasses. I would appreciate your comments as to whether video or still camera monitoring may be more efficient.