Report 2

Stage II **July 2000**

IMPACTS OF ROADS & POWERLINES ON THE WET TROPICS OF QUEENSLAND WORLD HERITAGE AREA

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Terms of Reference

Roads and Power Lines Project

To examine the impacts of roads and powerlines on the fauna and flora of the Wet Tropics and to determine the effects of road closure and restricted use on native fauna and flora.

Through the Wet Tropics Plan a number of roads and tracks have been closed or have restricted access because of their potential impact on fauna and flora. This project will monitor the impacts of road/track closure/opening on the native fauna and flora and the spread of exotic weeds and other pest organisms. It will look at the damage to roads/tracks caused by increased use.

In summary this project will provide:

1) An assessment of the impact of road/track closure/opening on the Wet Tropics
2) An assessment of road/track damage through increased or decreased use
3) Indicators of impacts of road opening/closure for future monitoring.

Outcomes for WTMA:

- Increased knowledge base for decision-making on roads and tracks in the Wet Tropics
- Improved decision-making for permits and road management and usage

(Ref: Contract No. 420)

Acronyms

DNR	Department of Natural Resources
EPA	Environmental Protection Agency (formerly the Department of Environment and Heritage)
GIS	Geographic Information System
Rainforest CRC	Cooperative Research Centre for Tropical Rainforest Ecology & Management
TESAG	School of Tropical Environmental Studies and Geography, James Cook University
QPWS	Queensland Parks and Wildlife Service (formerly the Department of Environment and Heritage)
WTMA	Wet Tropics Management Authority
WTQWHA	Wet Tropics of Queensland World Heritage Area
WTMP	Wet Tropics Management Plan

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(1) GIS support - access to spatial databases and professional advice;
(2) Access to library facilities, reports and data sets;
(3) Loan of traffic counters; and
(4) Project consultation and professional advice from both scientific and planning staff.

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(2) Information with respect to DNR counters; and
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Section 1: The Effect of Canopy Closure and Road Verge Habitat on Small Mammal Community Composition and Movements

Research Objective

The objective of this study was to examine the effects of narrow rainforest roads on small mammal community composition and movements with the following aims:

- To determine whether edge effects in small mammal community composition differ between areas where there are no roads (forest interior), along narrow roads where rainforest canopy closure is maintained and along narrow roads with wide grassy and woody weed verges;
- To determine to what degree small mammal movements are inhibited by a narrow rainforest road with canopy closure or with a wide grassy and woody weed verge; and
- To determine whether small mammal species alien to the rainforest habitat are able to penetrate areas where there are no roads (forest interior), where rainforest canopy closure is maintained or where a wide grassy and woody weed verge is present.

Key Findings

- Grassland and feral small mammals can intrude along the grassy and woody weed verges of a narrow road traversing rainforest. These species existed even where short lengths of road with canopy closure subdivided the grassy verge habitat. However they failed to penetrate the rainforest interior and were not resident at the road edge where canopy closure was maintained.
- Rainforest small mammals were not excluded from a narrow grassy and woody weed verge either by the alien habitat or by the presence of grassland small mammals, possibly due to the proximity of woody weeds which appeared to be favourable, though not ideal, habitat for rainforest species. However rainforest species abundance was halved in comparison to that of the adjacent forest edge and interior.
- Small mammal community composition at the edge was altered adjacent to a narrow road with a grassy verge, with generalist species increasing and a concomitant reduction in a more specialist rainforest species. However, where canopy closure was maintained and there was little obvious disturbance to the understorey and ground layers, small mammal communities were comparable to the forest interior with the exception of a probable reduction in abundances of less common species.
- The narrow road caused inhibition of crossing movements of several small mammal species, regardless of the clearing type (grassy and woody weed verge or closed canopy) in comparison with the forest interior. Movements of a larger species were unaffected by a road with canopy closure.

Recommendations

- Maintenance of canopy closure to prevent intrusions into rainforest of small mammals alien to rainforest habitats and reduce edge effects in small mammal community composition.

Management Implications

- A grassy and woody weed verge allows penetration of small mammals alien to the rainforest environment, but these species do not penetrate the forest interior or where canopy closure is maintained over the road.
- Canopy closure also reduces edge changes in small mammal community composition in comparison to rainforest edges adjacent to grassy and woody weed verges.
- The presence of the road is the primary factor causing inhibition of road crossing movements by rainforest small mammals, irrespective of whether the clearing has canopy closure or grassy and woody weed verges.

Further Research

- It is hoped to continue this study in the vicinity of the Maalan Road, to examine the success rate of rehabilitation strategies and the effects of weed control undertaken by management agencies.

Section 2: Edge Effects of Roads and Powerline Clearings on Microclimate

Research Objective

- The main objective of this project was to quantify the differences between microclimate variables at the forest edge and those of the forest interior and then estimate the intensity of microclimate edge effects associated with linear clearings of differing widths and degrees of canopy cover. Three treatments were examined: powerline corridor, road with grassy verge and road with closed canopy.

Key Findings

- Photosynthetically active radiation (PAR) had a consistently significant relationship with distance from the edge across all treatments and in both seasons. PAR had the most significant relationship with distance of all the microclimate variables. The strongest gradients from the edge to forest interior for PAR were seen on the powerline corridor and the open canopy treatments, whilst the gradients were less pronounced on the closed canopy treatment.
- Soil surface temperature in the dry season and soil temperature at 10cm depth in the wet and dry seasons had steeper gradients from the edge to the interior in open canopy and powerline corridor treatments, whilst closed canopy had relatively constant soil temperatures from the edge to the interior.
- Air temperatures and vapour pressure deficits had relatively constant gradients from the edge to the interior on the closed canopy treatment, with slightly more pronounced gradients shown for the open canopy and powerline corridor treatments.
- Overall, the closed canopy treatment had the weakest and most constant microclimate gradients from the edge to the forest interior, indicating that the linear clearing associated with this treatment had less impact upon microclimate than those of the open canopy and powerline corridor. Values for all microclimate variables decreased with increasing distance from the edge at the powerline corridor and open canopy treatments in both seasons.
- Edge effects that penetrated further than the forest edge zone (0 to 8 metres) occurred for all microclimate variables at the powerline corridor, whereas only dry season vapour pressure deficit at 20cm and 150cm demonstrated a notable edge effect at the closed canopy treatment.
- Wet season vapour pressure deficit at 20cm showed an edge effect that penetrated up to 50 metres at the open canopy treatment.
- The powerline corridor exhibited the most pronounced microclimate edge effects for the three treatments.
- Penetration of edge effects in the wet season generally tended to be lower for air and soil temperatures and higher for PAR and VPD.
- Open canopy had higher dry season values and the powerline corridor had higher wet season values for PAR, soil temperature at 10cm depth and air temperature at 20cm.
- The powerline corridor had higher soil surface temperatures, and higher diurnal air temperatures in both seasons than the open canopy, and exhibited higher air temperature at 150cm in the wet season.
- Overall, the powerline corridor treatment tended to have higher values, especially at the edge in the wet season. However, the open canopy and powerline corridor treatments frequently showed similar values from the near edge/transitional zones to the forest interior.

Management Implications

- This study has demonstrated that linear clearings associated with roads and powerline corridors have an effect on rainforest microclimate at the clearing/rainforest interface.
- The degree of microclimatic edge effect is affected by the type of linear clearing – in general, a narrow clearing with canopy cover maintained overhead will have less of a microclimatic edge effect than a clearing without canopy closure.
- A wider clearing such as that for a powerline or highway is likely to cause greater intensity of edge effects (i.e. distance of penetration into the rainforest) than is a narrower one, particularly if canopy closure is maintained.

Section 3: Edge Effects of Roads and Powerline Clearings on Rainforest Vegetation

Research Objective

- The main objective of this project was to determine to what extent the rainforest vegetation had been changed structurally and in species composition as a result of the presence of linear clearings, and whether the detected changes varied according to the type of linear clearing. The same treatments described in Section 2 were used in this study.

Key Findings

- The powerline corridor had the highest absolute numbers of individuals, families, genera and species in comparison with the open canopy and closed canopy treatments.
- Most species recorded were uncommon with only a few species being abundant.
- Patterns of species distribution from the edge to the forest interior may indicate successional stages within each treatment. The greatest mean number of species at the powerline corridor occurred between 0 and 20 metres, species number decreasing towards the forest interior. At the open canopy number of species was high at the edge, numbers then steadily decreased to 30 m and then increased in the forest interior (50 to 100 m). However, at the closed canopy a steady increase in species from 0 to 16m occurred, with a pronounced decrease from 20 to 30 m then an increase from 50 to 100m, although species numbers within the forest interior remained lower than species numbers at the edge.
- The species richness of vines, pioneers and rainforest species was highest at the powerline corridor and least at the open canopy while weed species were greatest at the open canopy and least at the closed canopy.
- Disturbance indicators including weeds, vines and pioneers were most common at the edge of the powerline corridor, whilst the closed canopy edge had the greatest proportion of rainforest species.
- There was great variability in seedling numbers both within and between treatments. However, seedlings markedly increased inwards at the edge zone (0 to 8 metres) for all three treatments, then decreased towards the forest interior at the closed canopy treatment but increased towards the forest interior at the powerline corridor and open canopy treatments. This difference between edge zone and forest interior seedling abundance was significant.
- The saplings on the open canopy and powerline corridor treatments tended to occur in higher concentrations at the edge, with sapling numbers at 12 metres being similar to those of the forest interior at 100 m. However, saplings on the closed canopy were more uniformly distributed from the 0m to the 100m data sampling points.
- There was no significant difference in combined seedling and sapling numbers between linear clearing types. However, combined seedling and sapling numbers were similar to those of the forest interior from 8 metres inwards.

Management Implications

- The findings of this study suggest that where roads must dissect tracts of rainforest, these should be narrow to allow for retention of canopy over them with consequent maintenance of forest processes and reduction in weed invasions.
- Wider clearings for roads and powerline corridors without canopy retention allow greater invasion of weeds, result in greater penetration of disturbance indicator species into the forest and generally cause a greater change in forest structure.
- Road and powerline corridor construction should not be considered complete until revegetation of easements or verges with rainforest species has been completed. Revegetation programs should be monitored to ensure that forest succession is proceeding towards a state as close as possible to that prior to construction. Edges should be encouraged to ‘seal’ with native rainforest species rather than with exotics and weeds. Ideally, construction methods that require minimal disturbance to rainforest vegetation and soil should be employed if a linear clearing must dissect rainforest.
- Finally, the option of avoidance of rainforest habitat should be given serious consideration when deciding whether or not to build linear constructions through rainforest.

Section 4: Geochemical Impacts on Roadside Soils in the Wet Tropics of

Research Objective

- The objective of this study was to carry out an initial geochemical assessment of soils within the Kuranda Range and Gillies Range transport corridors. Heavy metal distribution patterns including distance from the road and soil profile concentrations were examined. Levels of heavy metal concentrations were compared with levels considered safe for the environment.

Key Findings

- Generally, concentrations of copper, lead and zinc were found to decrease with increasing distance from the road.
- The distribution of heavy metals appeared to be affected by many factors associated with the nature of both these roads, including the vegetation, terrain, sharp corners and steep slope. Comparison of samples from a grassy verge transect (little or no vegetation), and a rainforest transect (thick vegetation), suggested that thick vegetation appears to be a factor which reduces the penetration of heavy metals.
- Mean concentrations of manganese, zinc and copper were higher in Kuranda Range samples adjacent to slight - moderately curved and sharply curved sections than mean concentrations adjacent to straight sections of road, whilst the mean concentration of lead was highest in samples adjacent to straight sections of road.
- The heavy metals copper, lead, zinc, nickel and manganese decreased in concentration down the soil profile, while iron concentrations were generally higher in subsoil samples.
- On both Gillies and Kuranda Range Roads, mean concentrations of copper, lead and zinc in topsoils were higher than mean background levels. Sediment samples also had higher concentrations of lead than background levels, with several samples also being higher in zinc.
- Although more sampling is required, total heavy metal concentration analysis of Kuranda Range samples indicated that concentrations of copper, manganese and nickel in some topsoil samples exceeded ANZECC/NHMRC environmental investigation levels and that the mean topsoil concentrations of copper and manganese also exceeded these environmental investigation levels.

Recommendations

- More comprehensive sampling of soils at study sites, especially on the Gillies Range, to enhance data analysis, further investigation of the effect of road design and driving conditions on the amount of heavy metals emitted from vehicles and the effect of wind on the deposition and distribution of heavy metals especially in contained areas.
- A more extensive study into the effects of vegetation types on heavy metal distribution.
- A more extensive study of the distribution and penetration of heavy metals in soil samples and sediments adjacent to roads and relationship of this distribution and penetration to the bioavailability of heavy metal pollutants to flora and fauna (choosing indicator species).
- Consideration and development of pragmatic management and engineering techniques to restrict movement and distribution of metal pollutants.

Management Implications

- Heavy metal distribution in soils appeared to be related to road use for several heavy metals.
- Prevention of such contamination could best be achieved by avoidance of natural areas during construction of new roads.
- For extant roads, distribution of heavy metals into soils may be restricted by thick vegetation (however further research is required). It is therefore recommended that the maintenance or reestablishment of roadside vegetation be a requisite component of road upgrading and construction. This strategy is in accord with recommendations developed from research examining linear barrier impacts on small mammals and arboreal mammals (see sections 1, 6, 7 of this report).

Further Research

- A Doctor of Philosophy candidate in Earth Sciences, Mr Bradley Drabsch, supervised by Dr Bernd Lottermoser, will undertake more extensive studies on this subject during 2000 - 2003. The title of his thesis is proposed to be: *"The dispersal, bioavailability and impact of automotive emissions and metal pollutants in the Wet Tropics of Queensland World Heritage Area"*.

Section 5: Vehicular Noise Disturbance in Rainforest

Research Objectives

The main objective of this project was to accumulate baseline data on vehicular noise and its penetration characteristics into wet tropical rainforest. The specific aims were:

- Quantification of the level and penetration distance of noise generated by a vehicle in a rainforest setting;
- Determination of the effect of type of road surface and / or the presence of a grassy verge on the level and penetration distance of vehicular noise; and
- Observation of actual traffic noise levels on two highways traversing the Wet Tropics and the effect of landscape and road design variables on these noise levels.

Key Findings

- Ambient noise levels at the edge of the road (0 m) and 100 m within the interior of the rainforest were not significantly different ($t = 0.167$, $df = 23$, $P>0.05$).
- Ambient noise level at 0 m and the vehicular noise level was significantly different at 0 m ($t = 35.636$, $df = 23$, $P<0.001$) and 100 m ($t = 2.572$, $df = 23$, $P<0.05$).
- Distance was found to be the most significant factor ($df = 7$, $F = 725.856$, $P<0.001$) affecting the level and penetration of vehicular noise while road surface and verge type had no significant effect ($P>0.05$) on the relationship of noise over distance.
- Vehicular noise penetrates well over 100 m into the rainforest at levels that may contribute to the degradation of habitat for some species of fauna.

Management Implications

- As the relationship between noise and faunal behaviour is uncertain, the precautionary principle has been invoked to suggest that a minimum 200 m buffer zone could be modelled in the Wet Tropics Management Authority (WTMA) geographical information system (GIS) to delineate a possible disturbance zone.

Further Research

- Fauna of interest occurring within this disturbance zone could be studied to determine the potential for vehicular noise impacts.

Section 6: Evaluation of Overpasses as Crossing Routes for Arboreal Species

Research Objective

- The objective of this research is to assess the potential use of artificial canopy linkages to enhance habitat connectivity and promote the safe crossing of road corridors by arboreal fauna.

Preliminary Findings

- This study is beginning to show that arboreal and scansorial animals such as rainforest ringtail possums and rodents of various species will use simple aerial connections or ‘canopy bridges’ as a crossing route above the road surface.
- The infrared-triggered camera has captured images of a rainforest ringtail possum (almost certainly the lemuroid ringtail possum, *Hemibelideus lemuroides*) on the existing structure. Several images of a green ringtail possum, *Pseudochirops archeri*, using the canopy overpass have also been captured.
- The net installed beneath the bridge has collected scats from the following species: *H. lemuroides; Pseudochirulus herbertensis;* and *Melomys cervinipes.*
- Scats from the following species have been collected from the road surface in the vicinity of the bridge: *H. lemuroides; P. herbertensis; Pseudochirops archeri; Dendrolagus* sp. and *Hypsiprymnodon moschatus.*
- The preliminary results appear to indicate that arboreal, scansorial and terrestrial species movement is not greatly inhibited by the installation of the artificial structure.

Management Implications

- Canopy overpasses are utilised by arboreal rainforest possums. It is as yet uncertain whether

possums cross the road using the existing structure.
- It is possible that subdivision of rainforest possum populations by roads may be ameliorated by overpasses. However more research using overpasses across wider road clearings needs to be undertaken before the effectiveness of these structures in reducing linear barrier effects across larger roads and highways is able to be determined.

Further Research
- Further research with respect to predation of animals using such structures is required.

Section 7: Road Crossings by Arboreal Mammal Species Questionnaire

Research Objective
- The objective of this research was to collate and analyse experience and knowledge of researchers and managers, spotlighting tour operators and naturalists / wildlife rescuers with respect to arboreal species and their road crossing habits.

Key Findings
- Habitat and Distribution and Road Crossing Summaries for seven rainforest possum species, two species of Tree-Kangaroos and six species of gliders (including road crossing behaviour and identification of roadkill locations) have been compiled.
- Identification of plant species useful in mitigating road impacts for arboreal species

Recommendations
- Maintain canopy connections across roads to cater for arboreal species and encourage new connections wherever possible.
- Consider the possibility of road bridges with high spans that allow maintenance of canopy connectivity below the bridge.
- Examine the effectiveness of canopy overpasses connecting rainforest in highway areas where it is not feasible to maintain or create canopy connections.
- Rehabilitation of grassy and weedy road verges will help prevent the intrusion of predators such as feral cats which prey on smaller arboreal species.
- Roadside revegetation should consider the wildlife occurring in the vicinity and make provision for canopy connections where possible whilst avoiding fruiting species where Cassowaries occur or trees with extremely attractive young foliage where Tree-kangaroos are common.
- Undertake research into the effectiveness of faunal underpasses for use by Tree-kangaroos.
- If underpasses are used by Tree-kangaroos, examine the effectiveness of 'floppy fencing' in preventing Tree-kangaroos from crossing at situations other than where underpasses are provided.
- Traffic calming measures including rumble strips, and slow-speed designs that include chicanes and curves may aid in prevention of mortality at known 'roadkill hotspots'.
- Maintain roadside tall trees by the roadside in glider habitat areas to allow maximum glide distances above vehicle height to be achieved.
- Replace barbed wire fencing of the road with other fencing strategies in areas of glider habitat.

Management Implications
- Maintenance or creation of canopy connections above roads will aid management in maintaining populations of many rainforest and open forest arboreal possum and glider species, through avoidance of linear barrier effects and road mortality.
- Provision of faunal underpasses may aid in prevention of Tree-kangaroo mortality but research and monitoring is required.
- In tall open forest and eucalypt and melaleuca woodlands, maintenance of tall trees in roadside vegetation and removal of barbed wire fencing should encourage safe glider road crossings.

Further Research
- Research and monitoring of strategies to mitigate linear barrier effects and road mortality, such as faunal underpasses and artificial canopy bridges, is required.

IMPACTS OF ROADS AND POWERLINES

Section 1: The Effect of Canopy Closure and Road Verge Habitat on Small Mammal Community Composition and Movements

1. The Effect of Canopy Closure and Road Verge Habitat on Small Mammal Community Composition and Movements

Miriam Goosem

Summary: *This study demonstrated that grassland and feral small mammals can intrude along the grassy and woody weed verges of a narrow road traversing rainforest. These species existed even where short lengths of road with canopy closure subdivided the grassy verge habitat. However they failed to penetrate the rainforest interior and were not resident at the road edge where canopy closure was maintained. Rainforest small mammals were not excluded from a narrow grassy and woody weed verge either by the alien habitat or by the presence of grassland small mammals, possibly due to the proximity of woody weeds which appeared to be favourable, though not ideal, habitat for rainforest species. However rainforest species abundance was halved in comparison to that of the adjacent forest edge and interior.*

Small mammal community composition at the edge was altered adjacent to a narrow road with a grassy verge, with a generalist species increasing and concomitant reduction in a more specialist rainforest species. However, where canopy closure was maintained and there was little obvious disturbance to the understorey and ground layers, small mammal communities were comparable to the forest interior with the exception of a probable reduction in abundances of less common species. The narrow road caused inhibition of crossing movements of several small mammal species, regardless of the clearing type (grassy and woody weed verge or closed canopy) in comparison with the forest interior. Movements of a larger species were unaffected by a road with canopy closure.

1.1 Introduction

'Internal fragmentation' of small mammal populations by roads and other linear clearings that traverse through large areas of habitat has been demonstrated in many areas of the world. Such 'linear barriers' may inhibit crossings of the clearing by small mammals in habitats as diverse as desert (Garland and Bradley 1984), grasslands (Wilkins 1982), heath (King 1978), agricultural lands (Cole 1978, Kozel and Fleharty 1979, Swihart and Slade 1984) and temperate forests (Oxley *et al.* 1974, Mader 1984, Bakowski and Kozakiewicz 1988). Wildlife habitat is divided by such 'linear barriers', causing subdivision of populations into smaller population sizes which may be ecologically or genetically less viable (Schafer 1990). Barrier effects of roads have also been recorded for many larger mammals including reindeer and elk (Klein 1971, Ward 1973), bear (McLellan and Shackleton 1988, Brody and Pelton 1989), antelope (Pienaar 1968), and wolf, bobcat and red fox (Mech 1989, Allen and Sargent 1993, Thurber *et al.* 1994, Mladenoff *et al.* 1995, Lovallo and Anderson 1996).

In tropical rainforest linear barrier studies have demonstrated severe inhibition of movements across roads for understorey birds (Mason 1995), and arboreal possums (R. Wilson, pers. comm.) as well as small mammals (Barnett *et al.* 1977, 1978, Burnett 1992, Goosem and Marsh 1997, Goosem, in press). However, for several species, although narrow rainforest roads inhibit small mammal movements, the road does not constitute a complete barrier (Burnett 1992, Goosem, in press). Crossings can be encouraged by translocating animals across the road (Burnett 1992), or by baiting on only one side of the barrier (Burnett 1992, Goosem, in press). In contrast, Goosem and Marsh (1997) demonstrated a complete barrier effect on the movements of tropical rainforest small mammals posed by the presence of a powerline clearing with a 60 metre wide grassy swathe. Rainforest small mammals used remnant and regrowth rainforest connections remaining in gullies to cross the powerline clearing but could not be induced to cross the grassy swathe. The presence of a grassland small mammal community within the powerline clearing appeared to prevent movements of rainforest small mammals (Goosem and Marsh 1997), grassland species possibly outcompeting the rainforest species and thereby excluding them from the powerline clearing.

Where rainforest roads have a similar, but narrower, grassland verge, the possibility exists that similar subdivision of small mammal populations may occur. It has been demonstrated that rainforest small mammals will move through grassland areas of the Atherton Tablelands, where congeneric grassland species are absent (Laurance 1989, Williams and Marsh 1998). However, even occasional dispersal crossings of the road may be prevented, if, in addition to traversing the alien grassy habitat, the rainforest species must contend with competition from better-adapted grassland small mammals. Middleton (1993) reported that grassland small mammals intruded along the grassy road verges of the Palmerston Highway and one road in the South Johnstone road network. The effect on small mammal movements of narrower roads with grassy swathes is still relatively unknown, although Goosem (in press) did observe that wider clearing widths significantly reduced crossing rates during the breeding season. Maintenance of canopy closure over a road may prove important in the prevention of linear barrier effects attributable to more open areas with grassy verges.

Powerline clearings and roadsides through forests are often maintained as grassland or low, shrubby swathes (Goosem 1997). Fauna alien to the surrounding forest habitat may penetrate along these narrow strips of alien habitat (Anderson *et al.* 1977, Getz *et al.* 1978, Johnson *et al.* 1979, Kroodsma 1982, Chasko and Gates 1982). Feral species, including predators such as cats and foxes (May and Norton 1996, Burnett 1995), cane toads (Seabrook and Dettman 1996) and pigs (Mitchell and Mayer 1997) also penetrate forests along linear clearings. Grassland and feral small mammal species have been observed to intrude along Wet Tropics rainforest roads (Goosem 2000), as well as powerline clearings (Middleton 1993, Goosem and Marsh 1997). The presence of these better-adapted species may prevent colonisation of the alien grassland habitat by rainforest species (Middleton 1993, Goosem and Marsh 1997), as well as preventing movements of rainforest species across the clearing. However, it appears that intrusions by grassland species may be much more unlikely in areas (such as at Mt Lewis) where grassland road verges are subdivided by long lengths of road with rainforest canopy closure preventing grassland establishment (Goosem and Turton 1999). Whether grassland species can intrude along narrow rainforest roads with interconnected grassy verges or where short lengths of rainforest canopy closure divide the grassland habitat is yet to be determined.

Edge effects consist of a diverse array of ecological changes occurring at and in the vicinity of the abrupt, artificial margins of natural habitat with adjacent anthropogenically-modified habitat. Edge alterations in the composition of small mammal communities have been demonstrated along rainforest roads (Goosem 2000), species such as the fawn-footed Melomys favouring edges while bush and Cape York rats are less common near the edge. The presence of grassy verges where the road clearing width measured 20 metres generally resulted in greater edge alterations in community composition, although edge effects could be detected during the breeding season even where clearing widths were narrower and grassy verges were absent (Goosem 2000). Along grassy powerline clearings, edge effects in small mammal community composition were also evident (Goosem and Marsh 1997), effects being less noticeable adjacent to rainforest regrowth in gullies which formed a narrow ‘corridor’ connecting rainforest on either side of the powerline clearing. The small mammal composition of narrow rainforest road edges with a grassy verge or with canopy closure needs to be compared with that of the forest interior.

The objective of this study was to examine the effects of narrow rainforest roads on small mammal community composition and movements with the following aims:

1) To determine whether edge effects in small mammal community composition differ between areas where there are no roads (forest interior), along narrow roads where rainforest canopy closure is maintained and along narrow roads with wide grassy and woody weed verges;

2) To determine to what degree small mammal movements are inhibited by a narrow rainforest road with canopy closure or with a wide grassy and woody weed verge; and

3) To determine whether small mammal species alien to the rainforest habitat are able to penetrate areas where there are no roads (forest interior), where rainforest canopy closure is maintained or where a wide grassy and woody weed verge is present.

The South Johnstone road network was chosen for this study as it occurs in an area of high conservation value comprising Complex Mesophyll Vine Forest (Type 1a, *sensu* Tracey 1982), the habitat of many species of rare or threatened conservation status. Road and powerline clearings create a network of potential linear barriers with grassland and woody weed habitats. The Wet Tropics Management Authority requires input concerning the effect of these roads and has provided funding to the Department of Natural Resources to undertake trials for the control of weeds along the road. The objective of these trials is to determine whether chemical weed control will allow the release of rainforest tree species, thereby rehabilitating long areas of road verges without the requirement for large-scale tree planting. Department of Natural Resources personnel collaborated in the current project to allow the study to be undertaken prior to the weed control measures being undertaken. It is hoped that an examination of the impact of the weed control measures on the movements of small mammals can be undertaken within the next few years, utilising the present study as baseline data. Protocols will be established to undertake this monitoring of the effects of rehabilitation.

1.2 Methods

Study Sites
Six study sites were established in Wooroonooran National Park and State Forest 756 in the Complex Mesophyll Vine Forest (Tracey 1982) along the Maalan Road, part of the South Johnstone road network. The road has a very low traffic volume, only 2-4 vehicles per day being recorded during the trapping study. Sites incorporated the road clearing of approximately 8 metres in width, including drains. Two sites (Site 3 - 8052300N 357700E, Site 6 – 8051400N 358600E) were chosen where the road verge consists of Guinea grass (*Panicum maximum*) and molasses grass (*Melinus minutiflora),* with the woody weeds, lantana (*Lantana camara*) and wild raspberry (*Rubus moluccanus*) occurring closer to the rainforest edge. Altogether the weedy verge is 12-16 metres wide on either side of the road centre, resulting in two rows of traps being placed in grass or weeds on either side of the road. A second pair of sites was chosen where the rainforest canopy meets completely above the road, providing complete canopy closure (Site 2 – 8050900N 359200E, Site 5 – 8054500N 362300E). The third pair of sites was chosen as controls 100 metres inside the forest (Site 1 –8053200N 361700E, Site 4 – 8052400N 360800E). All sites are more than one kilometre apart. None of the sites incorporated any potential faunal underpasses (e.g. culverts).

Grid-trapping Methods
A trapping grid (56 m x 40 m) incorporating 48 trap sites, was established at each site (Figure 1.1). On each side of the road, the grid consisted of four rows running parallel to the road clearing at distances of 4, 12, 20 and 28 metres from the rainforest edge. Each row consisted of six Elliott Type A small mammal traps placed 8 metres apart. The distance between rows and between traps within rows was chosen so that any movement between traps must be at least 8 metres or at least identical to the distance required to cross the road clearing. In order to capture larger mammals such as *Uromys caudimaculatus*, one wire cage trap was placed on each of six of the eight rows with the Elliott trap at either the second or fifth position (Figure 1.1). The two rows without a wire cage trap were never adjacent. On each night 54 traps were set. Trapping was conducted over three or four consecutive nights in each trapping session. Table 1.1 shows the trapping sessions and number of nights trapped for each site. Effort at each site varied to obtain an equivalent number of individuals of rainforest species in each treatment (Table 1.1 and Table 1.3).

Figure 1.1. Design of the trapping grids for canopy closed site and grassy verge site. The forest interior site design is identical, without a road present.

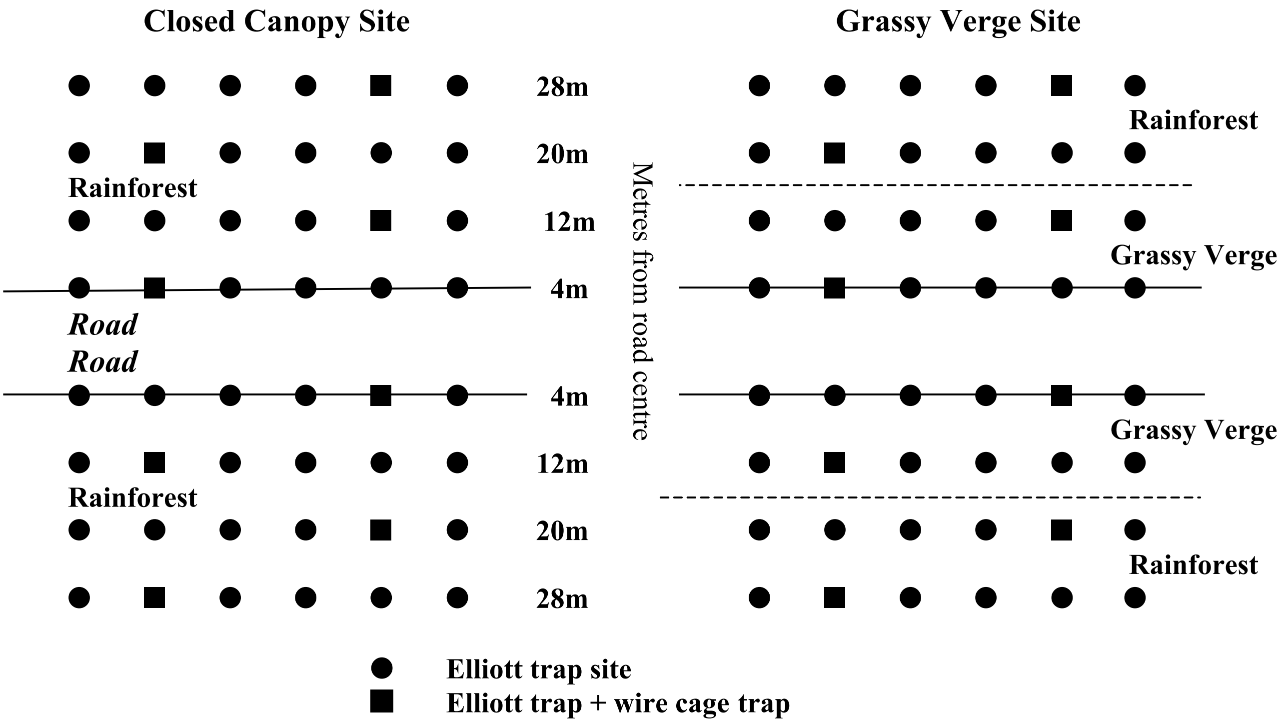


Table 1.1 Number of nights and month of trapping session for each site.

Treatment	Site	Trapping session (Nights trapped per trapping session)
Forest Interior	1	Sep 98 (3); Dec 98 (3); May 99 (4)
	4	Sep 98 (3); Dec 98 (3); Jun 99 (3)
Closed Canopy	2	Sep 98 (3); Dec 98 (3); Jan 99 (3); May 99 (4)
	5	Sep 98 (3); Dec 98 (3); Jan 99 (3); Jun 99 (3)
Grassy Verge	3	Sep 98 (3); Dec 98 (3); May 99 (4)
	6	Sep 98 (3); Dec 98 (3); Jan 99 (3); Jun 99 (3)

Traps were baited with a mixture of rolled oats and vanilla essence. All animals were released at point of capture. *Rattus fuscipes* (bush rat), *R. leucopus* (Cape York rat), *R. sordidus* (canefield rat), *Melomys cervinipes* (fawn-footed melomys), *M. burtoni* (grassland melomys), *Antechinus flavipes* (yellow-footed antechinus), *A. stuartii* (brown antechinus) and *Mus musculus* (house mouse) were individually marked with monel metal or brass fingerling tags through the ear pinna. *Uromys caudimaculatus* (white-tailed rat), *Hypsiprymnodon moschatus* (musky rat-kangaroo) and *Perameles nasuta* (long-nosed bandicoot) were marked individually by tattooing of the ear pinna. Two rainforest rodents, *Rattus leucopus* and *Rattus fuscipes*, were not able to be separated in the field, as the only satisfactory method of distinguishing them in the Palmerston area is by skull features (Goosem and Marsh 1997). Since both were present on the sites, the two species are designated in this report as *Rattus* sp.

Data Analysis

Data analysis of small mammal species composition used the number of animals known to be alive (KTBA) as the response variable i.e. individuals captured in a trapping session or captured subsequently after being captured in a previous trapping session. Data were pooled into four locations at each site defined by distance from the road (Table 1.2). The effects of road verge treatment and distance from the road (close to road or further from road, see Table 1.2) on species composition was examined by three-dimensional contingency analysis.

Table 1.2. Location classification

Location	Side of Road	Distance from centre of road
1 (close to road)	Eastern	4 and 12 m
2 (further from road)	Eastern	20 and 28 m
3 (close to road)	Western	4 and 12 m
4 (further from road)	Western	20 and 28 m

The effects of road verge treatment and location (Table 1.2) on the number of individuals KTBA of *Rattus* sp. and *Melomys cervinipes* were examined using analysis of variance. Data were pooled over the three or four trapping sessions for each treatment. Aggregated data were transformed to achieve constant variance within groups using $\log_{10}(X+0.1)$. Where clearing type effects were significant, special contrasts partitioned the two degrees of freedom associated with the clearing type effects to determine the major contributions to those effects. The clearing type contrasts examined were: 1) forest interior vs canopy closure; and 2) an average of forest interior and canopy closure with grassy verge. Where location effects were significant, orthogonal contrasts partitioned the three degrees of freedom associated with the location effects to determine the major contributions to those effects. The location contrasts examined were: 1) rainforest close to road vs rainforest further from road; 2) the difference between rainforest close to the edge and rainforest further away on one side of the road vs the equivalent difference on the other side of the road; and 3) rainforest on one side of the road vs rainforest on the other side.

1.3 Results

Community Structure

The six sites were grid-trapped for a total of 3564 trap-nights. Seven species of rainforest small mammal were recorded, while three species of grassland small mammal were captured at the grassy verge sites (Table 1.3). No grassland small mammal species were found at forest interior or closed canopy sites. Captures of *A. flavipes, A. stuartii, P. nasuta* and *H. moschatus* were insufficient to be considered in data analysis, except as a combined ‘other rainforest species’ category in χ^2 analyses.

The structure of the small mammal community varied with clearing type (Figure 1.2, Table 1.3). Only species recognised as preferring rainforest habitats were found at both the forest interior sites and the sites with canopy closure. In contrast, the presence of grass and woody weeds in the verge allowed the ingress of three species recognised as preferring grassland habitats: the grassland Melomys, *Melomys burtoni,* the canefield rat, *Rattus sordidus* and the feral house mouse, *Mus musculus*.

Table 1.3. Numbers of small mammal species known to be alive (KTBA) and captured at forest interior (no road) sites, sites with canopy closure over the road surface and sites with a wide verge of grass and woody weeds.

Species	Forest Interior (No road)		Canopy Closure		Grassy Verge	
	KTBA	Captures	KTBA	Captures	KTBA	Captures
Rainforest Species						
Rattus sp.	62	160	68	210	53	120
M. cervinipes	22	54	25	68	48	104
U. caudimaculatus	10	13	4	6	1	3
A. flavipes	2	2	1	1	0	0
A. stuartii	3	3	0	0	2	2
P. nasuta	0	0	1	1	0	0
H. moschatus	0	0	0	0	1	1
Total Rainforest	**99**	**232**	**99**	**286**	**105**	**230**
Grassland Species						
M. burtoni	0	0	0	0	7	23
R. sordidus	0	0	0	0	8	26
M. musculus	0	0	0	0	7	10
Total Grassland	**0**	**0**	**0**	**0**	**22**	**59**

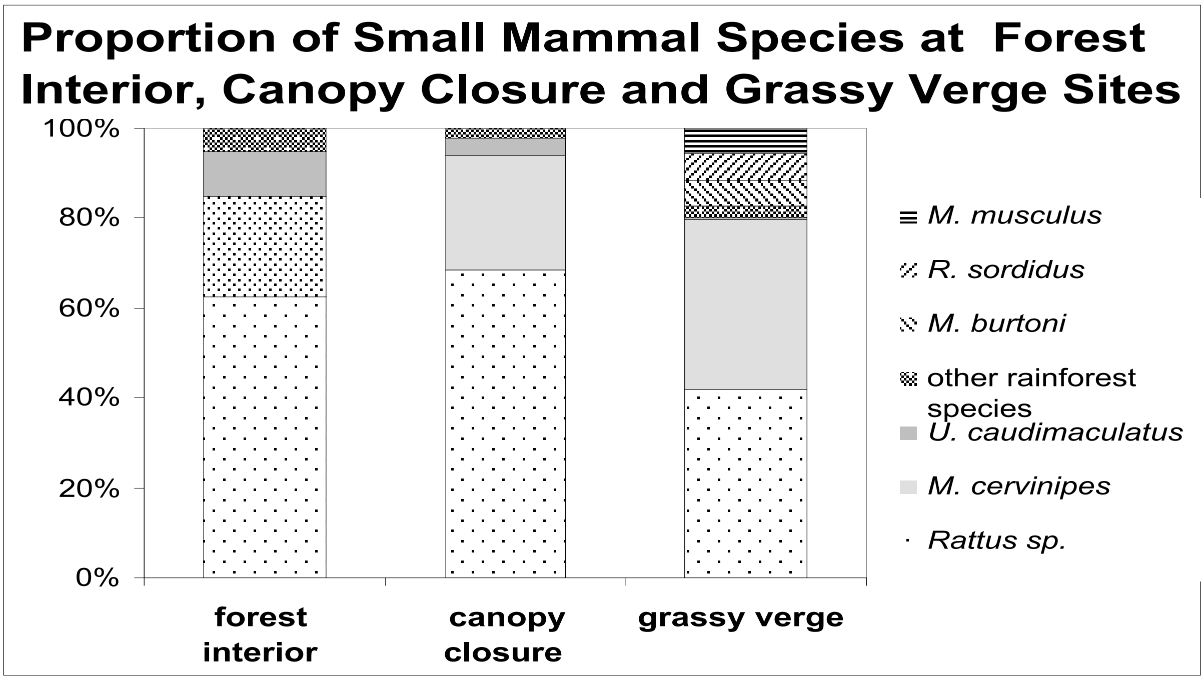
Three dimensional χ^2-analysis (Table 1.4) showed that the proportions of rainforest species (*Rattus* sp., *M. cervinipes* and all other rainforest species) were dependent on clearing type and distance from the road (whether occurring on the two trapping rows close to the road edge i.e. 4 and 12 metres or at trapping rows further from the edge i.e. 20 and 28 metres). Tests of partial independence of the three factors (species, clearing type and distance) showed that clearing type effects were significant regardless of distance (Table 1.4). Figure 1.3 shows the patterns of this dependence of species on clearing type. Where closed canopy provided cover above the road surface, a greater proportion of *Rattus* sp. occurred close to the road edge than in the grassy verge. In contrast, higher proportions of *M. cervinipes* than *Rattus* sp. occurred in the grassy verge and in the rainforest edge adjacent (grassy verge site further from road) than at the closed canopy sites. Very few of the less common rainforest species were found close to any road, in comparison with the forest interior.

Table 1.4. Three-dimensional χ^2-analysis of clearing type[a] and distance[b] on the proportions of *Rattus* sp., *M. cervinipes* and other rainforest species[d] and tests for partial independence of the three factors[c].

Model	χ^2	Df	P
Species, clearing type, distance	53.485	12	**<0.001**
Species, (clearing type + distance)	41.212	10	**<0.001**
Distance, (species + clearing type)	14.193	8	<0.100
Clearing type, (species + distance)	51.892	10	**<0.001**
Species, clearing type	40.025	4	**<0.001**

[a] Clearing type had three levels – forest interior, closed canopy and grassy verge.
[b] Distance had two levels - close to road (4 and 12 m) and further from road (20 and 28 m).
[c] Due to the multiplicity of tests, $\alpha = 0.01$
[d] Other rainforest species comprised *U. caudimaculatus, A. flavipes, A. stuartii* and *H. moschatus*.

Figure 1.2. Composition of the small mammal community at each of the three road verge types: rainforest interior at least 100 metres from the road; narrow road with closed canopy over the road surface; and grassy and woody weed road verge along a narrow road.



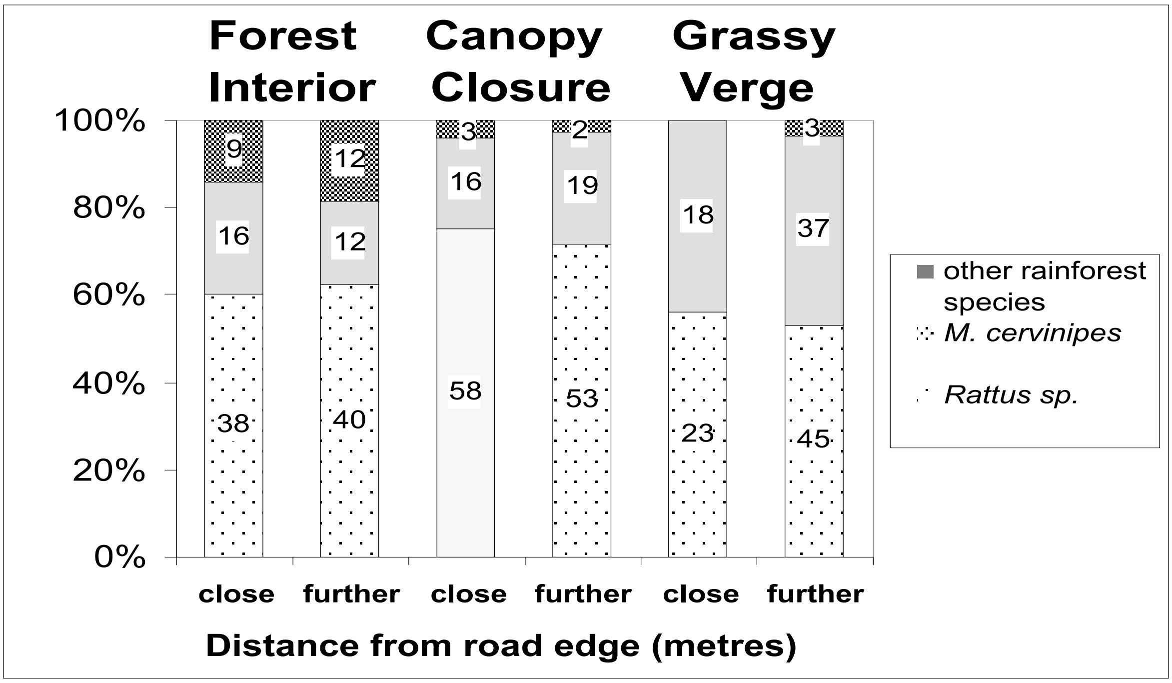
Individuals known to be alive were pooled over three or four trapping sessions and over all trapping rows from each of two sites at each road verge treatment.

As expected, in the absence of any road (forest interior sites), there was little difference in proportions of rainforest species between trapping rows in the centre of the grid (close) and those on the outskirts (further) (Figure 1.3). The lack of distance effects are demonstrated in the similarity between proportions of rainforest species close to the road and further from the road for both closed canopy sites and grassy verge sites. However abundances of rainforest species are reduced close to the road in the grassy verge (Figure 1.3), where they are replaced by grassland species (Figure 1.2), which form 33.9% of individuals. A small proportion (5.6%) of grassland species penetrate the rainforest edge at the grassy verge site, where they were found only in the trapping row on the very edge of the forest/woody weed interface.

The habitat preferences of the major rainforest species are shown in Figure 1.4. There was little variation in abundance of *Rattus* sp. throughout the forest interior grid, whereas abundance increased slightly close to the road on one side of the closed canopy treatment. There also was a slight decrease in *Rattus* sp. close to the road at the grassy verge sites. However, under the rainforest canopy bordering the grassy verge (20-28 metres from the road centre), *Rattus* sp. abundance was similar to that at the forest interior and closed canopy sites Therefore there was no obvious 'edge effect' at the rainforest/weed and grass interface for *Rattus* sp. The decrease in abundance in less favourable grassy and weedy habitat at the grassy verge site was not large enough to cause a significant location or clearing type effect when analysis of variance was performed on the *Rattus* sp. data (Table 1.5).

In contrast, the abundance of *M. cervinipes* generally increased close to the road at the closed canopy sites and decreased close to the road at the grassy verge treatments while remaining relatively stable throughout the forest interior sites (Figure 1.4), resulting in a significant clearing type effect when data were analysed by ANOVA (Table 1.5). For *M. cervinipes*, forest interior sites were not significantly different from closed canopy sites, while the mean abundance of *M. cervinipes* found in the forest interior and closed canopy sites contrasted highly significantly with that at the grassy verge sites (Table 1.5).

Figure 1.3. Composition of the small mammal community pooled over two sites for each of three clearing types[a] and two distances[b]. Rainforest species that occurred in low abundances (*U. caudimaculatus, A. flavipes, A. stuartii, P. nasuta and H. moschatus)* were pooled into the 'other rainforest species' category.



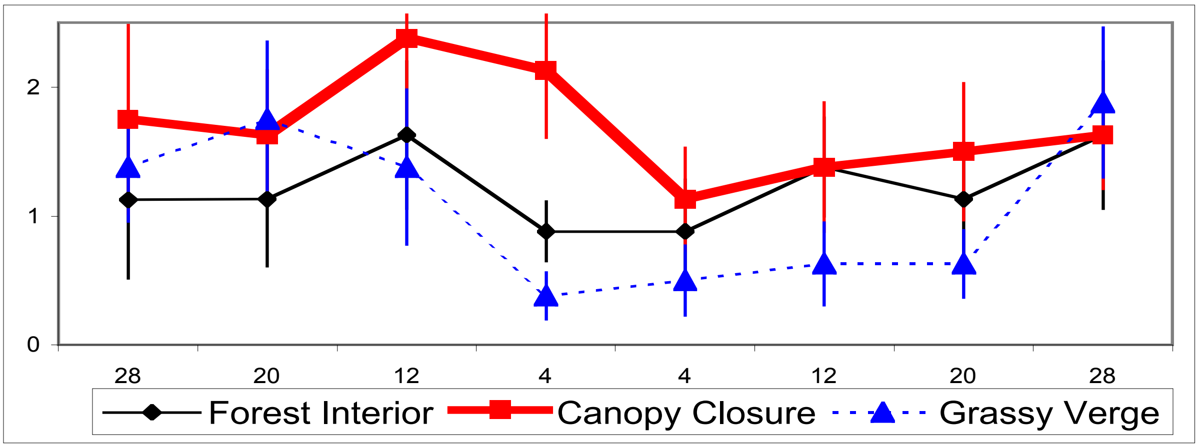
[a] There were three clearing types (i.e. road verge types) – forest interior (no road), closed canopy above the road and grassy and woody weed road verge.
[b] The two distances at each treatment were a) close to the road (4 and 12 metres from the road centre) and b) further from the road (20 and 28 metres from the road centre).

U. caudimaculatus was patchily distributed in low abundances, limiting the possibility of patterns. However analysis of variance showed that clearing type was significant (Table 1.5), due mainly to the contrast between almost no captures at the grassy verge site and few captures at the closed canopy site in comparison with low but relatively constant abundance in the forest interior (Figure 1.4, Table 1.5).

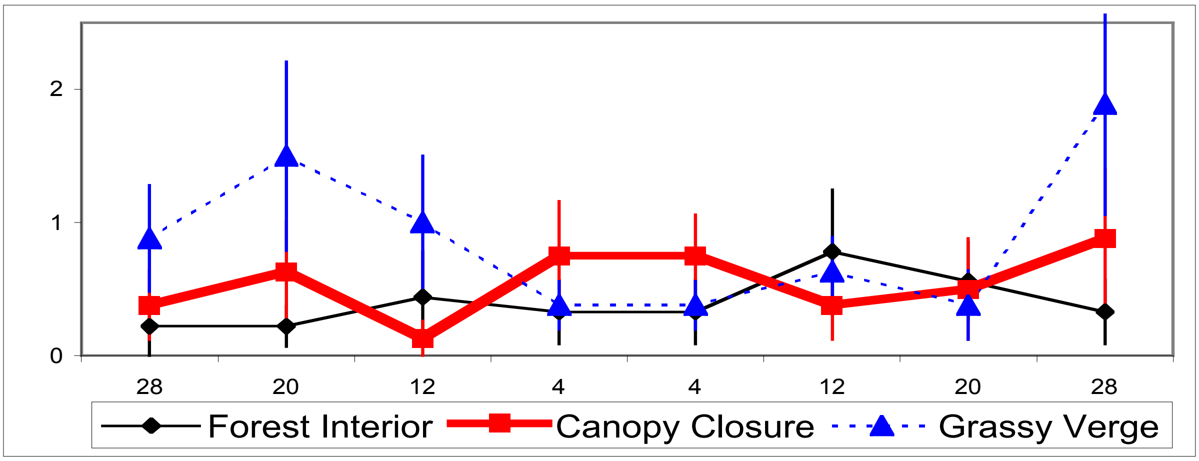
Grassland species were only found at the grassy verge sites, and therefore dependent on that clearing type, making analysis of variance for the effect of clearing type on individual species redundant. The occurrence of grassland species is shown in Figure 1.5. Both *Mus musculus* and *R. sordidus* were only found in the grassy verge. *Melomys burtoni* occasionally intruded at the edge of the rainforest where it abutted the woody weeds and grass.

Figure 1.4. Abundance of rainforest small mammals from 28 metres inside the forest on one side of the road across the road (or pseudo-road) to 28 metres inside the forest on the other side of the road. Means and standard errors are shown for data pooled over clearing types and trapping rows.

Rattus sp.



Melomys cervinipes



Uromys caudimaculatus

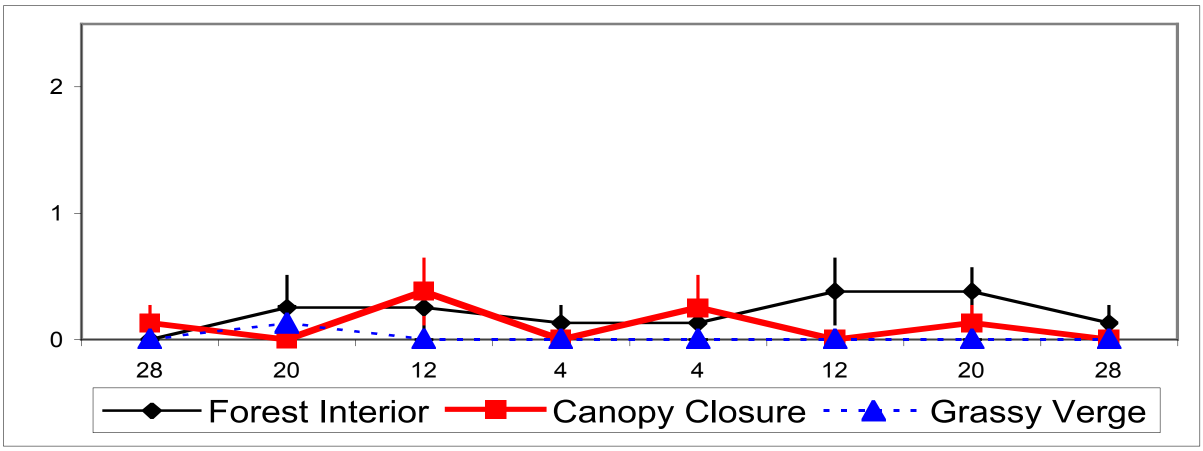


Table 1.5. Results of ANOVA testing the effects of location and clearing type on the number of *Rattus* sp., *M. cervinipes* and *U. caudimaculatus.*

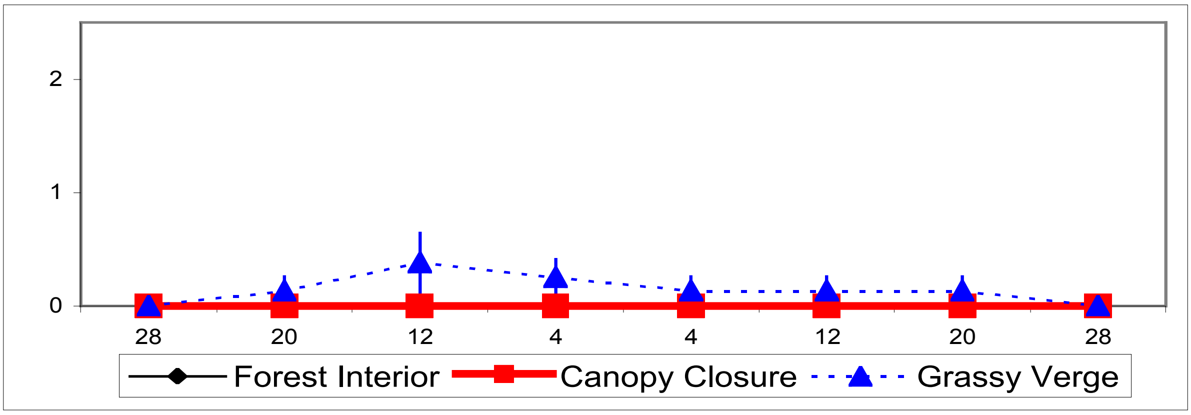
Species	Source of Variation	df	MS	F	P
Rattus sp.	Location	3	0.02	0.37	0.776
	clearing type	2	0.07	1.46	0.253
	site nested in clearing type	3	0.06	1.41	0.266
	location * clearing type	6	0.03	0.64	0.697
	site nested in clearing type * location	9	0.05	1.05	0.433
M. cervinipes	Location	3	0.02	0.17	0.916
	clearing type	2	0.66	4.71	**0.019**
	site nested in clearing type	3	0.21	1.50	0.239
	clearing type * location	6	0.07	0.53	0.779
	site nested in clearing type * location	9	0.05	0.35	0.949
	special contrast between forest interior and canopy closure	1	0.02	0.12	0.728
	special contrast between the mean of forest interior and canopy closure with grassy verge	1	1.29	9.30	**0.006**
U. caudimaculatus	Location	3	0.00	0.02	0.996
	clearing type	2	0.51	8.69	**0.001**
	site nested in clearing type	3	0.01	0.14	0.937
	clearing type * location	6	0.06	1.06	0.415
	site nested in clearing type * location	9	0.06	0.99	0.472
	contrast between interior and canopy closure	1	0.64	10.85	**0.003**
	contrast between forest interior and the mean of canopy closure and grassy verge	1	1.00	17.06	**0.0004**

Movements and Road Crossings

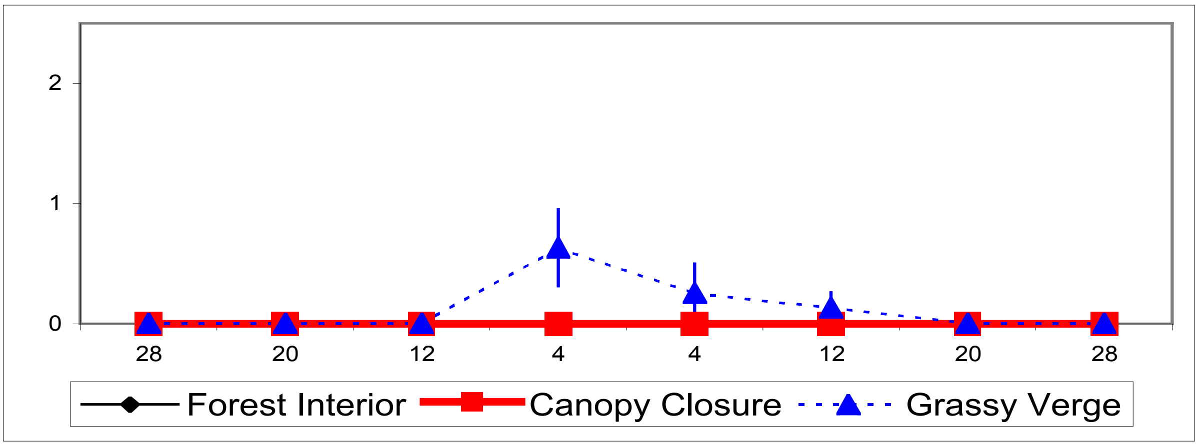
Movements and road crossings for all species are shown in Table 1.6. For *Rattus* sp., road crossing rates were significantly inhibited (Table 1.7) at the closed canopy sites and grassy verge sites, in comparison with the forest interior sites (Figure 1.6). Road crossings by *M. cervinipes* also differed (Table 1.7, Figure 1.6) between closed canopy, grassy verge and forest interior treatments. The reduction in crossing rate observed at the closed canopy and grassy verge sites approached significance when compared with the forest interior (Table 1.7), although few data were available (Table 1.6). The few data for *U. caudimaculatus* suggested no inhibition of crossings at closed canopy sites (the only movement recorded was a crossing) compared with forest interior sites (Figure 1.6). *U. caudimaculatus* did not cross the road at the grassy verge site, the only movement for this species recorded there was towards the forest interior. The inclusion of all movements recorded both during and between trips does not change the pattern evidenced for first movements (Table 1.6).

Figure 1.5. Abundance of grassland small mammals from 28 metres inside the forest on one side of the road across the road (or pseudo-road) to 28 metres inside the forest on the other side of the road. Means and standard errors are shown for data pooled over clearing types and trapping rows.

M. burtoni



Mus musculus



R. sordidus

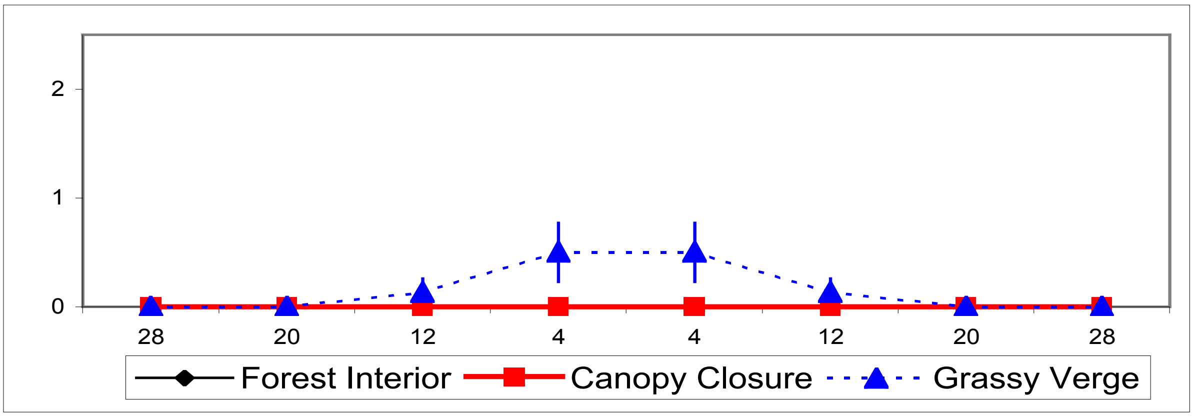
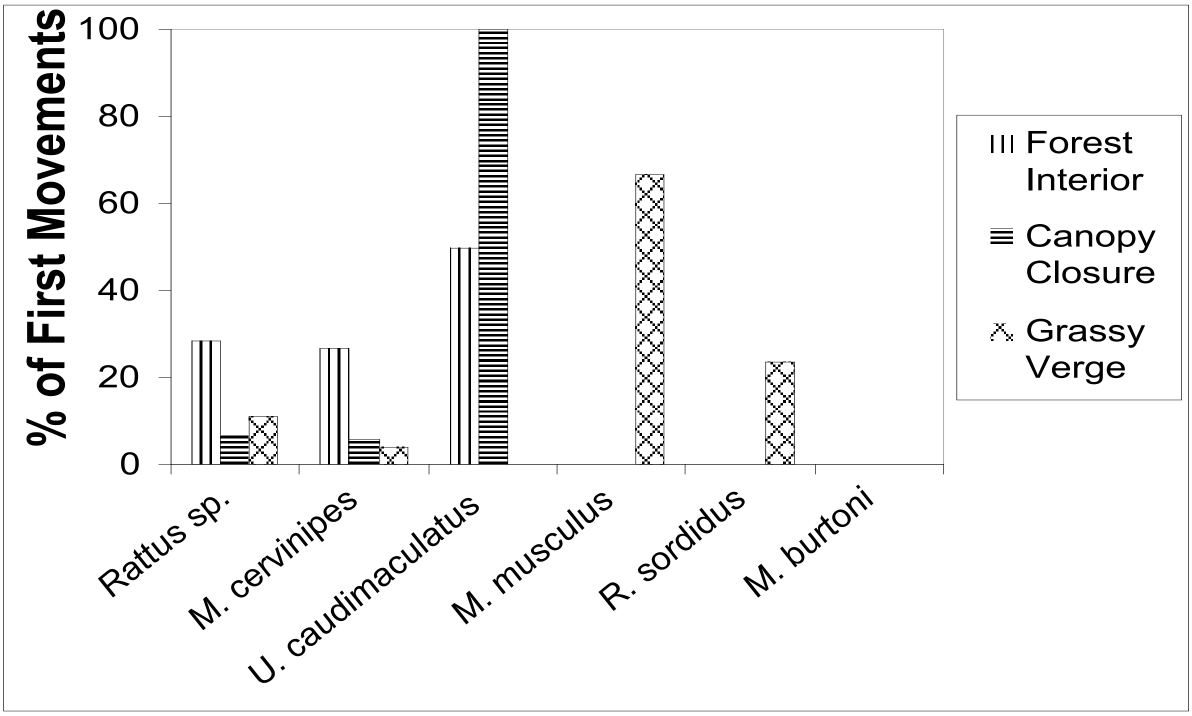


Table 1.6. Movements and road crossings at forest interior (no road) sites, sites with canopy closure above the road surface and sites with a grassy and weedy road verge extending at least 12 metres from the road centre.

Species	Site	Treatment	Movement > road width[a] ([b])	Crossings [a] ([b])	% crossings[a] ([b])	Movement parallel or into forest from Row D/E[c]	Crossing from Row D/E[c]	% crossing from Row D/E[c]
Rattus sp.	1	forest interior	32 (60)	7 (14)	21.9 (25.0)	4	3	42.9
	4	forest interior	17 (26)	7 (9)	41.1 (34.6)	3	7	70.0
	total	**forest interior**	**49 (86)**	**14 (23)**	**28.6 (26.7)**	**7**	**10**	**58.8**
	2	canopy closure	16 (34)	1 (3)	6.3 (8.8)	5	3	37.5
	5	canopy closure	46 (95)	3 (6)	6.5 (6.3)	18	1	5.3
	total	**canopy closure**	**62 (129)**	**4 (9)**	**6.5 (7.0)**	**23**	**4**	**14.8**
	3	grassy verge	11 (25)	0 (3)	0 (12.0)	1	0	0
	6	grassy verge	19 (38)	2 (4)	10.5 (10.5)	3	0	0
	total	**grassy verge**	**30 (63)**	**2 (7)**	**6.7 (11.1)**	**4**	**0**	**0**
M. cervinipes	1	forest interior	12 (24)	2 (4)	16.7 (16.7)	2	3	60.0
	4	forest interior	3 (5)	2 (2)	66.7 (40.0)	0	1	100.0
	total	**forest interior**	**15 (29)**	**4 (6)**	**26.7 (20.7)**	**2**	**4**	**66.7**
	2	canopy closure	5 (12)	1 (2)	20.0 (16.7)	1	0	0
	5	canopy closure	12 (28)	0 (4)	0 (14.3)	10	4	28.6
	total	**canopy closure**	**17 (40)**	**1 (6)**	**5.9 (15.0)**	**11**	**4**	**26.7**
	3	grassy verge	18 (31)	1 (2)	5.6 (6.5)	3	2	40.0
	6	grassy verge	8 (22)	0 (2)	0 (9.1)	1	1	50.0
	total	**grassy verge**	**26 (53)**	**1 (2)**	**3.8 (3.8)**	**4**	**3**	**42.9**
U. caudimaculatus	1	forest interior	2 (3)	1 (2)	50.0 (66.7)	0	0	na
	5	canopy closure	1 (1)	1 (1)	100 (100)	0	0	na
	3	grassy verge	1 (2)	0 (0)	0 (0)	0	0	na
M. burtoni	3	grassy verge	6 (14)	0 (0)	0 (0)	2	0	0
	6	grassy verge	1 (2)	0 (0)	0 (0)	7	0	0
	total	**grassy verge**	**7 (16)**	**0 (0)**	**0 (0)**	**9**	**0**	**0**
R. sordidus	3	grassy verge`	2 (6)	0 (0)	0 (0)	4	0	0
	6	grassy verge	7 (11)	3 (4)	42.9 (36.4)	4	3	42.9
	total	**grassy verge**	**9 (17)**	**3 (4)**	**33.3 (23.5)**	**8**	**3**	**27.3**
Mus musculus	3	grassy verge	2 (2)	1 (1)	50 (50)	1	1	50
	6	grassy verge	1 (1)	1 (1)	100 (100)	0	1	100
	total	**grassy verge**	**3 (3)**	**2 (2)**	**66.7 (66.7)**	**1**	**2**	**66.7**

[a] First movements within trips.
[b] All movement within and between trips.
[c] All movements within and between trips from rows D or E i.e. trapping rows adjacent to road's edge.

Figure 1.6. The percentage of first movements that were road crossings for rainforest and grassland small mammal species at forest interior, closed canopy and grassy verge sites.



When *Rattus* sp. was captured in the trapping rows closest to the 'pseudo-road' (rows D and E) at the forest interior sites, crossings were very likely to occur (58.8 % of movements were crossings). The few data of movements from the trapping rows adjacent to the road on the closed canopy and grassy verge sites were insufficient to demonstrate that crossings were inhibited in comparison with the expected rate of 27.8% if movements in all directions were random (canopy closure: $\chi^2 = 1.838$, df = 1, P = 0.175; grassy verge: $\chi^2 = 0.470$, df = 1, P = 0.493). However, when compared with the forest interior, crossings from rows adjacent to the narrow road were significantly different, forming 14.8% of movements at the canopy closed sites and 0% at the grassy verge sites ($\chi^2 = 11.577$, df = 2, P = 0.003). Crossings of the road were inhibited (forest interior vs closed canopy + grassy verge: $\chi^2 = 9.085$, df = 1, P = 0.003).

In contrast, although *M. cervinipes* made relatively few road crossings, once an individual was captured on the trapping rows closest to the road, crossings were relatively likely to occur, irrespective of clearing type (forest interior 66.7%, closed canopy 26.7%, grassy verge 42.9%: $\chi^2 = 2.924$, df = 2, P = 0.232).

Movements of grassland species were sparse (Table 1.6), making generalisations regarding road crossing inhibition of these species difficult. However, a high proportion of the few movements by *R. sordidus* and *Mus musculus* at the grassy verge sites (Figure 1.6) were crossings, mostly from the rows adjacent to the road (Table 1.6). The few movements by *M. burtoni* did not include a crossing. Therefore, for at least two out of three grassland small mammal species, the road surface did not appear to pose a barrier.

Table 1.7. χ^2-analysis of the effect of clearing type[a] on the numbers of crossings of *Rattus* sp., *M. cervinipes* and other rainforest species[b] and tests for partial independence of the three clearing types.

Species	Model	χ^2	df[c]	P[d]
Rattus sp.	forest interior, canopy closure, grassy verge	9.185	2	**0.010**
	forest interior, (canopy closure + grassy verge)	7.761	1	**0.005**
	canopy closure, (forest interior + grassy verge)	2.982	1	0.084
	grassy verge, (forest interior + canopy closure)	0.939	1	0.332
M. cervinipes	forest interior, canopy closure, grassy verge	6.320	2	**0.042**
	forest interior, (canopy closure + grassy verge)	3.678	1	0.055
	canopy closure, (forest interior + grassy verge)	0.060	1	0.806
	grassy verge, (forest interior + canopy closure)	1.070	1	0.301

[a] Clearing type had three levels – forest interior, closed canopy and grassy verge.

[b]Other rainforest species comprised *U. caudimaculatus, A. flavipes, A. stuartii* and *H. moschatus*.

[c] Yates correction applied where df = 1.

[d] Significant effects are shown in bold, $\alpha = 0.05$.

1.4 Discussion

Intrusions by Grassland Small Mammals

The presence of a narrow road demonstrably altered the structure of the small mammal community. Grassy verges with woody weeds allowed the intrusion of three species of grassland small mammal alien to the adjacent rainforest habitat, one of these being a species feral to Australia. This finding agrees with previous work undertaken in a powerline clearing in the Wet Tropics (Middleton 1993, Goosem and Marsh 1997), where grassland mammals intruded along the grassy swathe of a 60 metre wide powerline clearing which connects with the narrow road examined in this study. However, no small mammals typical of grassland areas were found to be resident either in the forest interior, or, more importantly, where canopy closure occurred above the road surface. Thus, it appears that intrusions into rainforest of small mammals alien to rainforest habitats were prevented by canopy closure.

The grassy verge along the Maalan Road was not contiguous; being divided in several places by short stretches (up to 500 metres) of closed canopy. These stretches of closed canopy effectively isolated at least one (and to a lesser extent both) of the grassy verge sites from continuous grassy verge further along the Maalan road and from the grassland of the Palmerston powerline clearing. Both grassy sites were colonised by grassland small mammals, irrespective of their degree of isolation. There was no significant difference between proportions of grassland species close to the road at the two grassy verge sites (32.1 vs 35.3% of individuals). Therefore it appears that minor discontinuities in grassy verge connectedness do not affect the ability of grassland species to persist in the small areas of grassland habitat. This is in contrast to the findings at Mt Lewis (Goosem and Turton 1999), where it was found that where canopy closure existed over the road for several kilometres, no grassland species were captured in the highly isolated strips of grassy road verge examined. There were no significant differences between replicate sites demonstrated in the analyses of variance for the rainforest species *Rattus* sp., *M. cervinipes* and *U. caudimaculatus.* Therefore, it appears that greater isolation of one of the Maalan Road grassy verges has not aided in recolonisation of the alien habitat by rainforest species, as has occurred at Mt Lewis.

One of the interesting results recorded in this experiment was the degree to which rainforest species were found within the grassy and woody weed verge. Prior to this study, only grassland small mammals had been recorded within the linear clearing network of the South Johnstone roads and Palmerston powerline clearing (Middleton 1993, Goosem and Marsh 1997), other than along rainforest edges where lantana and wild raspberry formed a low continuous canopy. Thus in experiments along the powerline clearing in 1992, I captured *Rattus* sp. and *M. cervinipes* ten metres within the powerline clearing, but only adjacent to the woody weeds. The situation along the Maalan Road is analogous to the edge of the powerline clearing. The two trapping rows placed within the grassy and woody weed verge lie within twelve metres of the rainforest edge, and again woody weeds predominated close to the edge. Therefore the presence of a relatively high proportion of rainforest species was not unexpected, as these apparently utilise the woody weeds and, indeed, may become resident there (pers. obs. in powerline clearing where lantana now dominates much of the clearing).

Abundances of *Rattus* sp. and *M. cervinipes* were halved in the grassy and woody weed verge in comparison to the area at and beyond the rainforest edge at the same sites, whilst other rainforest species were not captured within the verge at all. Grassland small mammals partially replaced the rainforest species in the verge, but absolute abundance of small mammals was only about two thirds of that found under the rainforest canopy at and beyond the edge. The majority of this decline in abundance was due to the few rainforest individuals present in the rows immediately adjacent to the road, where the habitat was mainly grass (Figure 1.4). Concomitant with the lack of rainforest individuals in those trapping rows is an increase in grassland individuals (Figure 1.5). It appears that grassy habitat was unfavourable to rainforest species, as has been recorded in prior studies (Middleton 1993, Goosem and Marsh 1997), but rainforest species were not completely excluded. The likely reason for the ability of rainforest species to penetrate the grassy habitat is the close proximity to a more colonisable habitat of woody weeds. Therefore it appears that the degree to which grassland small mammals exclude their rainforest competitors from grassy habitat may depend on the extent of the areas of grassland habitat. This, in turn, is likely to be dependent on the maintenance regime for the grassland. Where fires were used as a management tool in the powerline clearing to maintain low vegetation beneath the powerlines, grassland was favoured over the woody weeds and the better-adapted grassland small mammals thrived and excluded their rainforest counterparts from the clearing (Goosem and Marsh 1997). Where fires were not viable along the verges of the Maalan Road, woody weeds encroached and have provided viable, although not ideal, habitat for rainforest species.

Edge Effects in Rainforest Small Mammal Community Composition

The presence of a narrow road, in addition to allowing penetration of grassland small mammals via the grassy verge, also caused alterations in the composition of the rainforest small mammal community at the rainforest edge. In this case the rainforest edge is considered to be the area immediately adjacent to the road at the closed canopy sites and the area beyond the grassy and woody weed verge at the grassy verge sites. The proportions of *M. cervinipes* occurring in or beyond the rainforest edge in comparison to *Rattus* sp. was greater at the grassy verge sites than at the closed canopy or forest interior sites, forming 45.1% of the total of both species compared with 21.6% - 29.6% at the other sites. This proportion was similar to that of the two species found within the grassy verge (43.9%). This agrees with results observed on the narrow Black Mountain road in areas with a wide clearing width (Goosem 2000). In that case, abundance of *M. cervinipes* increased close to the road while *Rattus* sp. decreased similarly to the present study. This effect was particularly noticeable adjacent to a wide clearing where canopy closure was not maintained, allowing the growth of a less-dense grassy verge comprising Guinea grass (*Panicum maximum*) and blady grass (*Imperata cylindrica*).

Adjacent to the Black Mountain road, edge effects in areas with canopy closure became prominent during the wet season when juveniles of *M. cervinipes* entered the trappable population, colonising the edges of the road (Goosem 2000). In the current study, no obvious edge effects in proportions of *M. cervinipes* and *Rattus* sp. were discernible where canopy closure was maintained, although wet season trapping did take place. One reason postulated for the increase in abundance of *M. cervinipes* and reduction in *Rattus* sp. close to the Black Mountain road was the increase in disturbed forest conditions at the rainforest edge (Goosem 2000). Disturbed forest correlates with elevated levels of ground cover, lawyer cane (*Calamus* spp.) and tree-falls (Laurance 1994) at anthropogenic edges where *M. cervinipes* increases and *Rattus fuscipes* decreases. *M. cervinipes* also increase in abundance at natural ecotones, again correlating with increased density of understorey vegetation (Williams and

Marsh 1998). In the current study, there was little obvious increase in ground cover, lawyer cane, tree-falls or understorey density associated with disturbance at the road edge where canopy closure was maintained. The two closed canopy sites were in very good condition, the major obvious disturbance factor being litter. In contrast, the rainforest edges at the grassy verge sites were very disturbed, being characterised by many tree-falls, high levels of lawyer cane and dense ground cover and understorey. Thus, it appears that avoidance of road edges by *Rattus* sp. may relate more to the disturbance status of the site, than to the presence of a road *per se*. Apart from the type of verge, environmental conditions including soil type are similar at the closed canopy and grassy verge sites. The presence of a grassy and woody weed verge may contribute to a high disturbance status in adjacent rainforest (see Chapter 5).

Only small numbers of other rainforest species, including *U. caudimaculatus, A. flavipes, A. stuartii, P. nasuta* and *H. moschatus* were captured. Thus generalisations with respect to road effects are of limited value. However, it must be noted that although these species formed 14.3 – 18.8% of rainforest species in the forest interior, they were only 2.7 - 3.9% of rainforest species at the closed canopy sites and 3.5% of rainforest species at or beyond the rainforest edge at the grassy verge sites. For *U. caudimaculatus*, the presence of a grassy verge appeared to reduce abundance (Table 1.5). There may be an effect of roads on these species, but data were mainly insufficient for statistical analysis.

Small Mammal Movements

The narrow rainforest road with closed canopy or with grassy verge caused significant inhibition of crossing movements for *Rattus* sp. and most likely for *Melomys cervinipes* in comparison with movements made at forest interior sites. Crossing movements were inhibited even though all species routinely moved the distance of eight metres required for a road crossing. However, inhibition was not complete as individuals of all common rainforest species were recorded as road crossers. There appeared to be no inhibition of crossings by *U. caudimaculatus*, although data were few. At least two of three grassland small mammal species appeared to be oblivious to the presence of the road, crossings forming a high proportion of movements. These results for rainforest small mammals agree with a similar experiment concerning width of road clearing undertaken in 1992 adjacent to the Black Mountain Road near Kuranda (Goosem 2000). Similar inhibition of crossings by small mammals has been demonstrated in many temperate habitats (Oxley *et al.* 1974, Wilkins 1982, Mader 1984, Swihart and Slade 1984) and in subtropical and tropical rainforest (Barnett *et al.* 1978, Burnett 1992).

The major focus of this study was to determine whether a road with a grassy and woody weed verge would inhibit crossing movements more than a road with canopy closure. To this end we almost completely eliminated any effects of traffic by choosing sites on a road with almost no traffic and the few vehicles traversing the road (mainly my own) limited to daylight hours when small mammals are inactive. There was no potential for movements to occur through underpasses such as culverts as these were absent from the vicinity of the sites.

The grassy verge and closed canopy treatments differed little in proportions of first movement crossings for *Rattus* sp. and *M. cervinipes*. However, there may be a difference for *M. cervinipes* if all movement data collected during and between trips is considered, rather than first movements. In this case, *M. cervinipes* did appear to make more crossings at the closed canopy sites than at the grassy verge sites.

Dispersal movements in the breeding season and during the influx of juveniles to the trappable population contributed to significant differences in crossing movements of *Rattus* sp. between wide and narrow clearings at the Black Mountain Road sites (Goosem 2000). In the current study, there was no difference discernible between canopy closed and grassy verge treatments and also no difference between dispersal and exploratory crossings. This study spanned the breeding season and part of the season when juveniles enter the trappable community. However, trapping sessions were more widely separated in time, so may have missed any effect of dispersal. Alternatively, the presence of individuals within the woody weed sections of the verge reduced the actual distance of alien habitat to cross, resulting in a higher proportion of exploratory crossings than experienced at Black Mountain Road. Very few individuals were present in ten metres from the centre of the road on the wide clearing Black Mountain road sites.

In this study, as has been demonstrated previously (Burnett 1992, Goosem 2000), *U. caudimaculatus* showed no signs of being inhibited from crossing the road with canopy closure. The greater size and mobility of the species has previously been suggested as the reason for lack of crossing inhibition by narrow roads (Burnett 1992, Goosem 2000). The species probably avoided the grassy verge habitat in the current study (see edge effects above) and was not recorded crossing at the grassy verge sites, but recorded captures and movements were insufficient to infer whether inhibition of movements occurred. Crossings of wider swathes of grassy verge habitat by *U. caudimaculatus* were completely inhibited along the Palmerston powerline corridor (Goosem and Marsh 1997), whilst no crossings were recorded at wider clearing sites along the Black Mountain road when grass was present in the verge (Goosem 2000). Unfortunately the current study has not provided sufficient data to determine whether the dense grass of the road verge similarly restricted movements of this large mobile species. *U. caudimaculatus* has been captured in grassland verges adjacent to woody weed patches at Mt Lewis (Goosem and Turton 1999).

1.5 Conclusions

Where a grassy and woody weed verge existed on a narrow rainforest road, alien small mammal species intruded and greater edge effects were observed than where canopy closure was maintained over the road surface. However, crossing movements by rainforest small mammals were not decreased in comparison with canopy closed sites, although crossings were inhibited at both treatments in comparison with the forest interior. Grassland small mammals were not resident under closed canopy.

1.6 Management Implications

- A grassy and woody weed verge allows penetration of small mammals alien to the rainforest environment, but these species do not penetrate the forest interior or where canopy closure is maintained over the road.
- Canopy closure also reduces edge changes in small mammal community composition in comparison to rainforest edges adjacent to grassy and woody weed verges.
- The presence of the road is the primary factor causing inhibition of road crossing movements by rainforest small mammals, irrespective of whether the clearing has canopy closure or grassy and woody weed verges.

1.7 Future Research

It is hoped to continue this study in the vicinity of the Maalan Road, to examine the success rate of rehabilitation strategies. The Department of Natural Resources had undertaken weed control along the grassy verges of many road sections of the South Johnstone network. My grassy verge sites were treated in September 1999 and November 1999. The degree of regeneration is to be monitored, in the hope that natural rainforest regeneration will take place without a requirement for extensive and expensive planting programs once competition with weeds has been reduced. I hope to undertake a second trapping series when regeneration is showing signs of success.

Section 2: Edge Effects of Roads and Powerline Clearings on Microclimate

2. Edge Effects of Roads and Powerline Clearings on Microclimate

Susan Siegenthaler and Steve Turton

Summary: *Roads and powerlines traverse many sections of the Wet Tropics of Queensland World Heritage Area (WTQWHA). Identification of impacts and subsequent effective management of these types of infrastructure is recognised by the Wet Tropics Management Authority (WTMA) as a significant challenge, particularly as human populations in the region continue to grow.*

The main aim of this project was to quantify the differences between microclimate variables at the forest edge and those of the forest interior and then estimate the intensity of microclimate edge effects associated with linear clearings of differing widths and degrees of canopy cover. Several microclimatic variables were measured including solar radiation, temperature and relative humidity (vapour pressure deficit), which are known major biological drivers in all ecosystems. Line transects of 100 metres were compared from the clearing edge to the rainforest interior on three types of linear clearings in the South Johnstone road and powerline clearing network: a road with canopy cover above the surface; a road with a grassy and woody weed verge that lacked canopy closure; and a powerline clearing.

A wide linear clearing without canopy cover, (i.e. the powerline corridor used in this study) had the greatest intensity of microclimatic edge effects, while a narrow linear clearing with canopy cover (i.e the road with closed canopy) showed the least microclimatic edge effects. The narrow linear clearing without canopy cover (i.e. the road with open canopy above and grassy verges) exhibited microclimatic edge effects of intermediate intensity. These findings have important implications for the protection and management of rainforest ecosystems in the WTQWHA that are at risk of human disturbance.

2.1 Introduction

Effective management of roads and powerline corridors is a major challenge facing WTMA in the effort to achieve the primary goal of protection, conservation, rehabilitation and presentation of the natural resources of the region (WTMA 1995). Many areas of the Wet Tropics of Queensland World Heritage Area (WTQWHA) have been affected by human settlement, agricultural practices and other human-oriented activities and are also dissected and fragmented by an estimated 1800 kilometres of roads, highways and powerline corridors (Goosem and Turton 1999). Further, because they have twice their length in edges, it can be conservatively estimated that roads and powerline corridors currently occupy 1100 hectares of the WTQWHA (Goosem 1997). Changes to ecological processes associated with these types of continuous linear clearings within adjacent rainforest have been shown to extend anywhere from 10 to 100 metres into the forest, further reducing the total area of remaining undisturbed forest habitat (Lawrance 1997a). Therefore, linear clearings have the potential to produce extensive abiotic and biotic edge effects at the boundary between the rainforest and the clearing (Spellerberg 1998).

Edge effects comprise a number of biological and physical changes to an ecosystem at the boundary (edge) between the natural environment and the contrasting, altered environment (Murcia 1995). Edge zones, human-disturbed microhabitats to which alien plants and animals are often well-adapted (Tyser and Worley 1992, Simberloff 1993, Goosem 1996, 1997, Goosem and Marsh 1997), exhibit generally altered ecosystem functions for varying distances into the rainforest. Edge effects have been found to be especially pronounced when the differences between the natural and the adjacent modified habitat are great (Laurance and Yensen 1991, Laurance 1990, Matlack 1994), resulting in conditions at the edge which are different to those of the forest interior, and which may extend as far as 100 metres or more into the forest itself (Laurance *et al.* 1998a).

The flora and fauna of tropical forests are particularly susceptible to edge effects due to their small, extinction-prone populations, low reproduction rates, poor recolonising ability in modified habitats, mutualistic interactions between species and high bias towards habitat specialisation (House & Moritz 1991, Simberloff 1993, Skole & Tucker 1993, Laurance *et al.* 1997b). Thus, a tract of rainforest dissected by a road or powerline corridor is highly vulnerable to edge effects at the clearing/forest boundary (Davidson 1988, Bennett 1990, 1991, Goosem 1996; Laurance *et al.* 1997b). Edge effects interact with each other, resulting in cumulative effects on the natural ecosystem with impacts yet to be quantified.

Some of the changes to microclimate observed at edges include increased solar radiation, increased air and soil temperatures, increased vapour pressure deficit and decreased relative humidity and alterations in hydrology, soil chemistry and soil biota (Murcia, 1995). For example, roads and road edges, by comparison with forest interiors, experience higher solar radiation levels and higher vapour pressure deficits during the day, wider diurnal temperature ranges, and higher wind speeds (Andrews 1990, Malcolm 1998). It is probable that edge effects may penetrate to greater distances into the forest interior where clearings are very wide, are devoid of vegetation and/or have no canopy cover over them (Goosem and Turton 1998).

Various studies have shown that changes to rainforest microclimate at edges vary according to a number of interdependent factors, including structural and functional forest type, soil type, disturbance history, nature of the adjacent matrix, edge age, edge aspect, topography, slope, altitude, latitude and macro-climatic regime (Davidson 1988, Saunders *et al.* 1991, Bierregaard *et al.* 1992, 1997, Kapos *et al.* 1993, Laurance 1997a, Donovan *et al.* 1997). However, although roads and powerline corridors produce microclimate edge effects which are similar to those observed at edges of forest fragments and within forest gaps, they also induce changes that are generally more prominent than those at gaps and are often unique (Turton 1993, Turton and Freiburger 1997). Relationships between microclimate and biological processes are complex and often non-linear, responding in unique ways to different management activities (Chen *et al.* 1999).

Studies in tropical and temperate forests elsewhere provide evidence for the existence of microclimatic edge effects, but the relevance of the results of these studies to the rainforests of north-east Queensland and linear clearings need to be considered in greater detail. Edge effect studies have often been inconclusive, confounded or apparently contradictory due to a lack of consistent methodology (Kapos *et al.* 1993, Murcia 1995, Crome 1997).

Most edge effect studies conducted in the WTQWHA have been primarily concerned with environmental changes at natural forest gaps and forest remnant edges (Turton and Freiburger 1997), and with impacts of linear clearings as barriers to movement of native fauna (Goosem, 1996, 1997, Goosem and Marsh 1997). Investigations of the microclimate regimes of rainforest-open forest ecotones (Turton and Duff 1992, Turton and Sexton 1996), rainforest interiors and treefall gaps (Turton 1990) and remnant rainforest edges (Turton and Freiburger 1997) in the Wet Tropics region provide data which can be used as approximations to microclimate edge effects that may be associated with linear clearings.

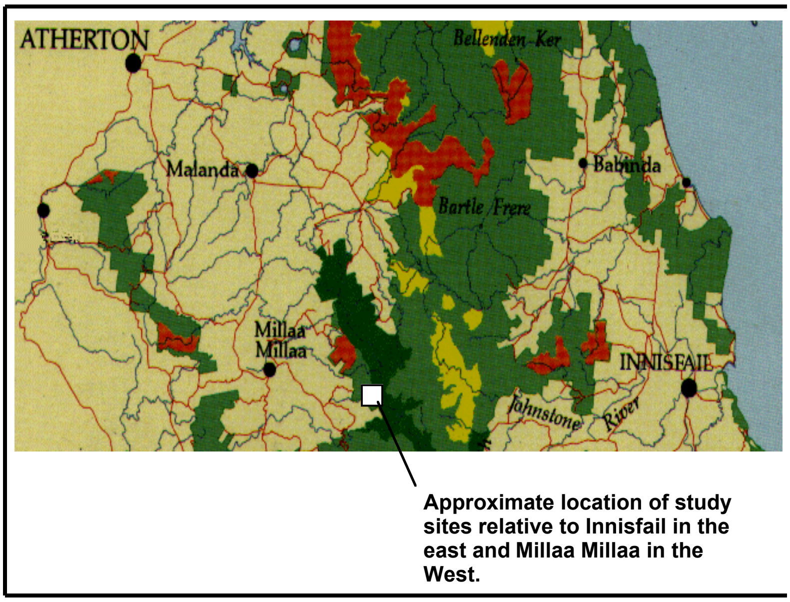
The need for more research into edge effects created by continuous linear clearings in the WTQWHA was highlighted by Laurance (1997a) who predicted that internal fragmentation of nature reserves of north-east Queensland and elsewhere by roads, highways and other linear clearings will be a primary management concern in the future. One rainforest management methodology which currently includes removal of forest canopy from above roadways, has been implemented upon the assumptions that canopy cover increases erosion, decreases the necessity for regular maintenance and ensures general safety of road users (DMRQ 1997, 1998). However, these assumptions may not be based upon sound ecological principles. Therefore, quantification of the responses of microclimatic variables to forest structural changes associated with the construction and maintenance of linear clearings is an important initial step towards integrated ecosystem research and more effective rainforest management (Chen *et al.* 1999).

2.2 Methodology

The Study Area

The study area was located in the Palmerston Highway-South Johnstone Road Network and the Kareeya to Innisfail powerline corridor, approximately 120 kilometres south-west of Cairns. The area is roughly bounded by Babinda and Innisfail to the north-east and Malanda and Millaa Millaa in the north-west within the 3000 mm to 4500 mm per annum isohyet of the Wet Tropics region (Fig.2.1).

Figure 2.1. Map of study area showing the approximate location of the study sites in relation to Innisfail and Babinda in the north-east and Malanda and Millaa Millaa in the north-west. This area receives the highest mean annual rainfall in Australia. Mt Bartle Frere and Mt Bellenden Ker, Queensland's highest peaks, are located at top centre right of the map.



The Study Sites

The study sites were situated within two areas: Wooroonooran National Park and State Forest 756, at an elevation of around 673 metres above sea level, and at a latitude of between 17^{o}35’29 to 17^{o}37’50 South and a longitude of 145^{o}42’20 to 145^{o}40’90 East. The area has been extensively logged in past decades and has also suffered disturbance due to mining activities. The Maalan Track (hereafter referred to as ‘the road’) is an unsealed, single carriage way road with a width of between 10-12 metres, which winds in a generally south-westerly direction along a ridge formed by the Table Top, Kaarru and Beatrice Ranges on the south-western side of the Palmerston Highway, approximately 16 kilometres east of Millaa Millaa. The Kareeya to Innisfail powerline corridor, ranging from 50 metres to 150 metres wide at its widest point, is crossed by the road at three locations along the 6.5 kilometres used for the study. The powerline corridor passes in an east-west direction up to the point where it is first crossed by the road, and then turns south-west to run almost parallel to the road thereafter.

Experimental Design and Site Selection

A nested split block design (Figure 2.2) was used with three treatments:
1) closed canopy across the road; 2) open canopy across the road with grassy verges on both sides; and 3) a section of the powerline corridor consisting of a wide grassy swathe (Table 2.1). Each treatment was assigned three replicate sites, with a pair of independent 100 metre line transects, slightly offset from each other on opposite sides of and perpendicular to the linear clearing within each replicate site location. Ten data sampling points were established at 0, 5, 8, 12 , 16, 20, 25, 30, 50 and 100 metre intervals along each line transect (Figure 2.2). The 0 metre data sampling point of the powerline corridor transects were placed 5 m inside the powerline corridor from the rainforest edge and the transect extended 95 m into the rainforest interior. The 0 metre data sampling point of the road treatments were placed in the centre of the road (also 5m from the forest edge). The 100 metre data sampling points were located in the rainforest interior on all transects, and acted as the within treatments control. Location of the data sampling points relative to the rainforest/linear clearing boundary and rainforest interior are shown in Figure 2.3 and 2.4. The closed canopy treatment was selected as the between treatment control against which the open canopy-grassy verge and powerline corridor treatments were to be compared. The former was considered to represent conditions more typical of 'undisturbed' rainforest within the context of this study.

Figure 2.2. Conceptual diagram of nested split block (repeated measures) experimental design. Ten data collection points were located along each transect (not shown). This type of experimental design is used where there is more than one fixed factor (e.g. treatment and distance), low replication and relationship between the experimental units (e.g. gradient from edge to forest interior).

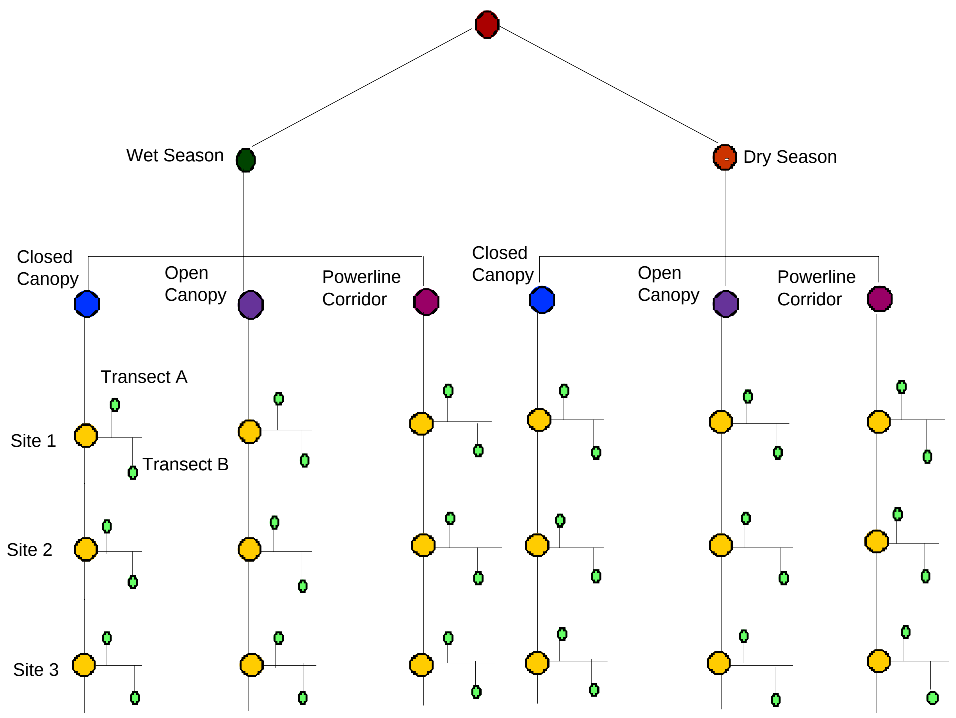
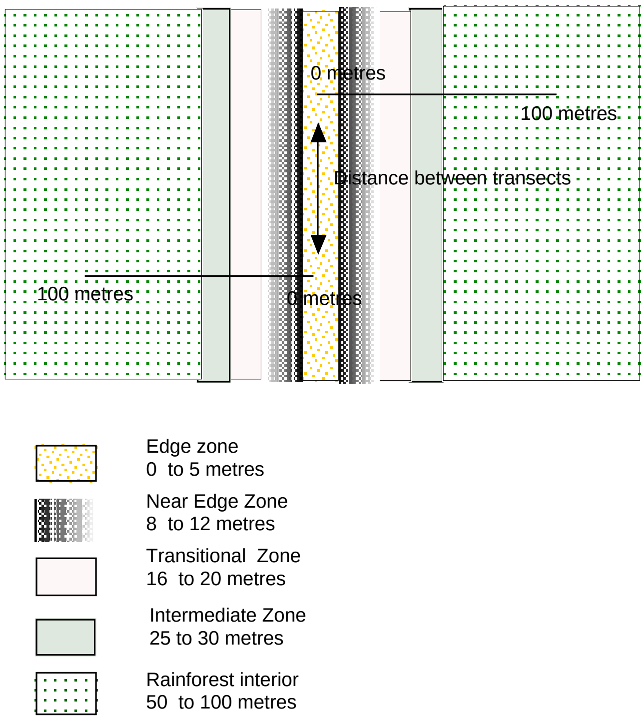


Figure 2.3. The generic layout of transects on the closed canopy and open canopy-grassy verge sites along the unsealed road. The shaded areas show zones, subjectively selected on the basis of observable changes in vegetation structure from the edge to the interior.



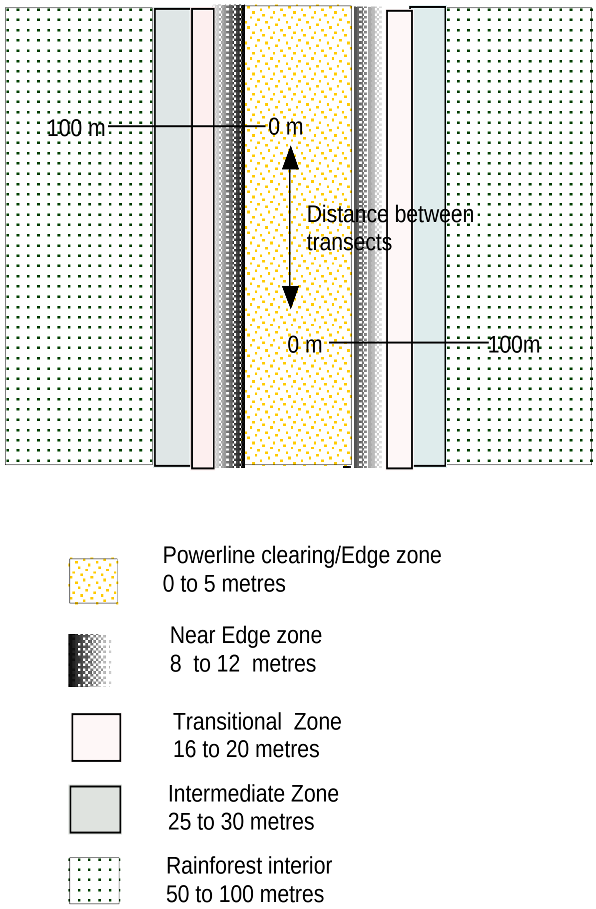
Criteria which formed the basis for the selection of treatment and sampling sites are shown in Table 2.1. Difficulties with wet season access and terrain limited the site choice for all treatments, as did the limited time frame available for the study. Powerline corridor sites were also limited by proximity to the Maalan Track.

Microclimate Data Collection

Microclimate data were collected during the wet season (April to early May 1999) and the dry season (August 1999) using the traverse method (Turton & Freiburger 1997) which increases replication and measurement precision. One transect of each pair was measured in the morning between 8:00 and 12:00 hours and the other in the afternoon between 13:00 and 16:00 hours to prevent bias towards a particular time of day.

Photosynthetically active radiation (PAR) and wind speed at 150 cm above the ground, ambient temperature (Ta) and relative humidity (RH) at 20 cm and 150 cm above the ground, soil surface temperature (TSS) and soil temperature at 10cm depth (TSU) were measured manually at each distance on each transect using a portable microclimate data collection unit. The equipment provides a framework upon which various instruments can be mounted and transported with relative ease through the rainforest, and allows for several microclimate variables to be measured simultaneously. Wet and dry bulb temperatures at 150 cm above the ground were also measured during traverses using a whirling hygrometer. Vapour pressure deficit (VPD) for 20 cm and 150 cm above the ground were derived from the Ta and RH measurements. Tiny Talk II dataloggers, placed at distances of 8, 12, 16, 20 and 100 m along one transect per treatment, were also used to take simultaneous diurnal measurements of RH and Ta at 150 cm over four consecutive days in both the wet and dry seasons.

Figure 2.4. The generic layout of transects on the powerline corridor sites relative to the rainforest interior and the powerline corridor. The shaded areas show zones, subjectively selected on the basis of observable changes in vegetation structure from the edge to the interior.



Hemispherical Photography

Hemispherical photography is a technique that has been used by many researchers to quantify the light regime below the forest canopy (Chazdon 1988, Turton 1988, Turton 1992, Turton and Duff 1992, Whitmore 1995, Turton and Sexton 1996). Sophisticated computerised analysis using WINPHOT (Gemlab Website, 1998) allows calculation of direct and diffuse below canopy photosynthetic photon flux density (PPFD), red to far red ratio, leaf area indices and percentage of canopy openness. These parameters enable assessment of the light conditions in the understorey relative to canopy structure.

A set of three hemispherical photographs were taken at each data sampling point along each transect (n = 640) using an Olympus OM-2 camera and Sigma 8mm f1.4 fish-eye lens, during June and July 1999. Utilisation of a fish-eye lens provides a viewing angle approaching 180 degrees, thus producing a circular projection of the sky hemisphere. Kodak T400CN T-MAX and Tri-X pan 400 black and white film were the preferred photographic media. Various combinations of aperture settings and shutter speeds were applied when taking the hemispherical photographs, and the most accurate representative photograph out of three for each data sampling site was selected for analysis of the above-mentioned parameters. For optimal results hemispherical photography should be done under an even overcast sky, or just after sunrise or just before sunset to ensure even backlighting (Whitmore 1995). However, due to the time constraints associated with this project, there were a few occasions when hemispherical photographs could not be taken during optimal weather conditions and/or times of day as described above.

Table 2.1. Summary of selection criteria for sites, transects and data sampling points. The treatment sites, replicate sites and data sampling units were selected on the basis of specific physical characteristics that were chosen to reduce the effects of possible confounding influences due to environmental heterogeneity.

SITE SELECTION CRITERIA

Site Details	Criteria
Treatment Catagories	
Closed Canopy	1. Tree crowns touching and/or overlapping across the road 2. No grassy verge
Open Canopy	1. Tree crowns not touching or overlapping 2. Grassy verge present on both sides of the road
Powerline Corridor	1. Grassy swathe 2. No canopy present across the powerline corridor.
Replicate Sites	
All sites to be located:	1. At the same altitude 2. Within the same vegetation type 3. Under the same climatic and edaphic influences 4. Within distances relevent to microclimate spatial scale (Oke, 1987)
Transects	
	1. No closer than 10 metres and no further apart than 500 metres 2. Transect pairs to be offset from each other on either side of the linear clearing 3. Orientation perpendicular to the linear clearing 4. Powerline corridor transects to be no closer than 50m to the road in order to avoid overlapping edge effects
Data Sampling Points	
	1. Distances between data sampling points to be the same on all transects. 2. Aggregation of sampling points up to 30 metres from the edge to maximise detection of edge effects.

Data Analysis

Descriptive statistics were generated for all raw data sets and are summarised in Appendix 2. Microclimate and hemiphot data were $\log_{10}$ transformed and analysed by repeated measures analysis of variance. Pairwise comparisons of season, treatment and distance means were carried out and the resulting estimated marginal means were plotted to identify the significant factors. This form of analysis, which accounts for many replicates with few repetitions, also allowed for testing of significant interaction between factors.

Significant relationships between microclimate parameters and distance and hemiphot parameters and distance were tested using Spearman's rank correlation co-efficient. Data from the Tiny Talk II Dataloggers were analysed by means of simple descriptive statistics and presented in tabulated and graphic format.

2.3 Results

The closed canopy treatment and forest interior (100 metre) data are used as controls for comparison of between treatment and within treatment effects. A brief summary of results are presented here, with more detailed microclimate results presented in Appendix 2.

Physical Characteristics of the Study Site

The control and powerline corridor treatments had similar aspects and tree heights at the forest edge. However, the powerline corridor is around 14 times wider than the closed canopy road sites (Appendix 2, Table 1). The open canopy treatment exhibited intermediate characteristics compared with the other two treatments, with similar slope to the powerline corridor, similar aspect, although affected more by sunlight in the afternoon, to both control and powerline corridor treatments and similar clearing width and average tree heights at the edge to the control treatment.

Differences in microclimate results within and between types of linear clearings

Although some differences were observed in the intensity of edge effect (especially for air temperature at 150cm), when wet and dry season data were pooled the overall trends for each microclimate variable on each treatment were similar to those shown when seasons were examined separately (Table 2.2).

Table 2.2. Comparison of each microclimate variable between each treatment to indicate the presence of microclimate edge effects, using the closed canopy forest interior zone (50 and 100 metre sampling points) as the control. Wet and dry season data have been pooled and the resultant means have been used. The shaded areas show the extent of penetration of edge effect for each microclimate variable.

Mean Microclimate Values (wet and dry season data pooled)	Edge Zone		Near Edge Zone		Transitional Zone		Intermediate Zone		Forest Interior	
Photosynthetically Active Radiation at 150cm	0 to 8 metres		8 to 16 metres		16 to 25 metres		25 to 50 metres		50 to 100 metres	
Closed Canopy	51	15	3	5	8	2	11	4	18	34
Open Canopy	160	131	60	4	5	7	40	5	7	11
Powerline Corridor	472	82	47	11	5	8	4	3	5	3
Soil Surface Temperature										
Closed Canopy	18	17	17	17	16	17	17	17	17	17
Open Canopy	19	18	17	17	17	17	17	17	17	17
Powerline Corridor	19	18	18	17	17	17	17	17	17	17
Soil Temperature at 10cm depth										
Closed Canopy	17	17	17	17	17	17	17	17	17	17
Open Canopy	18	17	17	16	16	17	16	16	17	16
Powerline Corridor	18	17	17	17	17	17	17	17	17	17
Air Temperature at 20cm										
Closed Canopy	18	18	18	18	18	18	18	18	18	18
Open Canopy	19	18	18	18	18	18	18	18	18	18
Powerline Corridor	19	18	18	18	18	18	18	18	18	18
Air Temperature at 150cm										
Closed Canopy	19	19	19	19	18	18	18	18	18	18
Open Canopy	20	19	19	19	19	19	19	19	19	19
Powerline Corridor	19	20	20	20	20	20	20	20	20	20
Vapour Pressure Deficit at 20cm										
Closed Canopy	360	384	364	337	324	326	320	319	326	324
Open Canopy	379	369	343	318	277	239	228	208	200	186
Powerline Corridor	246	246	226	220	212	208	201	196	194	178
Vapour Pressure Deficit at 150cm										
Closed Canopy	336	378	337	306	299	285	274	267	261	274
Open Canopy	344	337	288	251	210	179	173	165	130	108
Powerline Corridor	191	220	210	181	173	163	152	154	140	127

The closed canopy showed the lowest mean (± 1 S.E.) photosynthetically active radiation (PAR) in both seasons and the narrowest range, whilst the powerline corridor had the highest mean PAR in the wet season and the open canopy had the highest in the dry season (Appendix 2, Table 2). The range between minimum and maximum soil surface temperatures in the dry season was 6°C for all three treatments; however, during the wet season the range varied from 5°C for the open canopy, 7°C for the closed canopy and 8°C for the powerline corridor (Appendix 2, Table 3). Maximum soil temperatures at 10cm depth on the open canopy were similar in both seasons, but varied by 3°C between the seasons on the closed canopy and the powerline corridor, while minimum temperatures had varying results between treatments and seasons (Appendix 2, Table 4). Likewise, mean air temperatures at 20cm and at 150cm showed distinct differences between treatments, with the lowest temperatures on the closed canopy, the highest temperatures on the powerline corridor and intermediate temperatures on the open canopy sites (Table 2.2, Appendix 2, Tables 5 and 6). Unfortunately, the variable results for vapour pressure deficit at 20cm and 150cm are inconclusive requiring more measurements to establish definite patterns for each treatment type.

Table 2.3. The seasonal differences within and between treatments in the distribution of high (H), intermediate (I) and low (L) values for each microclimate variable.

Comparison of the Distribution of High, Intermediate and Low Values Microclimate Variables for each Treatment

Microclimate Variables	Photosynthetic-ally Active Radiation		Soil Surface Temperature		Soil Temperature at 10cm Depth		Air Temperature at 20cm		Air Temperature at 150cm		Vapour Pressure Deficit at 20cm		Vapour Pressure Deficit at 150cm	
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Treatment														
Closed Canopy	L	L	L	L	H	L	L	L	L	L	L	H	H	H*
Open Canopy-Grassy Verge	H	H*	L	H	L	H	I	I	I	I	H*	I	I	I
Powerline Corridor	I	I	H	I*	H*	I	H*	H	H*	H	I	L	L	L

Code Key:
L = lowest value; I = Intermediate value; H = high value; * = statistical significance (P<0.05)

Few seasonal differences in the microclimate variables were observed for each treatment (Table 2.3). Exceptions were for closed canopy in soil temperature at 10cm depth and for vapour pressure deficit at 20cm, and at open canopy and powerline corridor in soil surface temperature, soil temperature at 10cm depth and vapour pressure deficit at 20cm. When comparing the results of the control treatment with those of the open canopy-grassy verge and powerline corridor treatments, the following trends were observed:

- The closed canopy treatment had the lowest values for the majority of the microclimate variables measured in both the wet and dry seasons (Figures 2.5 and 2.6, Tables 2.2 and 2.3 and Appendix 2, Tables 1 to 10).
- The closed canopy had the least pronounced microclimate gradients from the edge to the interior (Table 2.4 and Appendix 2, Table 11) and experienced the lowest intensity of microclimate edge effects, with penetration of microclimate edge conditions rarely exceeding 8 metres (Table 2.5).
- Differences between the open canopy and powerline corridor treatment, which were more difficult to discern, were variable for PAR and VPD and more consistent for soil and air temperatures (Table 2.6).

Figure 2.5. Comparison of wet season mean values between treatments for each microclimate variable.

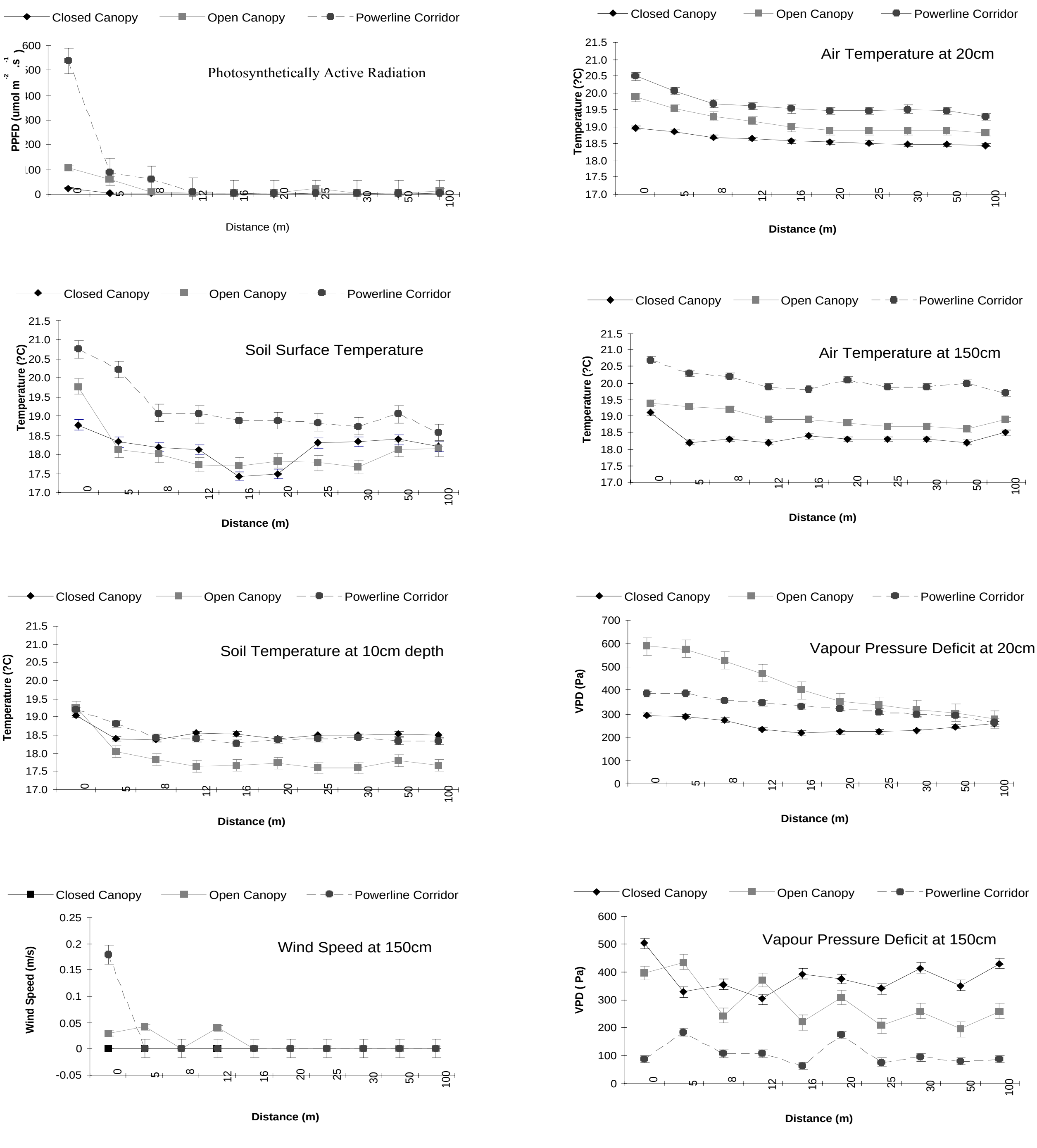


Figure 2.6. Comparison of dry season mean values between treatments for each microclimate variable.

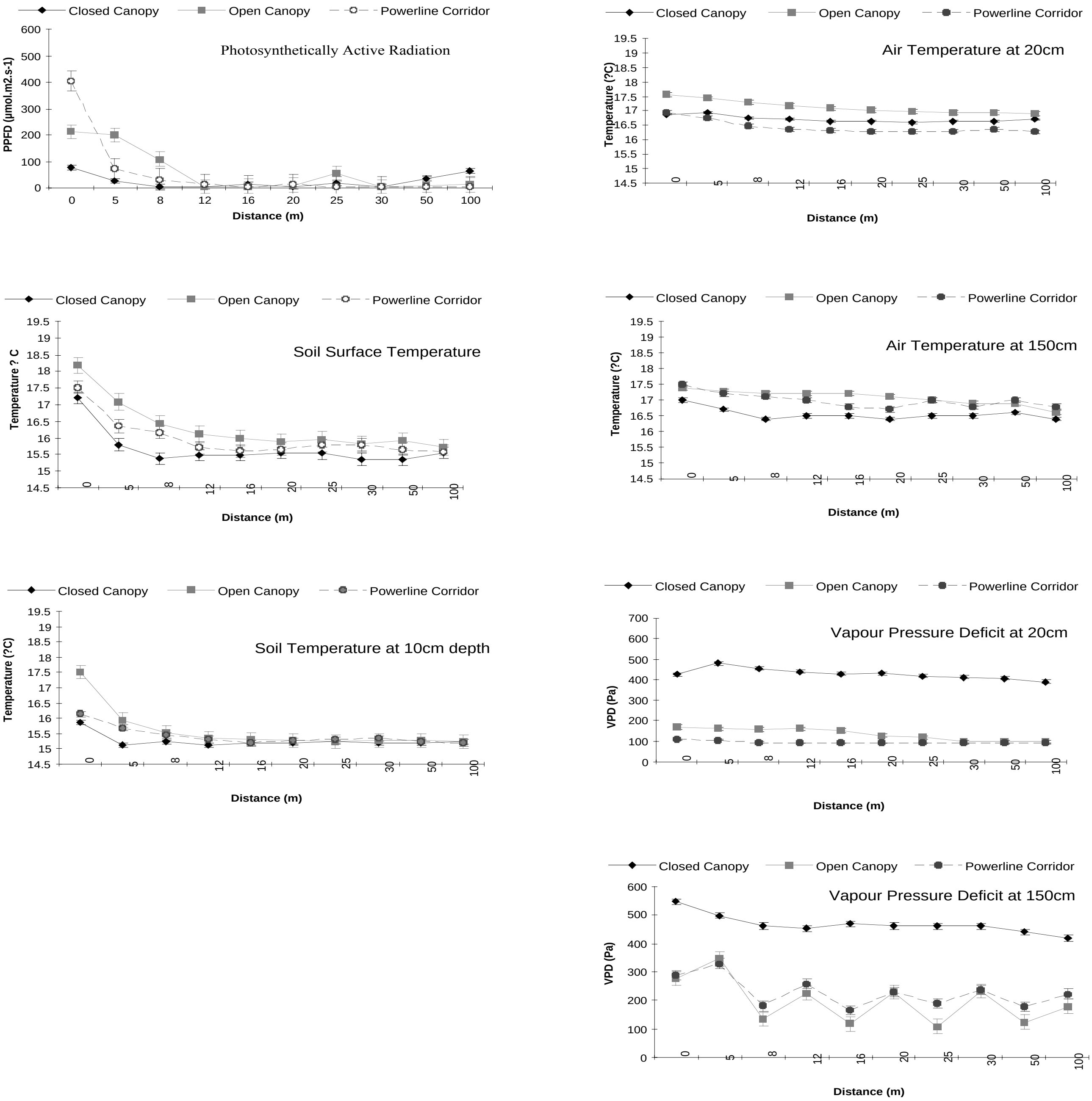


Table 2.4. The significance of microclimate edge effects as indicated by correlation between distance with each microclimate variable. The steepness of the microclimate gradient from the edge to the forest interior for each treatment is expressed as the strength (nil, weak, moderate or strong), the direction (negative or positive) and the significance (*, **, *) of the correlations between distance and microclimate variables.**

A negative relationship indicated that as distance increases, the variable value decreases. As the gradient between the edge and forest became more pronounced, the relationship with distance was stronger and more statistically significant.

Microclimate Edge Effects as Indicated by Correlations between Distance and Microclimate Variables

Microclimate Variables	Photosynthetically Active Radiation		Soil Surface Temperature		Soil Temperature at 10cm Depth		Air Temperature at 20cm		Air Temperature at 150cm		Vapour Pressure Deficit at 20cm		Vapour Pressure Deficit at 150cm	
Season	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
Treatment														
Closed Canopy	M- **	W-*	N	N	N	N	W-*	N	N	N	N	N	N	W-*
Open Canopy-Grassy Verge	M-***	M-***	N	M-***	W-*	W-***	N	W-*	N	N	W-**	W-**	W-**	N
Powerline Corridor	S-***	S-***	N	W-**	W-*	W-***	N	N	N	N	W-**	N	N	N

Code Key:
S - = strongly negative relationship; M - = moderately negative relationship; W - = weakly negative relationship; N = no significant relationship detected. Number of asterisks (*) indicates the degree of statistical significance.

Key Points:

- Photosynthetically active radiation (PAR) had a consistently significant relationship with distance from the edge across all treatments and in both seasons. The strongest gradients from the edge to forest interior for PAR were seen on the powerline corridor and the open canopy treatments, whilst the gradients were less pronounced on the closed canopy treatment.
- Soil surface temperature in the dry season and soil temperature at 10cm depth in the wet and dry seasons had steeper gradients from the edge to the interior in open canopy and powerline corridor treatements, whilst closed canopy had relatively constant soil temperatures from the edge to the interior.
- Air temperatures and vapour pressure deficits had relatively constant gradients from the edge to the interior on the closed canopy treatment, with slightly more pronounced gradients shown for the open canopy and powerline corridor treatments.
- Overall, the closed canopy treatment had the weakest and most constant microclimate gradients from the edge to the forest interior, indicating that the linear clearing associated with this treatment had less impact upon microclimate than those of the open canopy and powerline corridor.

Table 2.5. The intensity of edge effects as determined by the distance to which values of microclimate variables are greater than those of the forest interior, and more similar to those of the edge.

Distance (metres) of Penetration of Microclimate Change into the Forest

Microclimate Variables	Photosynthetically Active Radiation		Soil Surface Temperature		Soil Temperature at 10cm Depth		Air Temperature at 20cm		Air Temperature at 150cm		Vapour Pressure Deficit at 20cm		Vapour Pressure Deficit at 150cm	
Season	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
Treatment														
Closed Canopy	5	8	5	8	5	5	8	8	5	8	8	16	0-5	50
Open Canopy-Grassy Verge	8	12	5	12	12	16	16	16-20	12	30	50	0	8	8
Powerline Corridor	16	12	30	50	8	16	20	20	16	30	50	25-30	16	12

Key Points:

- Edge effects that penetrate further than the forest edge zone (0 to 8 metres) occur for all microclimate variables at the powerline corridor.
- Dry season vapour pressure deficit at 20cm and 150cm were the only microclimate variables to demonstrate a notable edge effect on the closed canopy treatment.
- Wet season vapour pressure deficit at 20cm showed an edge effect which penetrated up to 50 metres on the open canopy treatment.
- The powerline corridor exhibited the most pronounced microclimate edge effects for the three treatments.
- Penetration of edge effects in the wet season generally tended to be lower for air and soil temperatures and higher for PAR and VPD.
- Spearman’s rank correlation analyses (Appendix 2, Table 11) indicated that photosynthetically active radiation had the most significant relationship with distance of all the microclimate variables.

<u>**Summary of microclimate differences between clearing types**</u>

- Diurnal air temperatures at 150cm on the closed canopy were shown to have the lowest mean maxima and mean daily ranges, and the weakest gradients from the edge to the interior in both seasons (Figures 2.7 and 2.8, Appendix 2, Table 10).
- The descriptive statistics tables for each of the microclimate variables show the mean differences between the treatments and between the seasons, but do not reveal the differences within the treatments (Appendix 2, Tables 1 to 9). However, the tables for diurnal air temperature at 150cm (Appendix 2, Table 10) reveal the differences both between the seasons and the treatments as well as from the edge to the forest interior.
- The closed canopy had a predominance of low (L) values, whilst the powerline corridor and open canopy treatments had a predominance of high (H) and intermediate (I) values.
- The powerline corridor and open canopy treatments showed the greatest microclimate changes and the most significant (*) seasonal differences between the seasons, whilst only vapour pressure deficit at 150cm in the dry season was significant on the closed canopy treatment.
- The closed canopy treatment showed the least variability in microclimate between the seasons.

Table 2.6. Relative differences in microclimate from the edge to the forest interior between open canopy and powerline corridor treatments.

Microclimate Variable	Open Canopy-Grassy Verge		Powerline Corridor	
	Season	Distance	Season	Distance
Photosynthetically Active Radiation	Wet lower	0-12m	Wet higher	0-12m
	Dry higher	5-12m	Dry lower	5-12m,then same as OC from 12-100m
Soil Surface Temperature	Wet lower	0-100m	Wet higher	0-100m
	Dry lower	0-20m	Dry higher	0-20m, then same as OC from 20-100m
Soil Temperature at 10cm	Wet lower	0-100m	Wet higher	0-100m
	Dry higher	0-8m	Dry lower	0-8m, then same as OC from 12-100m
Air Temperature at 20cm	Wet lower	0-100m	Wet higher	0-100m
	Dry higher	0-100m	Dry lower	0-100m
Air Temperature at 150cm	Wet lower	0-100m	Wet higher	0-100m
	Dry same as PLC	0-100m	Dry same as OC	0-100m
Vapour Pressure Deficit at 20cm	Wet higher	0-30m	Wet lower	0-30m, then same as OC 30-100m
	Dry higher	0-30m	Dry lower	0-30m, then same as OC 30-100m
Vapour Pressure Deficit at 150cm	Wet higher	0-100m	Wet lower	0-100m
	Dry lower	8-100m	Dry higher	8-100m
	Dry higher	at 5m	Dry lower	at 5m
	Dry same as PLC	at 0m	Dry same as OC	at 0 m
Diurnal Temperature at 150cm	Wet lower		Wet higher	at 8,12 & 16m
	Wet same as PLC	at 20 & 100m	Wet same as OC	at 20 & 100m except 6am-6pm
	Dry lower	8,12,16,20 & 100m for 24 hours	Dry higher	8,12,16,20 & 100m for 24 hours

Key Points:

- Open canopy had higher dry season values and the powerline corridor had higher wet season values for PAR, soil temperature at 10cm depth and air temperature at 20cm.
- The powerline corridor had higher soil surface temperatures, and higher diurnal air temperatures in both seasons than the open canopy, and exhibited higher air temperature at 150cm in the wet season.
- Vapour pressure deficits were generally higher on the open canopy at the edge in both seasons.
- Overall, the powerline corridor treatment tended to have higher values, especially at the edge in the wet season. However, the open canopy and powerline corridor treatments frequently showed similar values from the near edge/transitional zones to the forest interior.
- Values for all microclimate variables, for both treatments and in both seasons, decreased with increasing distance from the edge.

Figure 2.7. Diurnal air temperatures at 150cm compared between each treatment and for each distance in the wet season.

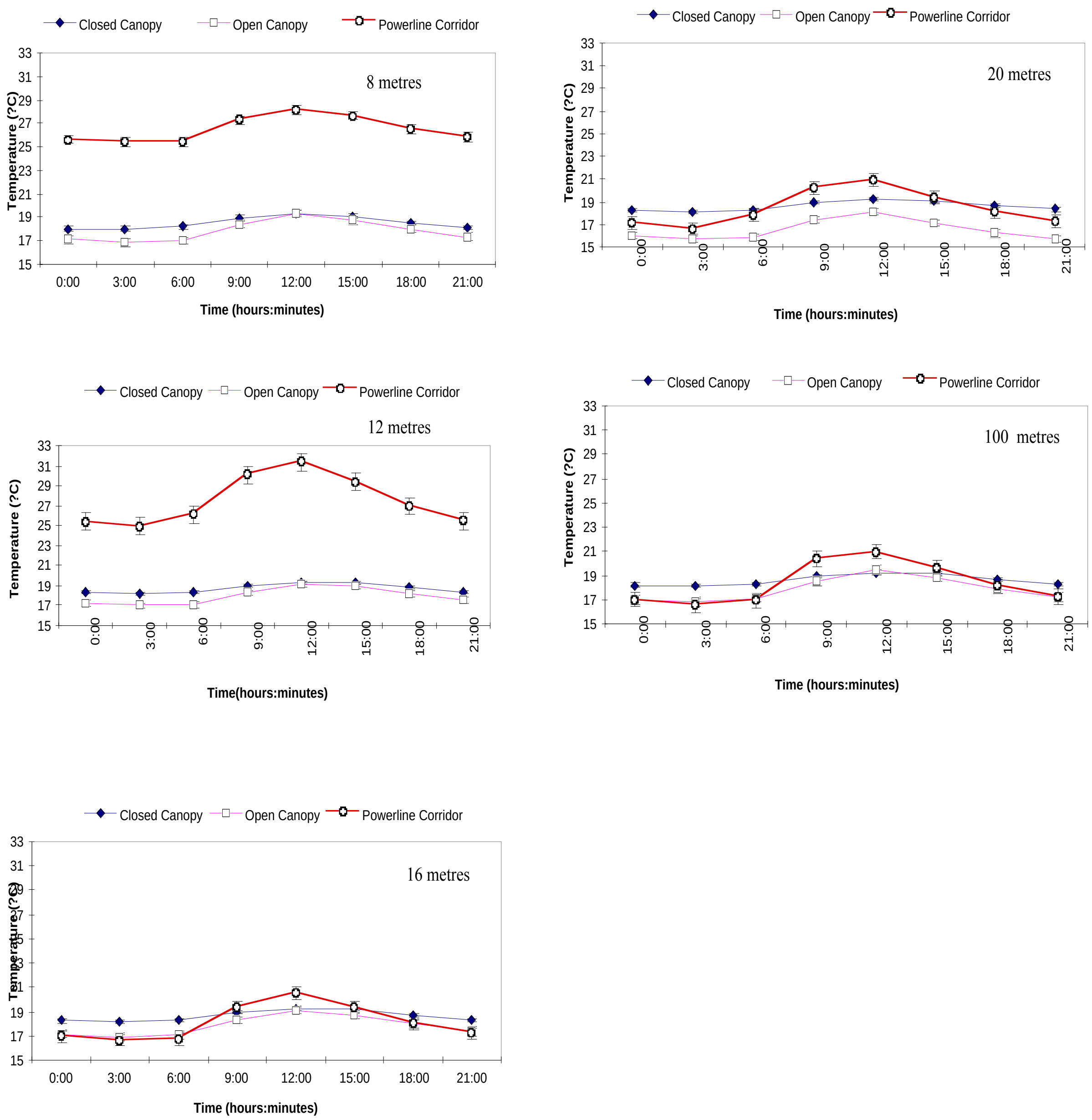
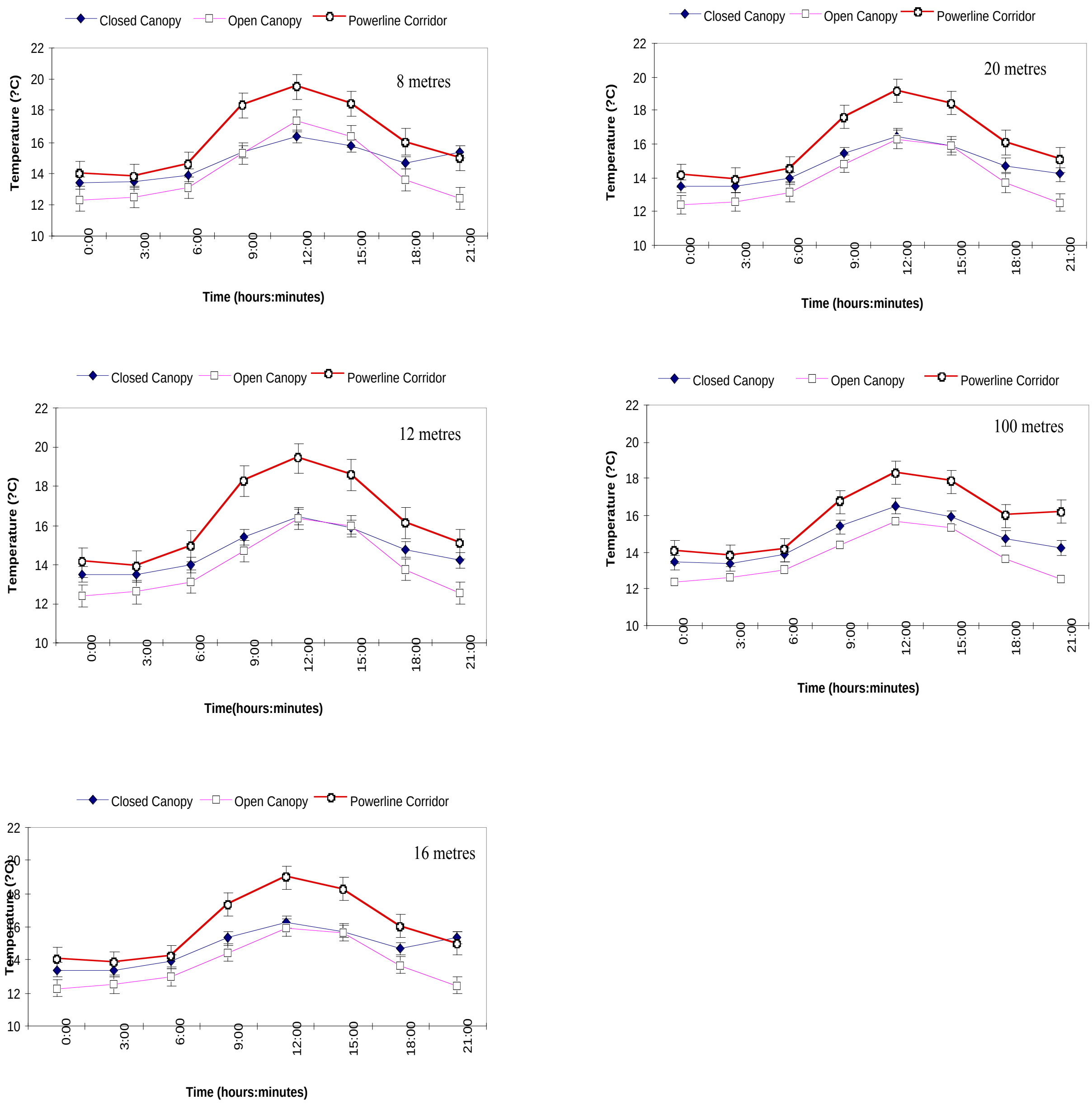


Figure 2.8. Diurnal air temperatures at 150cm compared between each treatment for each distance in the dry season.



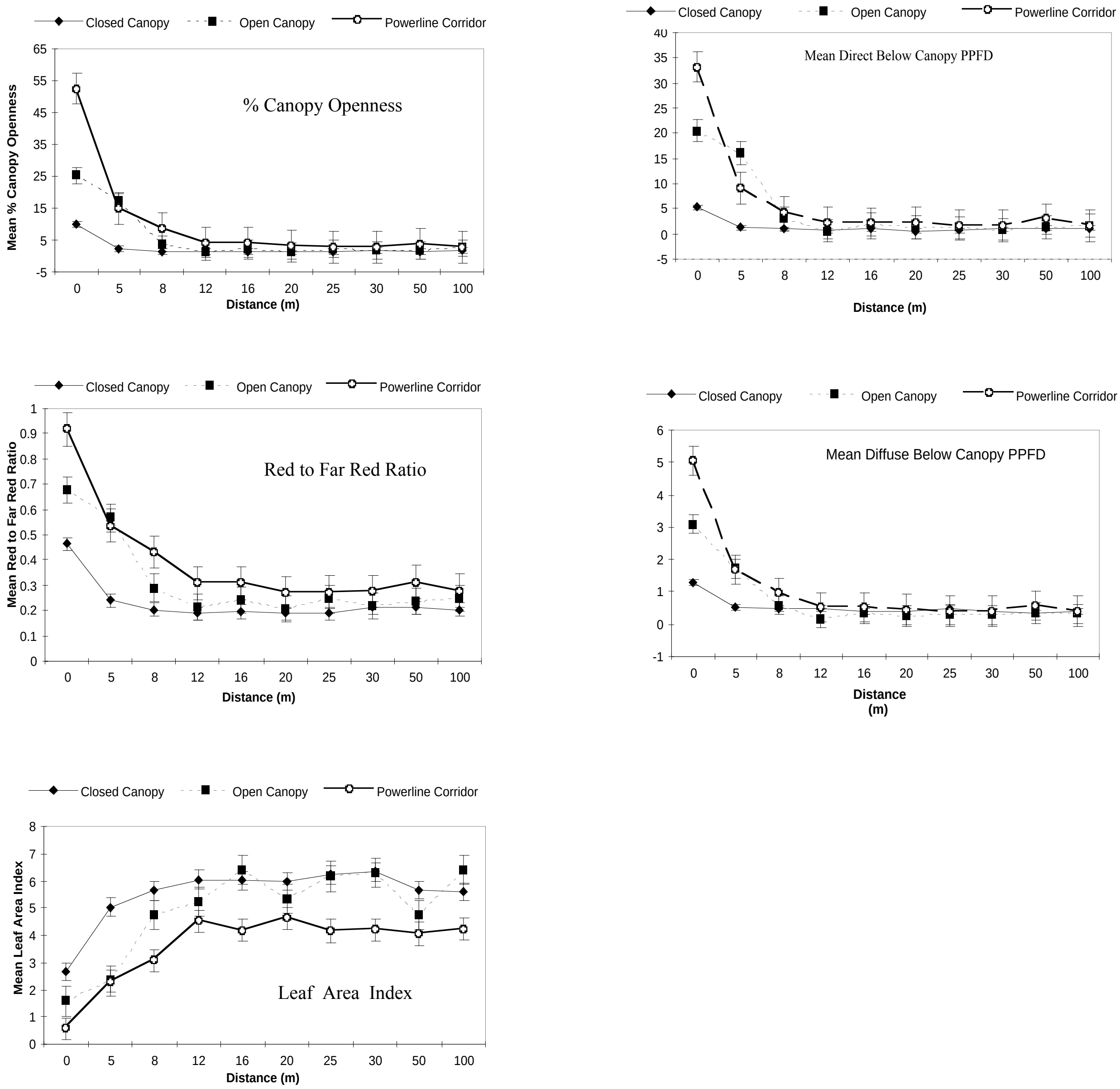
Repeated measures ANOVA for microclimate variables.

Repeated measures analysis of variance tested for significant differences between seasons, and clearing types, and between distances from the edge at each clearing type.

<u>Photosynthetically active radiation at 150cm</u>

Overall, PAR values during the dry season were higher than during the wet season although some seasonal variation between treatments were detected (Figure 2.9, Appendix 2, Table 12). Whilst the difference in PAR between the closed canopy and the powerline corridor and the open canopy and the powerline corridor were significant, the difference between the closed canopy and the open canopy was not. However, wet season PAR was significantly higher than dry season PAR on the powerline corridor (Fig 2.9, Appendix 2, Table 12). All three treatments, in both seasons, showed significant differences in PAR between the edge and the forest interior, with time of year and type of linear clearing having a significant effect on these differences (Fig 2.9, Appendix 2, Table 12).Therefore, an edge effect in PAR was shown as a result of the presence of a linear clearing, with the intensity of the edge effect influenced by the type of linear clearing and season. The difference in PAR between the edge and the forest interior was greatest on the powerline corridor during the wet season.

Figure 2.9. Plotted means of raw data generated by analysis of hemispherical photographs that compare the differences between treatments from the edge to the interior.



Soil surface temperature

There were observable differences in soil surface temperatures between the seasons and between the treatments with soil temperature higher on the powerline corridor in the wet season and higher on the open canopy in the dry season, but these differences were not statistically significant (Appendix 2, Figure 1 and Table 13). However, soil surface temperatures from the edge to the forest interior for all the treatments in both seasons were significantly different, but neither season nor treatment had a significant influence on these differences (Appendix 2, Figure 1 and Table 13). Therefore, the edge effects for this microclimate variable are similar for all the treatments and both seasons.

Soil temperature at 10cm depth

There were observable differences in soil temperatures at 10cm depth between the treatments with the open canopy having the lowest temperatures in the wet season and little difference between the treatments in the dry season, but these differences were not statistically significant (Appendix 2, Figure 2 and Table 14). The differences between soil temperatures at 10cm depth from the edge to the interior were statistically significant, and whilst dry season soil temperatures at 10cm depth were significantly higher than wet season temperatures, there was no significant influence due to the time of year on the differences detected between the edge and the interior (Appendix 2, Figure 2 and Table 14). However, there was a statistically significant influence due to the type of treatment on differences in soil temperature at 10cm depth between the edge and the interior, demonstrated by the lower temperatures on the open canopy treatment in the wet season (Appendix 2, Figure 2 and Table 14). Therefore, the type of treatment had an influence on the edge effects detected for this microclimate variable, with edge effects similar in both seasons.

Air temperature at 20cm height

Despite observable differences in air temperature at 20cm, with higher temperatures on the powerline corridor in the wet season and on the open canopy in the dry season, these differences were not statistically significant (Appendix 2, Figure 3 and Table 15). Significant differences in air temperature between the edge and the interior were observed for all treatments in both seasons, with the lowest air temperatures at 20cm on the closed canopy in the wet season (Appendix 2, Figure 3 and Table 15). Although there was no significant influence of time of year or type of linear clearing on air temperatures at 20cm, edge effects were more pronounced during the wet season on the open canopy and powerline corridor and less pronounced on the closed canopy (Appendix 2, Figure 3 and Table 15).

Air temperature at 150cm height

Differences in air temperature at 150cm between the treatments were more pronounced in the wet season than in the dry season, and differences between the edge and the interior were observed (Appendix 2, Figure 4 and Table 16). Significant differences between the edge and the interior were detected on all treatments, with lower air temperatures on the closed canopy compared to the open canopy and powerline corridor during both seasons (Appendix 2, Figure 4 and Table 16). However, wet season air temperatures at 150cm were significantly higher than those of the dry season, and pronounced edge effects for air temperatures at 150cm were detected on the open canopy and powerline corridor during the wet season (Appendix 2, Figure 4 and Table 16).

Vapour pressure deficit at 20cm height

The open canopy had the highest VPD at 20cm in the wet season while the closed canopy had the highest VPD in the dry season and significant differences between the treatments were detected in the dry season only, with significantly higher VPD on the closed canopy (Appendix 2, Figure 5 and Table 17). Significant differences between the edge and the interior on all treatments were detected in both seasons, with the most pronounced differences found on the closed canopy in the dry season and on the open canopy in the wet season (Appendix 2, Figure 5 and Table 17). Although there were no statistically significant seasonal differences in VPD at 20cm, the combined effects of time of year and treatment had significant influences on the differences from the edge to the interior between the treatments, with more pronounced edge effects observed on the open canopy treatment during the wet season and on the closed canopy treatment during the dry season.

Vapour pressure deficit at 150cm height

The closed canopy and open canopy had similar VPD at 150cm during the wet season, with values higher than those of the powerline corridor. However, during the dry season the closed canopy had the highest VPD values and the open canopy and powerline corridor had lower values (Appendix 2, Figure 6 and Table 18). Significant differences in VPD were detected between the treatments during the dry season only due to the higher VPD values on the closed canopy (Appendix 2, Figure 6 and Table 18). Again, no statistically significant seasonal differences in VPD were observed, however, the combined effects of the type of treatment and time of year had a significant influence on the differences from the edge to the interior for all treatments (Appendix 2, Figure 6 and Table 18).

Wind Speed at 150cm height
Although wind gusts were observed in the upper forest canopy on most data collection days, very little air movement was measured at 150cm in the understorey on any of the treatments during either the wet or the dry season. However, wind measurements were obtained during the wet season on the powerline corridor and open canopy at the edge only (Figure 2.5). The resulting data set was unsuitable for statistical analysis by repeated measures ANOVA, and is therefore presented as plots of the mean values only (Figure 2.5).

Summary of repeated measures ANOVA results
In conclusion, it can be seen that microclimate edge effects were associated with each type of linear clearing. The intensity of the edge effect was variably dependent on type of linear clearing and season. For example, PAR and VPD edge effects were an effect of the type of linear clearing and the time of year, edge effects of soil temperature at 10cm depth were an effect of the type of linear clearing only, and edge effects for soil surface temperature and air temperature at 20cm and 150cm heights were not an effect of season or type of linear clearing, but appear to be the result of a break in the continuity of the forest.

Analysis of Hemiphot Data
Results of analysis of the hemispherical photographs showed that percentage canopy openness, PPFD and red to far red ratios were higher from 0 to 5 metres only compared to the values for the forest interior, whilst leaf area index were the same as the forest interior values by 12 metres from the edge on the control treatment (Figure 2.10). The control treatment had the lowest mean values for percentage canopy openness, direct and diffuse below canopy PPFD and red to far red ratios and the highest mean leaf area index, thus demonstrating the most intact canopy of the three treatments (Figure 2.10 and Appendix 2, Table 19). In contrast, the powerline corridor treatment exhibited the reverse of the conditions of the control treatment and the greatest differences between the edge and the interior (Fig. 2.10 and Appendix 2, Table 19). Significant differences in percentage canopy openness ($P = 0.003$), direct below canopy PPFD ($P = 0.005$) and diffuse below canopy PPFD ($P = 0.005$) were detected between the treatments (Figure 2.11 and Appendix 2, Table 20). Likewise, significant differences in these parameters and in red to far red ratios and leaf area indices between distances were also detected ($P = 0.000$ in all cases), with a significant influence of treatment for all parameters except leaf area index (Appendix 2, Table 20).

Figure 2.10. Plotted estimated marginal means for photosynthetically active radiation (PAR).

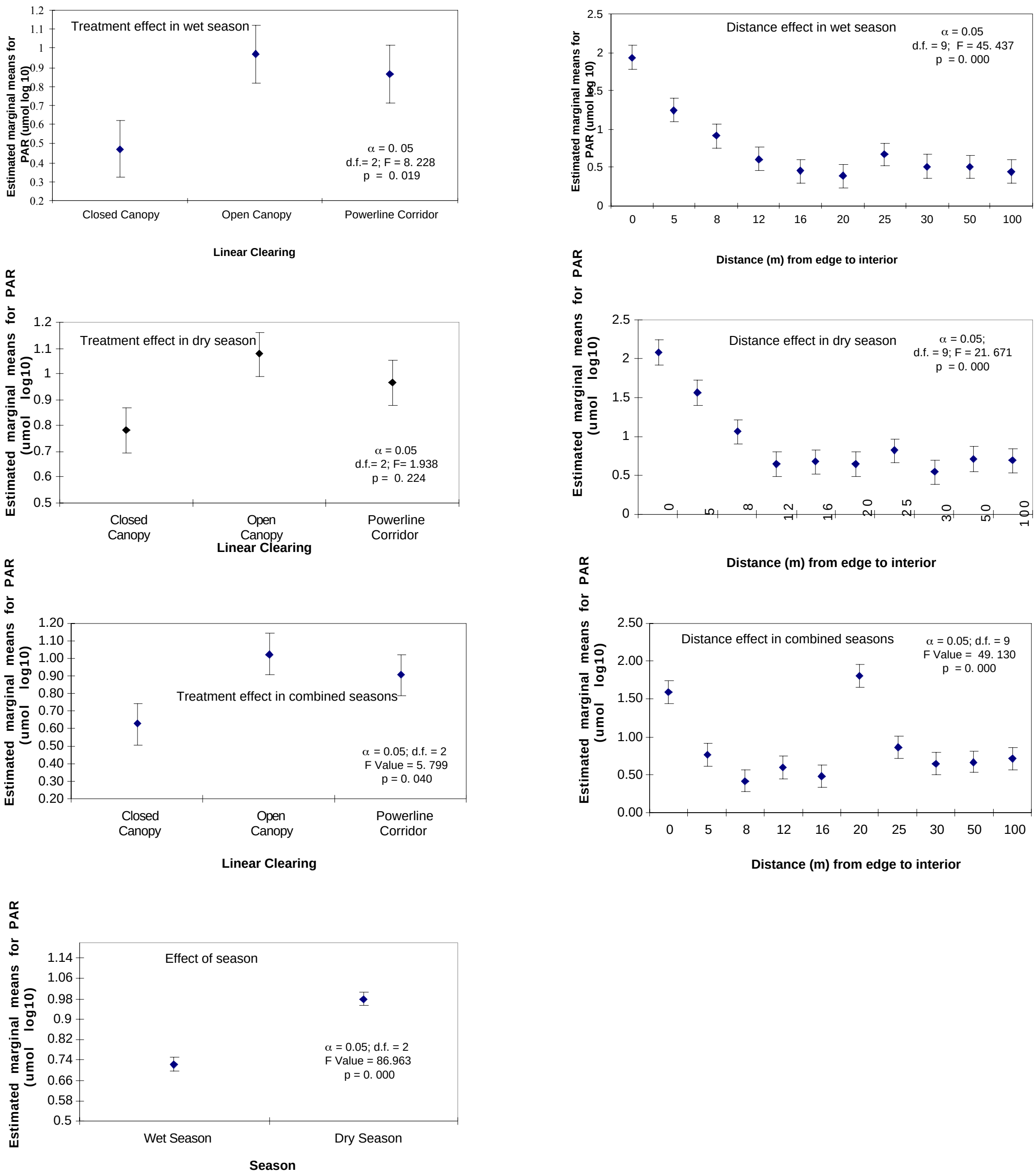
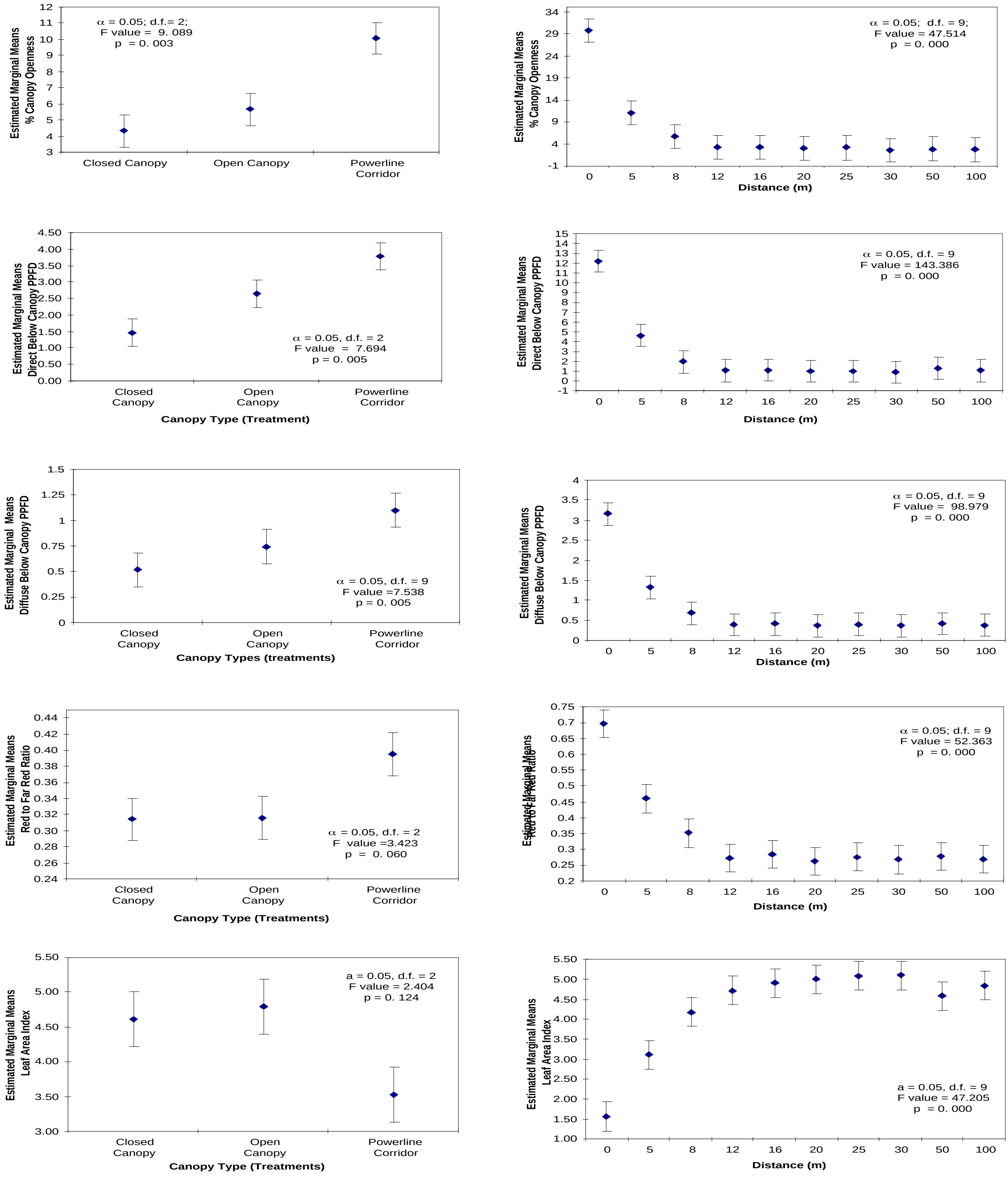


Figure 2.11. Estimated Marginal Means for Hemispherical Photo Data



2.4 Discussion

Examination of the raw data showed great variability in the amount of light able to penetrate to the forest understorey from the edge to the interior on all the treatments. This variability may have been related to a number of factors, including: amount of cloud cover and wind disturbance of the canopy during the data collection periods, natural heterogeneity in canopy architecture, seasonal changes in canopy foliage, incidence of canopy gaps due to tree and branch falls and temporal differences in solar angle and altitude.

According to Oke (1987) 99% of solar radiation intercepted by an intact rainforest canopy is utilized for photosynthetic and evapotranspirational processes and only a small proportion of total available solar energy penetrates to below the canopy. This results in minimal heating of and less pronounced temperature gradients between the air and the soil, and a generally more stable understorey microclimate (Whitmore 1995). However, when the canopy is disturbed, subsequent changes in the understorey microclimate occur. For example, air and soil temperatures and mass movements of air increase and air and soil moisture decreases (Whitmore 1995). The intensity of these microclimate changes, which are driven initially by solar radiation, is dependent upon the size of the gap in the canopy, height of the canopy, season, latitude, slope and aspect (Turton 1993, Murcia 1995).

The variability observed in soil temperature between the treatments may have been due to combined effects of differences in site micro-topography and percentage canopy openness and soil moisture along the gradient from the edge to the forest interior on each site. Minimum temperatures generally reflected the forest interior soil temperatures both at the surface and at 10cm depth, while the maxima reflected the temperatures at the edge (Appendix 2, Table 3). Turton and Freiburger's (1997) study of a rainforest fragment in north-east Queensland, showed higher values for air and soil temperatures and vapour pressure deficit at the edge and revealed significant effects of aspect in the wet season and significant edge effects for soil temperatures.

The higher vapour pressure deficit values observed on the closed canopy treatment in this study may be attributable to a number of factors: 1) the edges of the closed canopy sites were more open (lower stem density observed but not measured), thus allowing for greater movement of air from the track into the forest; 2) one of the closed canopy replicate sites is quite close to the Palmerston Highway also facilitating movement of dry air from the open highway into the forest; 3) transects on sites 2 and 3 of the closed canopy treatment were located on ridges and had sloping gradients which may have resulted in greater insolation, greater drying effects of wind and more rapid drying of soil due to better drainage. It would be expected that the open canopy and the powerline corridor would have higher VPD values than the closed canopy treatment because both had higher PAR values and higher air and soil temperatures (Table 2.2). Thus, it is hypothesised that better drainage of the closed canopy sites had a greater effect on VPD than any other factor.

In general, PAR and air and soil temperatures tend to be higher in the wet season, although this was not observed in this study. This result may have been due to wet season cloud cover and slightly lower solar angles in the dry season as observed by Turton and O'Sullivan (1995). The closed canopy showed the least variability in microclimate elements, the weakest gradients from the edge to the interior and the lowest edge effect intensity of the three treatments during both seasons. This is due to a more intact canopy on the closed canopy sites, which 'buffered' the understorey from the influences of changes in the external climate and to lower level and frequency of forest disturbance (Tables 2.3, 2.4, 2.5). This conclusion is supported by the hemispherical photographs of the canopy of each treatment, which showed the closed canopy to be the most intact canopy of the three, with a lower percentage canopy openness, lower light levels below the canopy, and a higher leaf area index whilst the powerline corridor lay at the opposite end of the spectrum (Appendix 2, Table 19).

The greatest differences between the open canopy and powerline corridor were observed within the first 30m from the edge, after which point these two treatments showed similar microclimate trends (Table 2.6).

Ecological Implications of Microclimate Edge Effects

Hopkins (1990) has stated that different disturbances affect forests in different ways dependent upon the intensity, size, extent and frequency of the disturbance, with the time to forest recovery and/or decolonisation determined by the combined influences of these factors. Therefore, the greater the impact a disturbance has on any one or more of these factors, the slower the recovery will be. In some cases, such as frequent disturbance, forest recovery may be arrested at a particular successional stage (Begon *et al.* 1986).

The disturbance factors described above can be applied to the three linear clearings used in this study to explain the different edge effects associated with them. For example, construction of a single-carriage way, unsealed road which has canopy retained over it is a small, confined and low intensity disturbance which produces minor edge effects. Retention of the canopy across the road minimises the need for frequent management of verges to remove weeds, thus, this type of disturbance could be seen as a low level disturbance which allows the adjacent rainforest to recover and ecosystem equilibrium to be regained after road construction is complete.

By comparison, a small, unsealed road with wide, treeless verges and open canopy produces larger, more intense and extensive disturbance. Further, disturbance at the edge becomes chronic as a result of frequent slashing and spraying of the verges to remove weeds and to prevent the canopy from over-arching the road. This effectively opens the edge zone of the forest, exposing it to the influences of the external climate, and permits the establishment of permanent changes in light regimes, temperature, moisture and air movement gradients between the rainforest interior and the road. Marked changes in rainforest structure have been found to be the consequence of repeated disturbance, with decline of species diversity and replacement of rainforest species with disturbance-tolerant species a common end result (Forman and Alexander 1998, Laurance *et al.* 1998a). (Edge effects associated with changes in vegetation are discussed in Section 3).

The type of disturbance created by construction of a powerline corridor is extremely intense initially, and damage to the adjacent rainforest is usually extensive (Fox *et al.* 1997). However, as powerline easements are rarely maintained, the conditions are ideal for growth of weeds and grasses and the rainforest edges can eventually 'seal', thus protecting the forest interior from the effects of the contrasting microclimate of the powerline corridor, although the risk of invasion by feral plant and animal species is increased (Saunders *et al.* 1991, Laurance *et al.* 1998a).

2.6 Conclusions

It can be hypothesised that the differences in microclimate observed between the treatments and between the edge and the forest interior, was due primarily to the combined effects of clearing width and percentage canopy openness at the forest edge as described by Turton (1993) (Appendix 2, Table 1). Effects may partially be due to the disturbance histories and maintenance regimes (edge age) of each of the different treatment types (Kapos 1989).

This study has enabled a preliminary comparison of microclimate regimes between forest edges which are frequently disturbed, edges which are not disturbed and edges which are not regularly disturbed but were associated with significant forest damage at the time of their creation (i.e. open canopy-grassy verge, closed canopy and powerline corridor respectively). It has been demonstrated that absence of canopy across continuous linear clearings results in changes to microclimate regimes at the forest edge, with understorey light regimes in particular being affected, validating the hypothesis of Goosem and Turton (1998). Finally, it must be considered that edge effects were detected although the road used in this study was unsealed with a single-carriageway and a low traffic volume, and the powerline corridor had closed 'edges' and relatively little disturbance. Thus, a further hypothesis may be proposed that wider, sealed roads with a heavier traffic volume and utility clearings which are kept clear of vegetation will produce much more intense and more pronounced edge effects.

These results have implications for abiotic and biotic rainforest ecological processes over time with changes expected in distribution and composition of both flora and fauna at the forest edge and in complex species interactions (Laurance *et al.* 1997b, Murcia 1995). Both the road with wide verges and no canopy cover and the powerline corridor produced intense changes in the microclimate and vegetation structure and composition at the edge of the adjacent rainforest, and each present a different set of ecological problems which must be addressed. The challenge for managers today is to identify the changes to rainforests produced by linear clearings and to determine how such changes affect both biotic and abiotic processes in the short and long-term, prior to construction going ahead. Stakeholders involved in the construction and maintenance of linear barriers which dissect rainforest in the WTQWHA need to be aware of the impacts that such features exert on the environment and be prepared to formulate and implement strategies which minimise resulting detrimental effects. Furthermore, it is ideal for all stakeholders involved in protection of rainforest to make a commitment to working co-operatively towards the primary goal of protection, conservation, rehabilitation and presentation of the natural resources in the WTQWHA (Wet Tropics Management Authority, 1995).

2.7 Management Implications

- This study has demonstrated that linear clearings associated with roads and powerline corridors have an effect on rainforest microclimate at the clearing/rainforest interface.
- The degree of microclimatic edge effect is affected by the type of linear clearing – in general, a narrow clearing with canopy cover maintained overhead will have less of a microclimatic edge effect than a clearing without canopy closure.
- A wider clearing such as that for a powerline or highway is likely to cause greater intensity of edge effects (i.e. distance of penetration into the rainforest) than is a narrower one, particularly if canopy closure is maintained.

Section 3: Edge Effects of Roads and Powerline Clearings on Rainforest Vegetation

3. Edge Effects of Roads and Powerline Clearings on Rainforest Vegetation

Susan Siegenthaler, Betsy Jackes, Steve Turton and Miriam Goosem

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Summary: *Identification of the impacts of roads, powerline clearings and other linear clearings that subdivide core habitat areas in the Wet Tropics of Queensland World Heritage Area (WTQWHA) and effective management of those impacts is a challenge faced by the Wet Tropics Management Authority (WTMA). Edge effects associated with linear clearings have been shown to contribute significantly to the habitat fragmentation associated with linear infrastructure.*

The main objective of this project was to determine to what extent the rainforest vegetation had been changed structurally and in species composition as a result of the presence of linear clearings, and whether the detected changes varied according to the type of linear clearing. A census of seedlings and saplings was conducted for each of three types of linear clearings: a road with canopy cover above the surface; a road with a grassy and woody weed verge that lacked canopy closure; and a powerline clearing in the South Johnstone road and powerline clearing network. Seedling and sapling numbers were correlated with results for microclimate and hemiphot variables (Section 2). An inventory of plant species occurring within 1.5m of each data sampling point was conducted for each linear clearing type, and all species were identified at least to genus and attributed to a 'disturbance indicator category'.

An edge effect in the distribution of seedlings and saplings from the edge to the forest interior was demonstrated. Significant correlations occurred between seedling and sapling numbers and microclimate elements. Edge effects were dependent on linear clearing type. The degree of alteration in forest structure at the edge was also dependent on linear clearing type and this was reflected in % canopy openness, leaf area index and the distribution of disturbance indicator species from the edge to the forest interior. Both the road with wide grassy and woody weed verges and the powerline corridor showed marked changes in vegetation structure and composition at the edge of the adjacent rainforest, whilst the closed canopy showed less pronounced changes. However, no significant difference in species richness was detected between the treatments.

These findings indicate that linear barriers produce vegetation edge effects that affect the distribution of seedling and sapling numbers and the distribution and proportions of disturbance indicator species from the edge to the forest interior. These vegetation edge effects are more pronounced where linear clearings are wide and have no canopy cover across them.

3.1 Introduction

The large-scale loss and fragmentation of tropical rainforests is of particular concern to scientists and natural resource managers working in the Wet Tropics of Queensland World Heritage Area (WTQWHA) (Cassells *et al.* 1988, Hopkins 1990, Laurance and Bierregaard 1997). In addition, edge effects associated with linear clearings have been shown to contribute significantly to habitat fragmentation and reduction by producing conditions which are different to those of the forest interior at the induced boundary between the forest and the contrasting matrix (Murcia 1995, Laurance *et al.* 1998a).

The consequence of construction of a linear barrier, such as a road or powerline corridor, is loss of habitat through destruction and alteration of vegetation and fragmentation of large areas of forest into smaller areas. Followed by this habitat loss and alteration is the creation of edge zones along both sides of the barrier (Andrews 1990, Spellerberg 1998). Thus, an edge habitat can develop which is typified by changes in structure and species composition of vegetation, composed mostly of non-forest ephemerals and opportunistic coloniser species, such as woody weeds, herbs and grasses (Tyser and Worley 1992, Forman and Alexander 1998). Changes in vegetation affects the movement and habitat utilisation of native fauna, causing subdivision of populations, inhibition of faunal movement across the barrier, loss of genetic variability and local extinctions (Mader 1984, Bennett 1991, Burnett 1992, Dunstan and Fox 1996, Goosem 1997, Goosem and Marsh 1997).

Fragmentation of forest gives rise to a landscape consisting of remnant areas of native vegetation surrounded by a matrix of land which has been modified for human activities or other developments (Saunders *et al.* 1991). Studies have revealed that the persistence of populations or entire communities of plants and animals is threatened by forest fragmentation, especially as fragments become too small to maintain viable population sizes (Begon *et al.* 1986, House and Moritz 1991, Simberloff 1993, Skole and Tucker 1993). According to House and Moritz (1991), when quantity and distribution of genetic variation of organisms is disrupted by the biological and physical changes associated with forest fragmentation, the ability of species to adapt to further environmental changes is diminished and species richness declines (Begon *et al.* 1986).

Roads have been described as ‘new geographical barriers’ to montane rainforest species which are already restricted to narrow and specific elevational ranges (Young 1994). In addition, roads and powerline corridors provide conduits for the accidental or deliberate importation of alien animal and plant pests and diseases (e.g. the tropical fungal disease *Phytothphora cinnamomii*) by vehicles (Bennett 1991, Tyser and Worley 1992, Spellerberg 1998, Forman and Alexander 1998). Some species are able to utilise roads to increase their geographical range, for example feral pigs, foxes and cats (Mitchell and Mayer 1997). Roads also can be used by wildlife hunters, poachers and trappers and are often a precursor to human immigration, settlement, deforestation and further environmental degradation (Bennett 1991).

Some workers propose that roads produce more intense edge effects than powerline corridors although both have similar disturbance effects during and immediately after construction. Vegetation can regrow across powerline clearings over time and the edges may eventually be sealed by dense (usually invasive) vegetation which supposedly dampens the intensity of edge effects, whereas roads maintain a starkly contrasting environment devoid of vegetation (Andrews 1990, Reed *et al.* 1996, Goldingay and Whelan 1997, Goosem and Marsh 1997).

Response of Tropical Forest to Disturbance

Floristically, the species that compose tropical forest communities have highly complex relationships with each other and their environment (Richards 1957). In particular, the structure and composition of rainforest flora are intimately linked via environmental conditions and disturbance (Richards 1957, Whitmore 1989). Disturbance is considered to be an integral factor in both the structural and compositional characteristics of tropical forests in north-east Queensland (Unwin *et al.* 1988, Nicholson *et al.* 1988, Olsen and Lamb 1988, Laurance and Yensen 1991, Hopkins 1990, Williams-Linera 1990, Bierregaard *et al.* 1992, Webb and Tracey 1994, Laurance 1997a, Ferreira and Laurance 1997, Fox *et al.* 1997). In the case of natural disturbances, structure and composition of a small gap may vary over a short temporal scale and individual species may change, but the overall community persists as a whole (Richards 1957, Perry 1996, Valverde and Silvertown 1997). However, human induced disturbances produce conditions which tend to be more severe, extensive and long-lasting and to which rainforest species are not well adapted (Perry 1996, Laurance 1997a). Tropical forests which have experienced disturbance, whether natural or artificial, exhibit pronounced changes in microclimate, particularly in light environment, with subsequent changes to structure and floristics (Hopkins 1990).

Treefall gaps of varying sizes, caused by the death of trees due to disease, senescence and strong wind events, are natural phenomena in tropical forests and their incidence plays a large role in the maintenance of diversity of rainforest flora, seedling germination, recruitment and sapling survival (De Vogel 1980, Whitmore 1989, Turton 1993, Perry 1996, Parker 1995). Such changes can be viewed as part of the 'forest cycle' or successional phases, in which tropical forests can be depicted as structural and compositional mosaics of gap, building and mature phase species (Gomez-Pompa and Vazquez-Yanes 1981, Whitmore 1989, Hopkins 1990, Valverde and Silvertown 1997).

In mature tropical rainforests the canopy is dense and closed, and the forest understorey develops its own unique microclimate which tends towards stability. Very little solar radiation penetrates, light levels are low and light transmitted through dense canopy leaves is rich in far red light and relatively rich in green light (Jones 1992, Stoutjesdijk and Barkman 1992, Turton and Duff 1992, Whitmore 1995). According to De Vogel (1980) seedlings of different types have varying preferences for light quality and quantity, humidity and short term temperature changes in the soil. Seedlings of herbaceous plants, pioneer shrubs and trees and some secondary forest species have seedlings which are adapted to open vegetation and bare soil, whilst seedlings of primary forest species belong to a category which do not thrive in exposed places and prefer dense cover. Herbaceous plants and pioneer species form the earliest successional stages, and have been shown to have seeds with wide dispersability and prolonged viability in soil seed banks which require a disturbance related environmental factor, such as an increase in temperature or a change in red far red light ratio to germinate (Gomez-Pompa and Vazquez-Yanes 1981, Perry 1996). Thus, factors such as severity, timing and frequency of disturbance act as filters on the available species pool which subsequently determines the composition of the early successional community (Perry 1996).

3.2 Methods

The location and general descriptions of the study area and study sites have been given in Section 2, therefore, only additional information relevant to the vegetation study will be included here.

The Study Sites

Webb and Tracey (1994) have classified the vegetation of the area as Complex Mesophyll Vine Forest (CMVF) Type 1b. The rainforest canopy is uneven due to logging, with a canopy height ranging from 24 to 36 metres. Specific details of dominant and emergent species were unavailable as a thorough species inventory for the study area has not been conducted to date.

The experimental design utilised was identical to that of the microclimate study (Figures 2.2 and 2.3). The closed canopy sites exhibited a lack of invasive weeds or grasses on the shoulders adjacent to the road, although understorey rainforest species such as *Pollia sp., Alpinia sp.,* and the rainforest grass *Oplis-menus composita* were present at the edge on some transects. The verges of the open canopy sites, which are controlled by the DNR (Forestry) by slashing and annual spraying with herbicide, were overgrown with *Panicum maximum*, *Melinis minutiflora, Ageratum houstonianum, Rubus spp.* and *Lantana camara* during the study period. The powerline corridor sites exhibited dense overgrowth of *Panicum maximum*, *Melinis minutiflora, Lantana camara* and other exotic weed species in excess of 2 metres high on the powerline corridor itself.

A hardened gravely surface, frequently disturbed by vehicular traffic, was the site of the 0 metre data points on the open canopy and closed canopy treatments, whilst thick, high grass, woody weeds and vines dominated the 0 metre and 5 metre data points of the powerline corridor. The 5 metre data points of the closed canopy were located at the forest edge in deep shade and those of the open canopy were located in the grassy verge between the forest edge and road edge in full sun.

Vegetation Data Collection

Aims of the vegetation sampling were:

1) To estimate the composition and distribution of plant species and density of seedlings and saplings from the edge to the forest interior along the established microclimate gradient; and

2) To determine whether there were relationships between species composition and distribution and density of seedlings to the detected microclimate edge effects.

Because sampling was conducted on heterogeneous vegetation along an environmental gradient with the view to determine the spatial distribution of species, a partial random sampling method was used, in which circular quadrats of 1.5m radius were placed at known intervals along two 100m line transects per treatment (Kershaw 1964; Barbour *et al.* 1987). Numbers of seedlings up to 20 cm in height and saplings between 20 cm and 150 cm in height were measured within each quadrat on all transects for each treatment. Transect data was then pooled to give a total value per treatment within a total area of 300m^2 per treatment.

A species inventory was conducted in the same manner, in which all species (excluding bryophytes, lichen and fungi) occurring in each quadrat were noted and then broadly classified on the basis of their known occurrence in disturbed forest and regrowth forest, into four groups: weeds, vines, pioneers and rainforest species. Due to time constraints, sample sizes for species had to be small, and therefore a species-area curve could not be generated.

Methodology for Classification of 'Disturbance Indicator' Species

The disturbance indicators were selected using a taxonomic approach, i.e. by species and the environmental conditions under which these are most commonly found to occur.

<u>Weeds</u>

This category included species that are typically found in fields, open areas, and waste lands, not local rainforest species, Australian native non-rainforest species, exotic species and grasses. In general, weeds are reliable indicators of disturbance as they are adapted to high light levels and are often exotic species (Auld and Medd 1987, Whitmore 1989). Species making up this group include opportunistic species with high fecundity, effective dispersal techniques and seeds with long viability (Goosem and Tucker 1995).

<u>Vines/climbers</u>

Non-rainforest species and rainforest natives that are found in the understorey where there has been sufficient disturbance to the canopy to allow penetration of light to facilitate their growth. These are often prolific in the canopy and therefore are tolerant of high light and temperature levels. They may be shade tolerant as seedlings and saplings but will climb towards higher light levels in order to complete their life cycles. Therefore, this classification was included as being representative of canopy disturbance, whether they are native rainforest species or introduced exotics, as they all thrive in high light, high temperatures and low moisture conditions (Laurance 1996, Laurance *et al.* 1998).

<u>Pioneers</u>

Many of the species identified as pioneers are gap/edge specialists or are rainforest species with tolerance to a wide range of environmental conditions. These have been included as indicators of early to mid successional stages of forest regeneration following structural disturbance to the forest in the past. Pioneer species are indicators of disturbance and their presence at rainforest edges suggests alteration to microclimate regimes, however, pioneer species may also indicate that forest regeneration processes are taking place (Whitmore 1989).

<u>Rainforest species</u>

These are described by Hyland and Whiffin (1993) as species which are found in well developed rainforest, often on a wide variety of sites. Many are understorey shrubs and small trees, therefore, this group represents species which prefer undisturbed rainforest conditions. Rainforest species often possess a high degree of shade tolerance.

Justification of use of zonation
The division of the area between the 0m and 100m data sampling points into five zones was based upon observable changes in vegetation structure from the edge to the interior, representing successional stages of forest regeneration as described by Gomez-Pompa and Vazquez-Yanes (1981). The edge zone (0m and 5m) was characterised by absence of vegetation in the case of the sites placed perpendicular to the road in addition to weeds, grasses, shrubs or vegetation with a very open canopy as in the case of the powerline corridor sites. However, the 5m data sampling point was placed where the forest began. The near edge zone (8 and 12 m) was typically an area of dense understorey vegetation, being a mixture of vines, saplings, shrubs and trees. The transitional zone (16 to 20m) showed a trend towards thinning of understorey plants and more mature trees that continued to the intermediate zone (25m to 30m) where tall, relatively widely spaced trees were found. More densely spaced tall trees and some understorey shrubs typified the forest interior zone (50m to 100m).

Plant species identification was conducted in the field with advice from Associate Professor Betsy Jackes and Mr Bob Jago and the assistance of Mr Mick Jackes and Ms Miriam Goosem. Species identification of a minimal number of plant specimens collected in the field was also conducted in the laboratory with the aid of the Australian Trees and Shrub Interactive Key (Hyland and Whiffin 1999) and various reference texts under supervision of Associate Professor Betsy Jackes.

Data Analysis
Information was obtained for each treatment type: number of individuals, families, genera and species; number of individuals per species, family and genera; number of individuals per disturbance category and frequency of occurrence of each species. A species inventory for the study area as a whole was also produced.

Hemispherical photographs of the edge (0m) and interior (100m) data sampling points were utilized to illustrate differences in canopy openness between the three treatment types. Descriptive statistics of the seedling/sapling and flora species data are summarised in Appendix 3.

Significant relationships between seedling and sapling numbers and distance, microclimate and hemiphot variables were tested examined using Spearman's rank correlations. Shannon Weiner indices and t-tests (Zar 1974) examined variation between clearing types in species richness (diversity and evenness). χ^2 goodness-of-fit and homogeneity tests examined the proportion of species in each disturbance indicator category to test for independence between categories and linear clearing type. Hemispherical photographs of the canopy from the edge (0m) to the forest interior (100m) at each data sampling point were used to illustrate differences in canopy structure between the three linear clearing types and between the edge and forest interior. The distribution patterns of seedlings and saplings in relation to the possible influences of linear clearing type and proximity to the linear clearing were examined using repeated measures ANOVA (see Section 2).

3.3 Results

Canopy structure and floristic composition and distribution

Figure 3.1 illustrates the differences in canopy structure between the three types of linear clearing and between the edge and the interior zones of each linear clearing using percentage canopy openness. It can be clearly seen that the powerline corridor has the most open canopy at the edge and the closed canopy has the most intact canopy at the edge. All types of linear clearing show similar, low percentage canopy openness at the forest interior as expected.

Distribution of species within and between types of linear clearing
In general, the distribution of individuals across taxonomic levels is similar between linear clearing types, although the closed canopy had the highest mean number of individuals at each taxonomic level

and the powerline corridor had the absolute highest number of individuals, as well as the highest number of families, genera and species of the three treatments (Figs 3.2 and 3.3).

The occurrence of individual species within treatments is illustrated by Figure 3.4. Each treatment had a greater number of species at a low frequency of occurrence (0 - 10% and 11- 20%), thus there were more rare species than common species present on each treatment. However, the powerline corridor treatment had slightly more commonly occurring species in frequency class 21 - 30% (Figure 3.4).

Figure 3.1. Hemispherical photographs taken on the Maalan Track road sites and Kareeya-Innisfail powerline corridor sites, West Palmerston in June, 1999. Percentage canopy openness is shown as inset. North is at the top of the photograph.

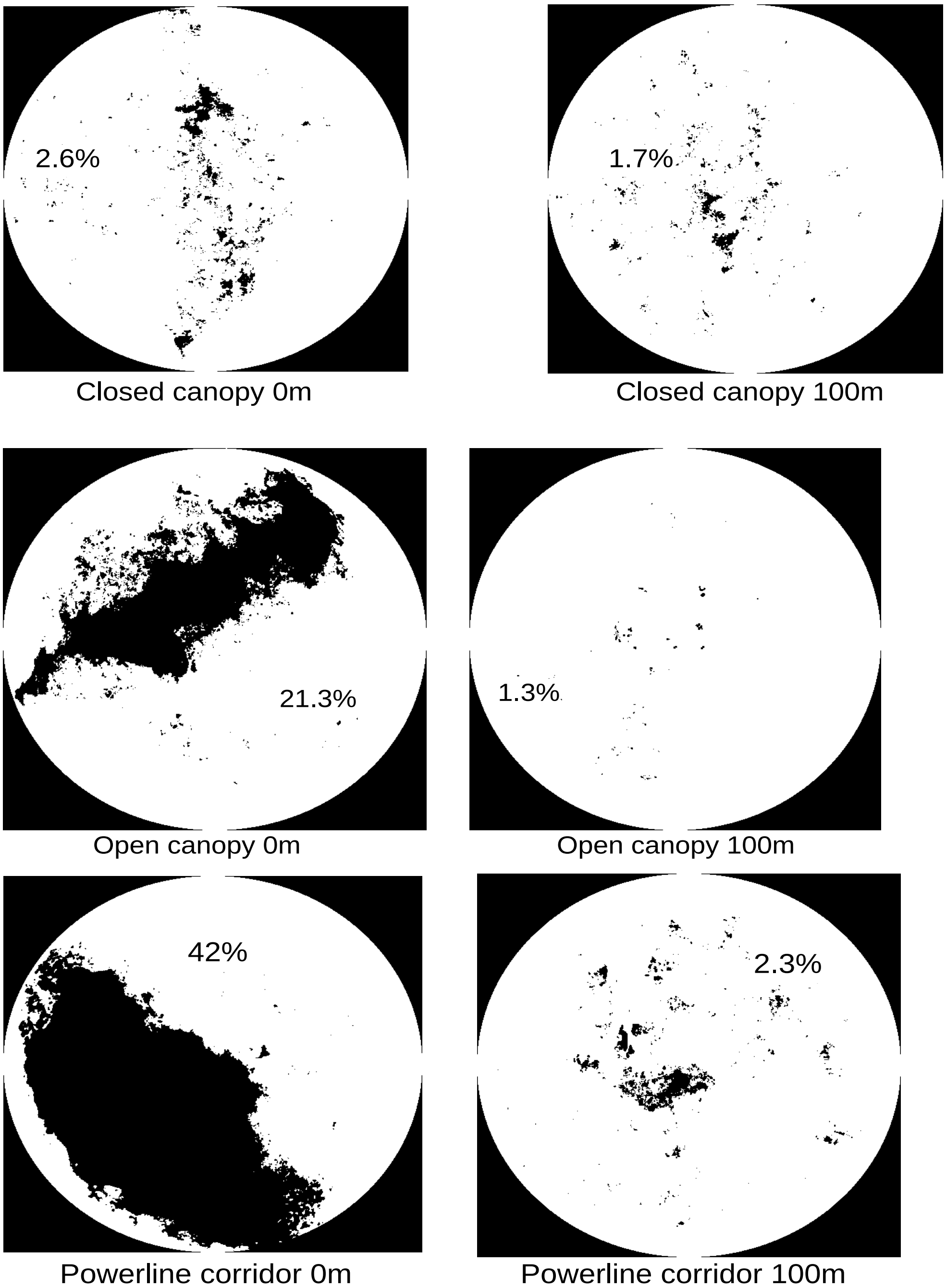
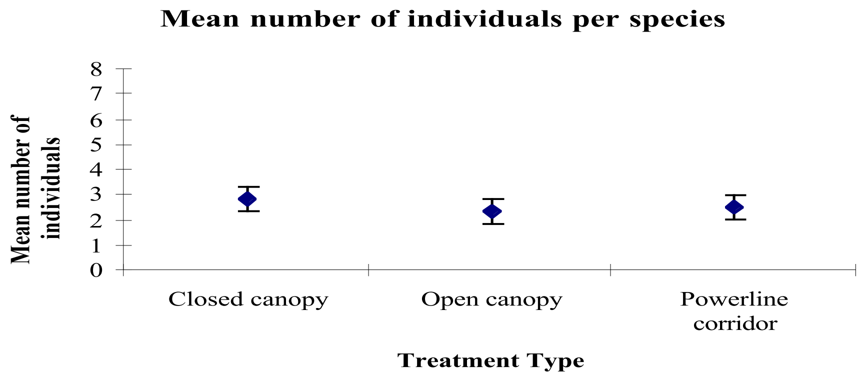
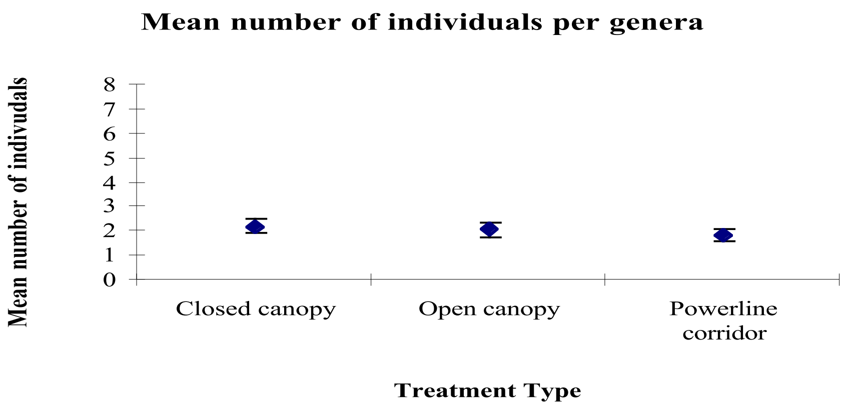


Figure 3.2. Mean number of individuals within each taxonomic level for each type of linear clearing.
Whilst differences in numbers of individuals at each taxonomic level exist between the treatments, these differences are not significant.





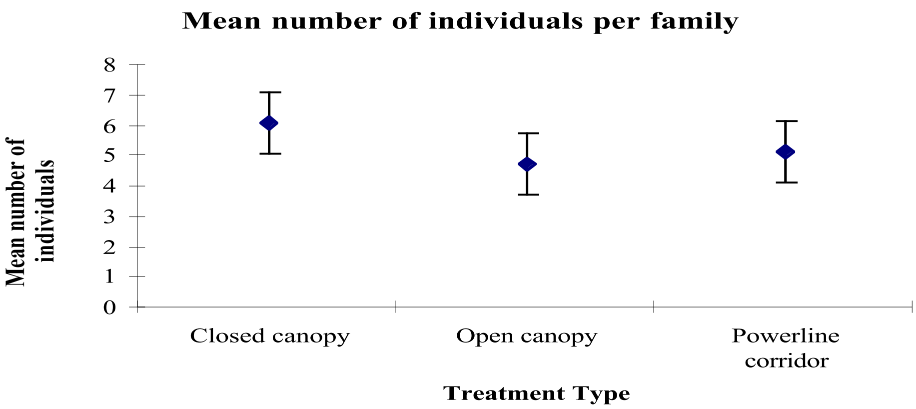
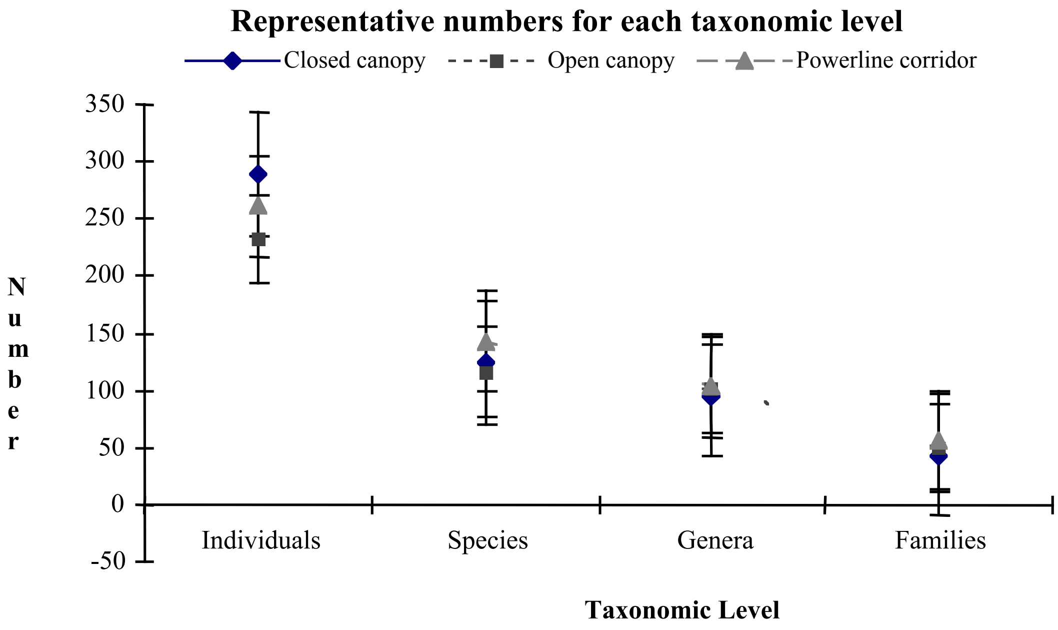


Figure 3.3



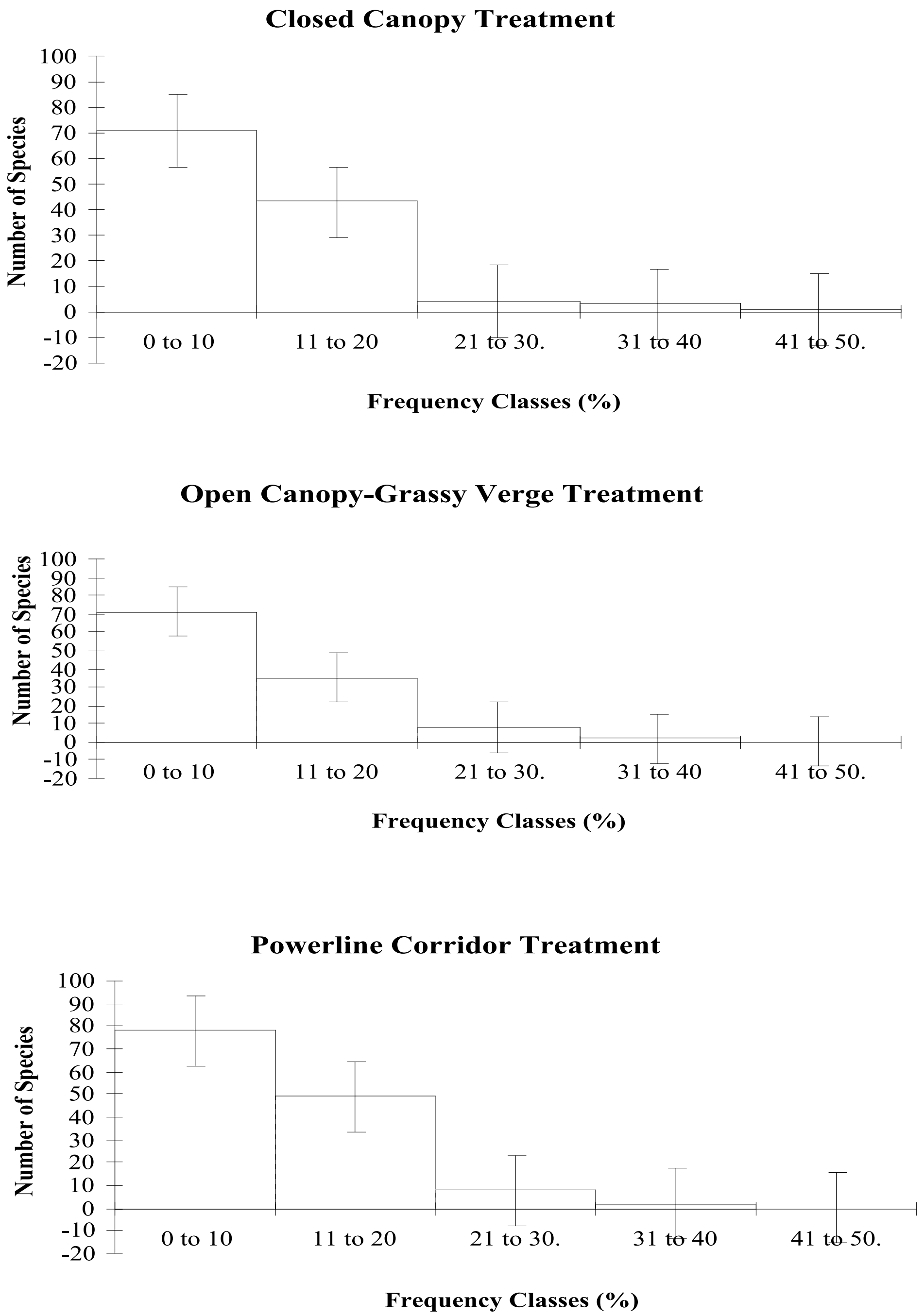
Key Points:

- Whilst the closed canopy treatment had the highest mean number of individuals at each taxonomic level and the open canopy treatment had the lowest, there is little difference between the treatments.
- However, the powerline corridor had the highest absolute number of individuals (289) with 233 and 261 for the open canopy and closed canopy respectively, and the highest absolute number of families, genera and species.

Shannon-Weiner indices of diversity (H) and abundance (J) showed that all the treatments had very similar values of H and J, with H = 5.686 and J = 1.147 on the powerline corridor, H = 5.450 and J = 1.40 on the open canopy and H = 5.582 and J = 1.166 on the closed canopy treatment (Appendix 3, Table 1). Shannon-Weiner t-tests showed no significant differences in diversity and abundance between the treatments (Appendix 3, Table 2).

The powerline corridor had a higher proportion of plant species at the edge and less in the forest interior. The closed canopy and open canopy treatments had fewer species at the edge and more in the forest interior, although the open canopy had more species at 12 and 16 metres (Figure 3.5).

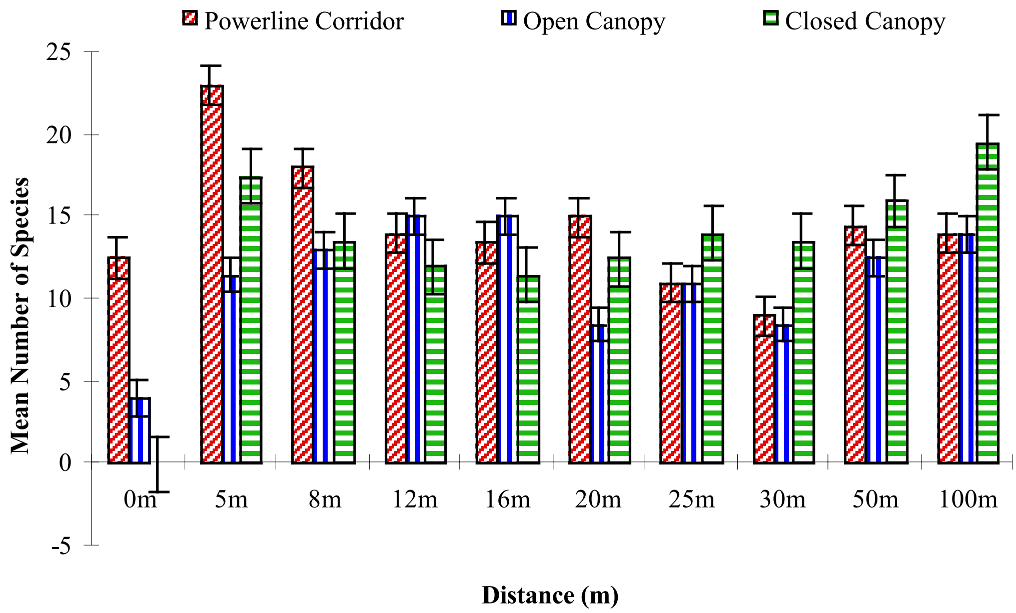
Figure 3.4. The number of quadrats (expressed as % frequency) in which an individual species occurs for each treatment.



Key Points:

- A greater number of species have a low frequency of occurrence and only a few species have a high frequency of occurrence, i.e. there are more rare species than common species.

Figure 3.5. Species distribution from the edge to the interior for each type of linear clearing.



Key Points:

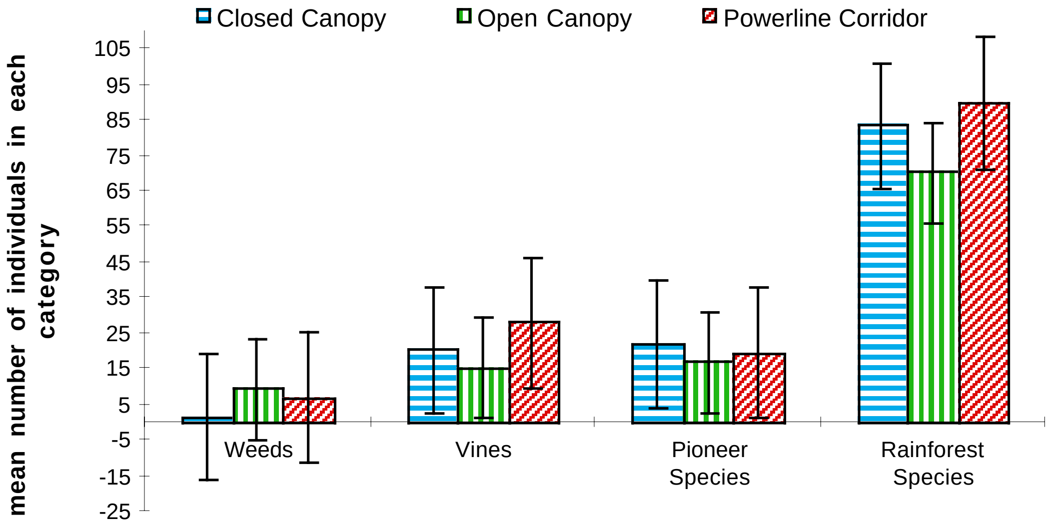
- The powerline corridor had the greatest mean number of species from 0 to 20 metres, decreasing towards the forest interior.
- The open canopy had its second highest number of species at 5 m, numbers then steadily decreased to 30 m and then increased at the forest interior (50 to 100 m).
- However, the closed canopy showed a steady increase in species from 0 to 16m, a pronounced decrease from 20 to 30 m then increased from 50 to 100m, although species numbers within the forest interior remained lower than species numbers at the edge.
- These patterns of species distribution from the edge to the forest interior may indicate successional stages within each treatment.

Distribution of species within disturbance indicator categories

The closed canopy had a greater proportion of rainforest species, followed by pioneers, vines and weeds. The powerline corridor had the highest number of vines and the open canopy had the highest number of weeds and the lowest number of rainforest species (Figure 3.6). Species which fell into the 'weeds' category included *Panicum maximum*, *Solanum mauritianum, Ageratum houstonianum, Sida retusa, Plantago major* and *Lantana camara*, found at the edge and near edge zones of both the powerline corridor and open canopy treatments. Examples of species in the 'vines' category identified on the powerline corridor and open canopy edge include several species of *Rubus*, both native and exotic, *Smilax australe*, *Ripogonum sp*., *Cissus vinosa, Palmeria scandens, Embelia australiasica, Piper sp, Commelina cyanea, Calamus moti* and *Calamus australis* (Jones and Gray 1977, Cronin 1989).

Neolitsea dealbata (present in large numbers both within the rainforest on the powerline corridor treatment and at the forest edge), *Alphitonia petriei, Alphitonia whitei, Alpinia modesta, Pandanus monticola, Bowenia spectabilis,* and several species of the Lauraceae family are examples of species identified in the 'pioneers' category (Goosem and Tucker 1995, Betsy Jackes pers. comm. 1999; Bob Jago pers. comm. 1999). Although, pioneer species appeared to be relatively evenly spread between the treatments, they attained their highest numbers on the powerline corridor and closed canopy sites, being more prominent from 8m to 20 m (Figure 3.7).

Figure 3.6. Mean number of species in each disturbance indicator category compared between each of the linear clearing types.



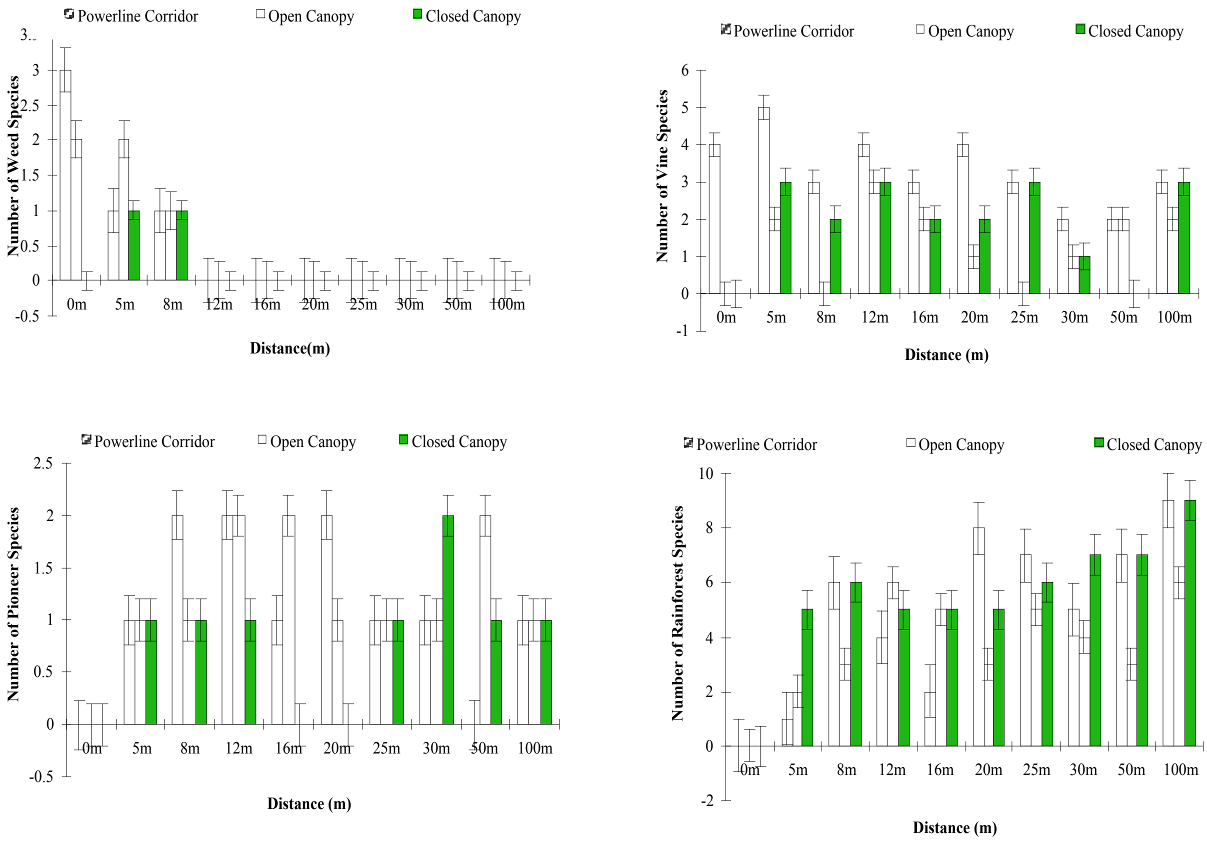
Key Points:

- The powerline corridor had the highest number of vines, pioneers and rainforest species and the second highest number of weeds.
- The closed canopy had the second highest numbers of vines, pioneers and rainforest species and the lowest number of weeds.
- The open canopy had the lowest numbers of vines, pioneers and rainforest species and the highest number of weeds.

The spatial distribution of species within these groups showed that rainforest species were proportionally greater in number from the edge to the interior than all other categories on the closed canopy treatment (Figure 3.7). Overall, the powerline corridor had the highest number of weeds, vines and pioneer species at the edge.

χ^2 goodness-of-fit and homogeneity tests showed that there was a significant difference in the numbers of species recorded in each indicator category, both between and within species (Appendix 3,Table 3). Appendix 3, Table 4 lists the species observed on each treatment site.

Figure 3.7. Mean number of species in each disturbance indicator category from the edge to the forest interior compared between the types of linear clearings.



Key Points:

- The powerline corridor has the highest number of weeds, vines and pioneer species at the edge, whilst the closed canopy has the highest number of rainforest species.

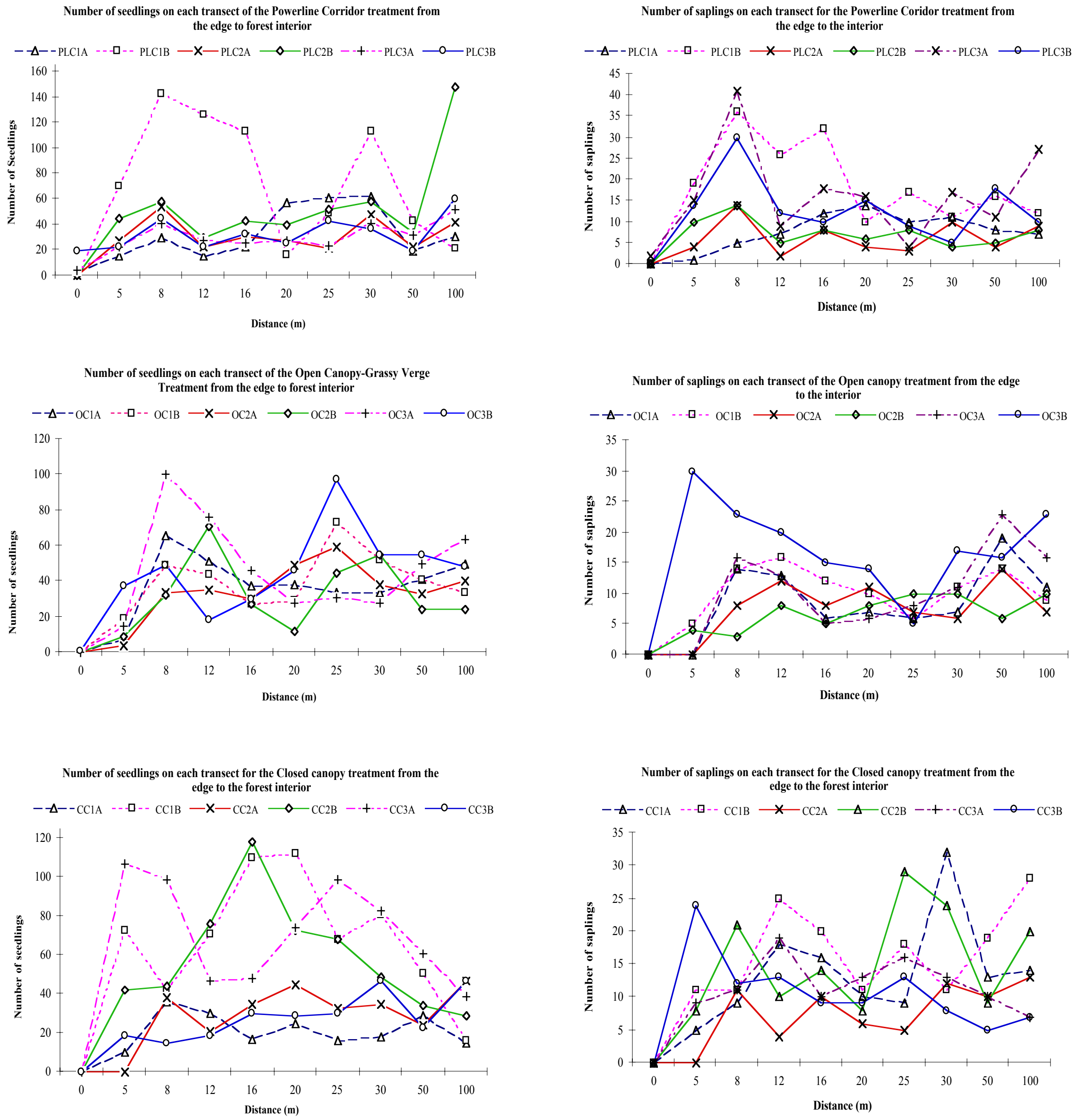
Seedling and Sapling Distribution

Whilst seedling and sapling numbers were highly variable within treatments they were not significantly different between clearing types. However, their distribution from the edge to the forest interior showed an edge effect. In addition, there were correlations between seedling and sapling numbers and microclimate elements and forest canopy structure.

<u>Examination of raw data: within treatment results</u>

Examination of the raw data revealed that seedling and sapling distributions on the closed canopy sites were highly variable from transect to transect and from the edge to the forest interior, with half the number of transects having relatively high seedling and sapling numbers and half having relatively low numbers (Figure 3.8). Seedling numbers on the powerline corridor and open canopy treatments increased sharply in the near edge zone and decreased again in the forest interior zone, while sapling numbers increased in the near edge, decreased in the transitional zone and then tended to remain relatively uniform. By contrast, the closed canopy treatment had a steady increase of seedlings up to the transitional zone and then a decrease to the forest interior, however, sapling numbers remained relatively constant from the near edge to the interior (Figure 3.9). However, there was a difference in seedling and sapling numbers between the edge and the forest interior for all types of linear clearings (Figure 3.9).

Figure 3.8. Number of seedlings and saplings on each transect compared between types of linear clearing.



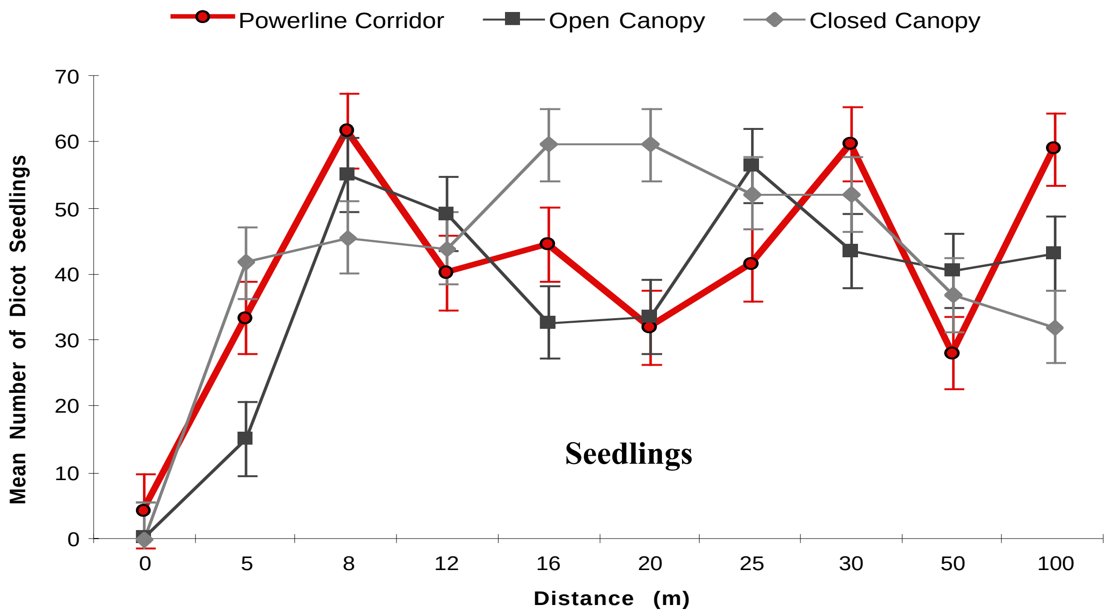
Key Points:

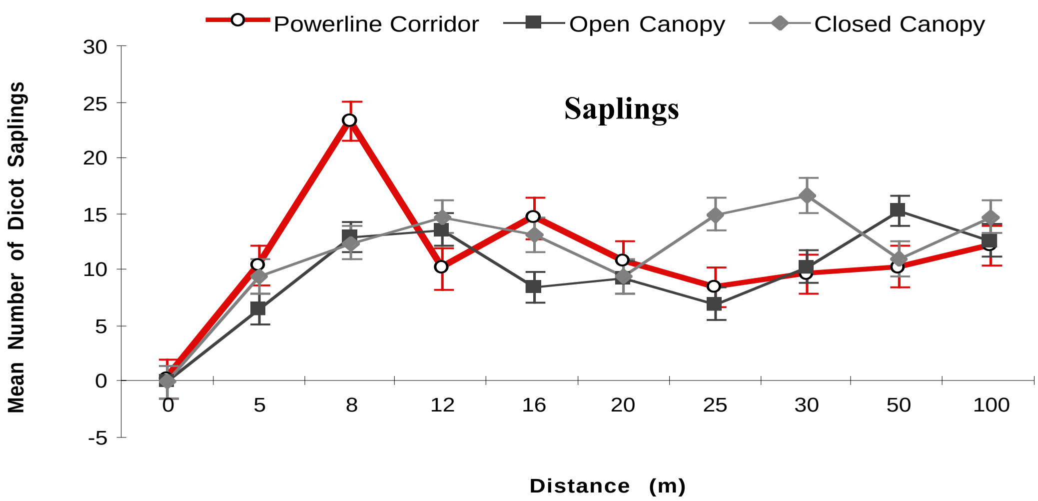
- There was great variability in seedling numbers both within and between treatments.
- Seedlings tended to be distributed relatively uniformly along the transects.
- The saplings on the open canopy and powerline corridor treatments tended to occur in higher concentrations at the edge, whereas saplings on the closed canopy were more uniformly distributed from the 0m to the 100m data sampling points.

Examination of raw data: between treatment results

Overall, all the treatments had increased seedling and sapling numbers within the edge to near edge zones, with the highest mean number of seedlings and saplings recorded for the closed canopy treatment and the lowest mean number of seedlings and saplings recorded for the open canopy treatment. The ratio of seedlings to saplings was found to be 4:1 (Appendix 3, Table 5).

Figure 3.9. Mean numbers of saplings and seedlings in each zone from the edge to the forest interior.





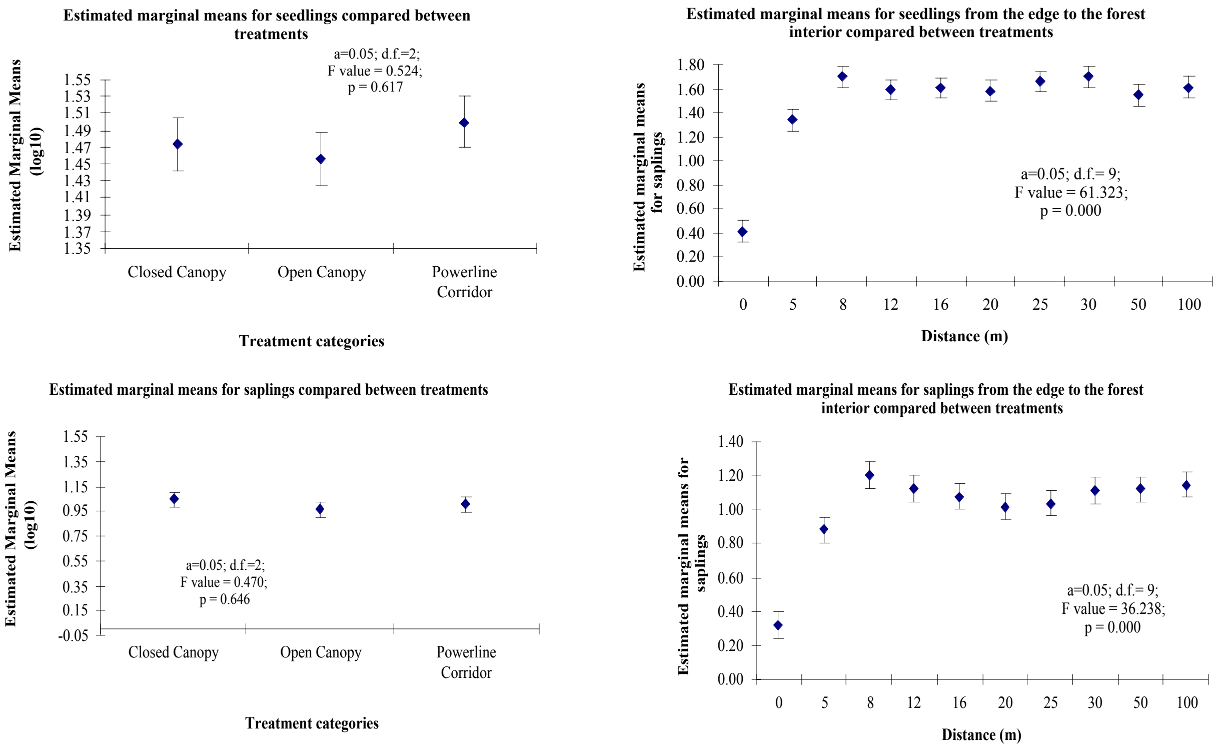
Key Points:

- All three treatments showed a marked increase in seedlings and saplings from 0m to 8m.
- Sapling numbers at 12m were similar to those of the forest interior at 100m.
- Seedling numbers on the closed canopy decreased to the forest interior, despite peaks at 16 and 20m.
- Seedling numbers were higher in the forest interior than at the edge (5m) on the open canopy and powerline corridor treatments.

<u>Results of repeated measures analysis of variance and Spearman's rank correlation analysis for seedlings and saplings</u>

No significant differences in seedling or sapling numbers were found to exist between the three types of linear clearing (Figure 3.10, Appendix 3, Table 6). However, significant differences were found in seedling and sapling numbers between the edge and the forest interior, with the treatment type influencing these differences (Appendix 3, Table 6). Spearman's rank correlation analysis showed highly significant relationships between seedling numbers and distance on all treatments, with a steep gradient of increase in seedling numbers at the edge. However, although sapling numbers showed a correlation with distance for all the treatments, this relationship was significant on the closed canopy and open canopy treatments only (Appendix 3, Table 7).

Figure 3.10. Plots of estimated marginal means for seedlings and saplings compared within and between treatments



Key Points:

- There was no significant difference in seedling and sapling numbers between linear clearing types.
- There was a significant difference between the edge zone and the forest interior.
- However, seedling and sapling numbers were similar to those of the forest interior from 8 metres inwards.

Correlation of seedling and sapling numbers with microclimate variables

On the closed canopy, seedling numbers increased as PAR and VPD at 20cm decreased and increased as air temperature at 150cm increased. However, of these the strongest correlation was between seedling numbers and PAR. On the open canopy, seedling numbers increased with decreasing PAR, soil temperatures, air temperature at 20cm and vapour pressure deficit at 20cm. The strongest correlations of these were for PAR and soil temperatures. Seedling numbers on the powerline corridor were only slightly correlated with PAR and soil surface temperature (Appendix 3, Table 8). In contrast, sapling numbers on the closed canopy were not significantly correlated with the microclimate variables. However, sapling numbers on the powerline corridor were significantly correlated with all microclimate variables, as were sapling numbers on the open canopy with the exception of air temperature at 150cm (Appendix 3, Table 9). The powerline corridor results suggested that there was a steep increase in sapling numbers as all microclimate variables decreased, whilst PAR and soil temperature had the greatest influence on sapling numbers on the open canopy treatment.

Correlation of seedling and sapling numbers with hemiphot variables
Seedling numbers on the closed canopy and open canopy treatments had significant to highly significant negative correlations with direct and diffuse below canopy photosynthetic photon flux density (PPFD), percentage canopy openness and red to far red ratio (RFR) and a significant positive correlation with leaf area index (LAI). Therefore, as direct and diffuse below canopy PPFD, percent canopy openness and RFR decreased seedling numbers increased, and seedling numbers increased with increasing LAI. Although correlations existed between closed canopy saplings and all hemiphot variables, correlations were significantly positive for LAI only. Similarly, open canopy saplings were significantly negatively correlated with direct and diffuse below canopy PPFD and significantly positively correlated with LAI, although non-significant correlations were detected for percentage canopy openness and RFR (Appendix 3, Tables 10 and 11).

Seedlings and sapling numbers on the powerline corridor treatment showed entirely different results, with no significant correlations for seedlings and a significant positive correlation detected between saplings and LAI (Appendix 3, Tables 10 and 11). The strongest correlations were seen between the closed canopy seedlings and all hemiphot variables and between LAI and seedling and sapling numbers on the open canopy and LAI and sapling numbers on the powerline corridor (Appendix 3, Tables 10 and 11).

Summary
The results of the vegetation study have shown an edge effect in the form of alteration to forest structure, species composition and seedling and sapling distribution has developed on all linear clearing types. The powerline corridor showed the most pronounced changes.

3.4 Discussion

The microclimatic conditions of the forest understorey are a function of the structural characteristics of the existing forest, which is, in turn, largely determined by the species that composed it. In addition, the external macroclimate influences the long-term persistence of older saplings, young and mature trees, shrubs and vines which supply a significant proportion of the seed stock upon which the structure and composition of the future forest will depend. Growth of seedlings and young saplings is primarily influenced by the microclimate of the understorey, within a temporal scale of days to weeks. Thus, a functional interdependence between the structure and species composition of the forest as a whole and the forest understorey exists, with the understorey microclimate regime acting as a 'filter' which differentially encourages some species and excludes others (Bazzaz 1996).

Disturbance to forest continuity
According to Hopkins (1990), Perry (1996) and others, disturbances of varying intensity, size, extent and frequency produce different rates and stages of successional regeneration within forests. Therefore, each type of linear clearing examined in this study provides an example of forest succession associated with a particular type of disturbance regime. On the basis of the degree of canopy openness (Figure 3.1), numbers of individuals at each taxonomic level (Figures 3.2 and 3.3), the frequency of occurrence of individual species (Figure 3.4) and distribution of species in each disturbance indicator category (Figure 3.6 and 3.7), the closed canopy could be viewed as an example of a late to primary successional forest, whilst the open canopy as an early successional forest and the powerline corridor as a mid-successional forest (Begon *et al.* 1986, Bazzaz 1996). However, the

distinctions between the types of linear clearing are not clear and a better illustration of this hypothesis is seen in the distribution of species within each disturbance category, and the numbers of seedlings and saplings between the edge and the forest interior (Figures 3.7, 3.9 and 3.10).

Effects of canopy openness on species distribution and composition

In a study of vegetation edge effects in a temperate rainforest remnant on the Robertson Plateau in New South Wales, Fox *et al.* (1997) found that species composition varied between the edge and interior, with more weeds and pioneer species present at the edge. This pattern of species distribution was also detected in the study at West Palmerston, with weeds and vines more prominent at the edge than at the interior on the powerline corridor and open canopy sites (Figures 3.6 and 3.7). Native rainforest vines are usually found in the upper canopy of the rainforest and are a characteristic life form within a Complex Mesophyll Vine Forest, however, their dominance alters the forest structure which in turn alters the microclimate. Rainforest species, which were most numerous on the closed canopy treatment, increased with increasing distance from the edge for all the treatments (Figure 3.7). This pattern of distribution highlights the effects of edges on rainforest species, which have been shown to have poor recruitment and survival rates and higher mortality rates at rainforest edges (Ferreira and Laurance 1997, Laurance *et al.* 1997a).

Effects of canopy openness on density and distribution of seedlings and saplings

Despite a high level of variation in seedling and sapling numbers within the treatments, seedling and sapling edge effects related to microclimate factors were observed in this study (Figure 3.10 and Appendix 3, Tables 6, 7, 8 and 9). Variation in seedling and sapling numbers between treatments and between the edge and interior may have been affected by a number of abiotic and biotic factors. Different species have differing phenologies, seed dispersal mechanisms, and fecundity, and their seedlings and saplings may be found in varying environmental conditions of soil moisture, microclimate and canopy structure. They are subjected to differences in predation, competition and disturbance regimes within each location (Bazzaz 1996).

A study of edge effects in a rainforest remnant on the Atherton Tableland, conducted by Turton and Freiburger (1997), showed that seedling numbers increased steadily from the edge to about 30m and then levelled off. In addition, more seedlings were observed on those transects in the east and west aspects, possibly as a result of higher light levels although light was not measured in Turton and Freiburger's (1997) study and the canopy was shown to be even and closed at the edge. The higher seedling numbers at the edge particularly on the east and west aspects reported by Turton and Freiburger (1997) may have also been related to the temperature and moisture conditions. In the West Palmerston study, seedling and sapling numbers on the open canopy and powerline corridor treatments tended to increase with increasing distance from the edge as light levels, soil temperatures, air temperature at 20cm and vapour pressure deficit at 20cm decreased (Appendix 3, Table 5). However, seedling numbers on the closed canopy were lower in the forest interior than at the edge (Figure 3.8).

The less hospitable environment at the edge zone (0 to 5 metres) on all the treatments may have contributed to the lower number of seedlings and saplings recorded there, as described in Section 2. However, greater numbers of seedlings and saplings occurred on each of the treatments within the near edge and transitional zones, which provided relatively disturbed soil exposed to higher light levels, higher air and soil temperatures, and wider diurnal and seasonal microclimatic fluctuations (Section 2). The microclimatic conditions at the edge enhanced growth of weeds, vines and pioneers on the open canopy and powerline corridor treatments whilst a general decline in seedling numbers was observed on the treatment where the canopy was closed (Figure 3.9), allowing less light to penetrate to the forest floor (De Vogel 1980, Perry 1996).

Rainforest seedlings generally cannot tolerate high light environments, especially immediately after germination and when they are very young, however, light is a less critical factor for many rainforest species once they have established (De Vogel 1980). Therefore, numbers of saplings did not differ significantly between the edge and the interior on any of the treatments (Figure 3.9). Many young rainforest species, especially those <50cm in height, utilise food stores in their cotyledons or obtain 'food' from the long-lasting seed endosperm, as in the case of large-seeded species, and are therefore not wholly dependent upon photosynthesis for survival (De Vogel 1980). For these seedlings, relatively low temperatures and high soil and air moisture may be more important to their survival and establishment. Additionally, some rainforest seedlings utilise different parts of the PAR continuum enabling them to survive and grow slowly under low-light conditions for relatively long periods of time (De Vogel 1980). However, once seedlings have attained a height of around ≥150 cm they are able to utilise more of the PAR continuum and an increase in light becomes a more critical factor to their survival. For understorey rainforest species, maintenance of understorey light, moisture and temperature conditions may be critical to successful flowering and fruiting as well as to individual survival.

3.5 Conclusions

Both the road with wide verges and no canopy cover and the powerline corridor showed marked changes in the vegetation structure and composition at the edge of the adjacent rainforest, whilst the closed canopy showed less pronounced changes. The linear clearings studied at West Palmerston can be classified according to the different disturbance factors and resulting edge effects associated with them, as discussed by Whitmore (1990). The closed canopy treatment, a single-carriage way unsealed road with canopy cover retained, is a relatively small, confined and low intensity disturbance that produces minor edge effects. Retention of the canopy across the road minimises the need for frequent management of verges to remove weeds, thus, this type of disturbance could be seen as a low level disturbance which allows the adjacent rainforest to recover and ecosystem equilibrium to be regained after road construction is complete.

By comparison, a small unsealed road with wide, treeless verges and open canopy, such as the open canopy-grassy verge treatment, produces larger, more intense and extensive disturbance. Disturbance at the edge becomes chronic as a result of frequent slashing and spraying of the verges to remove weeds and to prevent the canopy from encroaching across the road. This management approach produces a form of 'arrested succession' by opening the edge zone of the forest, and permitting the establishment of permanent changes in light regimes, temperature, moisture and air movement gradients between the rainforest interior and the road. Marked changes in rainforest structure have been found to be the consequence of repeated disturbance, with decline of species diversity and replacement of rainforest species with disturbance-tolerant species (Forman and Alexander 1998, Laurance *et al.* 1998).

The type of disturbance created by construction of a powerline corridor is extremely intense initially, and damage to the adjacent rainforest is usually extensive (Fox *et al.* 1997). However, as the clearing under the powerlines is rarely maintained and the conditions are ideal for growth of weeds and grasses, the rainforest edges can eventually 'seal', thus protecting the interior from the effects of the contrasting microclimate of the powerline corridor, although the risk of invasion by feral plant species is increased (Saunders *et al.* 1991; Laurance *et al.* 1998).

3.6 Management Implications

- The findings of this study would suggest that where roads must dissect tracts of rainforest, these should be narrow to allow for retention of canopy over them.
- Weeds should be kept to a minimum and road construction should not be considered complete until revegetation of the verges with rainforest species has been completed.
- Revegetation should aim at restoring the forest to as close to its pre-construction state as possible and revegetation programs should be monitored periodically to ensure that forest succession is proceeding towards this end.
- Finally, edges should be encouraged to 'seal' with native rainforest species rather than with exotics and weeds.

- Powerline corridors should be revegetated with rainforest species as part of the final construction phase and all efforts made to prevent invasions of weeds during the early stages of revegetation. Ideally, construction methods that do not require extreme disturbance to rainforest vegetation and soil should be employed if a powerline easement must dissect rainforest.
- Finally, the option of avoidance of rainforest habitat should be given serious consideration when deciding whether or not to build linear constructions through rainforest.

IMPACTS OF ROADS AND POWERLINES

Section 4: Geochemical Impacts on Roadside Soils in the Wet Tropics of Queensland World Heritage Area as a Result of Transport Activities

4. Geochemical Impacts on Roadside Soils in the Wet Tropics of Queensland World Heritage Area as a Result of Transport Activities

Glenys Diprose, Bernd Lottermoser, Sharon Marks and Tara Day

Summary: *Road based transport activities in the Wet Tropics of Queensland World Heritage Area (WTQWHA) can have an impact on the geochemical composition of soils adjacent to roads. Of particular interest is the contamination or pollution of soils in transport corridors by heavy metals such as lead, cadmium, zinc, iron, nickel and copper. This project presents a geochemical study of the heavy metal concentrations in topsoils along two major road corridors in the Wet Tropics region. The objective of this study (Diprose, 1999) was to carry out an initial geochemical assessment of soils within the Kuranda Range and Gillies Range transport corridors. Heavy metal distribution patterns including distance from the road and soil profile concentrations were examined. Levels of heavy metal concentrations were compared with levels considered safe for the environment.*

Generally, concentrations of copper, lead and zinc were found to decrease with increasing distance from the road. The distribution of heavy metals appears to be affected by many factors associated with the nature of both these roads, including the vegetation, terrain, sharp corners and steep slope. Comparison of samples from a grassy verge transect (little or no vegetation), and a rainforest transect (thick vegetation), suggested that thick vegetation appears to be a factor which reduces the penetration of heavy metals. The pollutants examined tended to occur further away from the road on the transect with little or no vegetation, however further research is required to confirm this indication. The results also suggested that mean concentrations of manganese, zinc and copper were higher in Kuranda Range samples adjacent to slight - moderately curved and sharply curved sections sections than mean concentrations adjacent to straight sections of road, whilst the mean concentration of lead was highest in samples adjacent to straight sections of road. A further pattern of distribution indicated by the results is that the heavy metals copper, lead, zinc, nickel and manganese decreased in concentration down the soil profile, while iron concentrations were generally higher in subsoil samples.

The results indicate that on both Gillies and Kuranda Range Roads mean concentrations of heavy metals copper, lead and zinc in topsoils were higher than mean background levels. Sediment samples were also found to have higher concentrations of lead than background levels, with several samples also being higher in zinc. Total heavy metal concentration analysis of Kuranda Range samples indicated that concentrations of copper, manganese and nickel in some topsoil samples exceeded ANZECC/NHMRC environmental investigation levels and that the mean topsoil concentrations of copper and manganese also exceeded these environmental investigation levels. More sampling is required, however, as these existing concentrations of heavy metals in topsoils adjacent to the Kuranda Range road suggest that these topsoils would be classified by regulatory authorities as contaminated with copper and manganese (and potentially nickel).With the predicted increases in traffic levels on both the Kuranda and Gillies Ranges the maintenance of ongoing monitoring, and management of the impacts of heavy metals concentrations are considered critical.

4.1 Introduction

Over the last four decades the issue of pollution resulting from transport activities has gained in importance. Pollution of the atmosphere, surface dusts, soil and water has increased with the rapid rise of vehicle numbers. Transport activities may result in the addition of heavy metals such as lead, cadmium, zinc, iron, nickel and copper to soils in and around transport corridors. Of the numerous investigations of transport-related heavy metal pollution many have concentrated on lead due to the health concern for humans. Lead isotope analysis has been used to determine the source of the lead found in soils, comparing that from petrol and agricultural activities as opposed to those occurring naturally in background soils. Other studies have investigated the effect of heavy metals on soil and vegetation near roads.

Heavy metals are found naturally in soil, but generally only in small concentrations. Natural concentrations vary as can the behaviour of heavy metals in soils. Sources and types of heavy metals derived from vehicles include:

1) tyre wear (zinc, lead, chromium, copper and nickel) (Singh and Stinnes 1994):
2) wear of studded tyres (iron, nickel, molybdenum, tungsten, chromium, cobalt, cadmium, titanium and copper);
3) corrosion of bushings, brake wires and radiators (copper, iron, nickel, chromium and cobalt);
4) wear of brake linings (nickel, chromium and lead);
5) wear of brake pads (copper, zinc and manganese) (Viklander 1998) and
6) leaded petrol (the major souce of lead) (Viklander 1998).

The severity of heavy metal contamination depends on several factors including the amount of traffic, climatic factors, organic matter, other metal ions and pH (Scanlon 1991). In order for soil to be classed as being contaminated the heavy metal concentrations are (a) to be greater than the background levels and (b) to be over the environmental investigation levels established by regulatory authorities (Barzi *et al.* 1996). Table 4.1 lists the environmental investigation levels for various heavy metals in Australia along with an example of some samples taken in rural Australia.

Table 4.1. Environmental investigation levels (ANZECC/NHMRC 1992) for some heavy metals in soils with an example of rural soil levels.

Heavy Metal	Environmental Investigation Levels (ppm)	Australian rural soil samples (Barzi *et al.* 1996)	
		Number of samples	Range of Values
Copper	60	500	1 – 190
Lead	300	160	2 – 160
Zinc	200	500	<2 – 200
Cadmium	3	180	<1
Manganese	500	800	4 – 13 000
Nickel	60	200	2 – 400

The Australian National Environment Protection Council (NEPC) has put forward draft guidelines for the assessment and management of contaminated land. These guidelines give the background ranges and the environmental investigation levels along with a list of various land use types and the health based investigation level (Table 4.2). The different land use divisions are (NEPC 1999):

A) Standard residential with garden / accessible soil and where the home grown produce contributes less than 10% of vegetable and fruit intake and where no poultry is kept. Includes places like childcare centres, kindergartens, pre-schools and primary schools.
D) Residential with minimal opportunities for access to the soil. Includes dwellings with fully and permanently paved yard space such as a high-rise, apartments and flats.
E) Parks, recreational open space and playing fields. Includes secondary schools.
F) Commercial / industrial such as shops, offices, factories and industrial sites.

Table 4.2. National Environment Protection Measures for the Assessment of Site Contamination (NEPC 1999).

Heavy Metal	Background Range (ppm)	Health Based Investigation Levels (ppm) in various exposure settings				Interim Ecological Investigation Level (ppm)
		A	D	E	F	Urban Areas
Copper	2 – 100	1 000	4 000	2 000	5 000	100
Lead	2 – 200	300	1 200	600	1 500	600
Zinc	10 – 300	7 000	28 000	14 000	35 000	200
Cadmium	1	20	80	40	100	3
Manganese	850	1 500	6 000	3 000	7 500	500
Nickel	5 – 500	600	2 400	600	3 000	60

4.2 Methods

Site description

The Kuranda Range Road is located on the Macalister Range north of Cairns and the Gillies Range Road traverses the Lamb Range to the south. These two roads provide access to the Atherton Tablelands from Cairns and the surrounding coastal area. The daily traffic on the Kuranda Range is approximately 5 746 vehicles as of 1996 with an expected growth rate of 3.2% per year. The Gillies Highway has approximately 1 525 vehicles per day as of 1996 with an expected growth rate of 4.2% per year. The commercial component of total traffic volume is 9% for the Kuranda Range and approximately 12% for the Gillies Highway (Department of Main Roads 1999).

The geology of the region is mostly Hodgkinson Metamorphics. Granite makes up about half of the Gillies Range and both granite and observed hornfels are found in smaller amounts on the Kuranda Range. The soil types found on the Kuranda Range are described by Murtha *et al.* (1996) and include soils of the Galmara, Bicton, Bingil, Buchan, and Mission series. Soil series found on the Gillies Range include Galmara, Bicton, Bingil, Utchee, Tyson, and Pin Gin (Murtha *et al.* 1996).

Sampling procedure

Due to high traffic volume and the narrowness of the road on both the Kuranda and Gillies Ranges, sampling was restricted to locations that maximised researcher and motorist safety. The collection period was in late April and May 1999 after a period of high rainfall.

Samples collected from each of the Gillies and Kuranda road corridors consisted of 30 topsoil samples, five sediment samples (sediment from gutters) and five background topsoil samples. Soil samples were collected in duplicate from the top 5 – 10 cm of the soil profile using a steel garden trowel. Sediment samples were collected from drains running off the road. Background soil samples were taken in undisturbed areas at least 50 m away from the road, with the exception of one, which was taken at 30 m. The soil, sediment and background sampling sites adjacent to the Kuranda Range road are identified in Figure 4.1 and adjacent to the Gillies Highway are identified in Figure 4.2.

To examine the effect of vegetation on the distribution of heavy metals two 50 m transects were set up on the Kuranda Range road. The first transect was located in a relatively open area with grass approximately 1 m in height, adjacent to a sharply curved section of road. The second transect was located in an area of closed canopy forest with dense shrubs and groundcover, adjacent to a straight section of road. Both transects were laid on the same geology type, Hodgkinson Formation. Top-soil samples were taken of the top 5 – 10 cm along these transects at distances of 2.5 m, 5 m, 10 m, 20 m, 30 m, 40 m and 50 m from the road. Samples on the Kuranda range that showed high concentrations of lead were re-sampled. This time the surface soil was collected from the top 5 – 10 cm and then the subsoil was sampled using a post hole digger.

Samples of bitumen and brake pads were also collected for lead isotope analysis. Bitumen was taken from the side of the road and used brake pads were obtained from an automobile repair shop. Post-sampling classification to examine the relationship between road characteristics and heavy metal concentrations was used. This classification involved assigning topsoil sampling sites, using a 1:25000 scale map with sampling sites plotted, to one of three classes:

1) adjacent to a relatively straight section of road (approximately 180º-160º);
2) adjacent to a slight – moderately curved section of road (approximately 159º-130º); and
3) adjacent to a sharply curved section of road (approximately <129º).

Sample analysis

Analysis of samples was carried out by a variety of agencies. All samples underwent partial acid digestion and were analysed by atomic adsorption spectrometry (AAS) for cadmium, copper, iron, manganese, lead, zinc and nickel. A selection of samples from the Kuranda Range underwent X-ray diffraction analysis to determine mineralogy, lead isotope analysis to determine lead source and inductively coupled plasma atomic emission spectrometry (ICPAES) for determination of total heavy metal concentration.

Figure 4.1 Soil, background and sediment sample sites on the Kuranda Range Road.

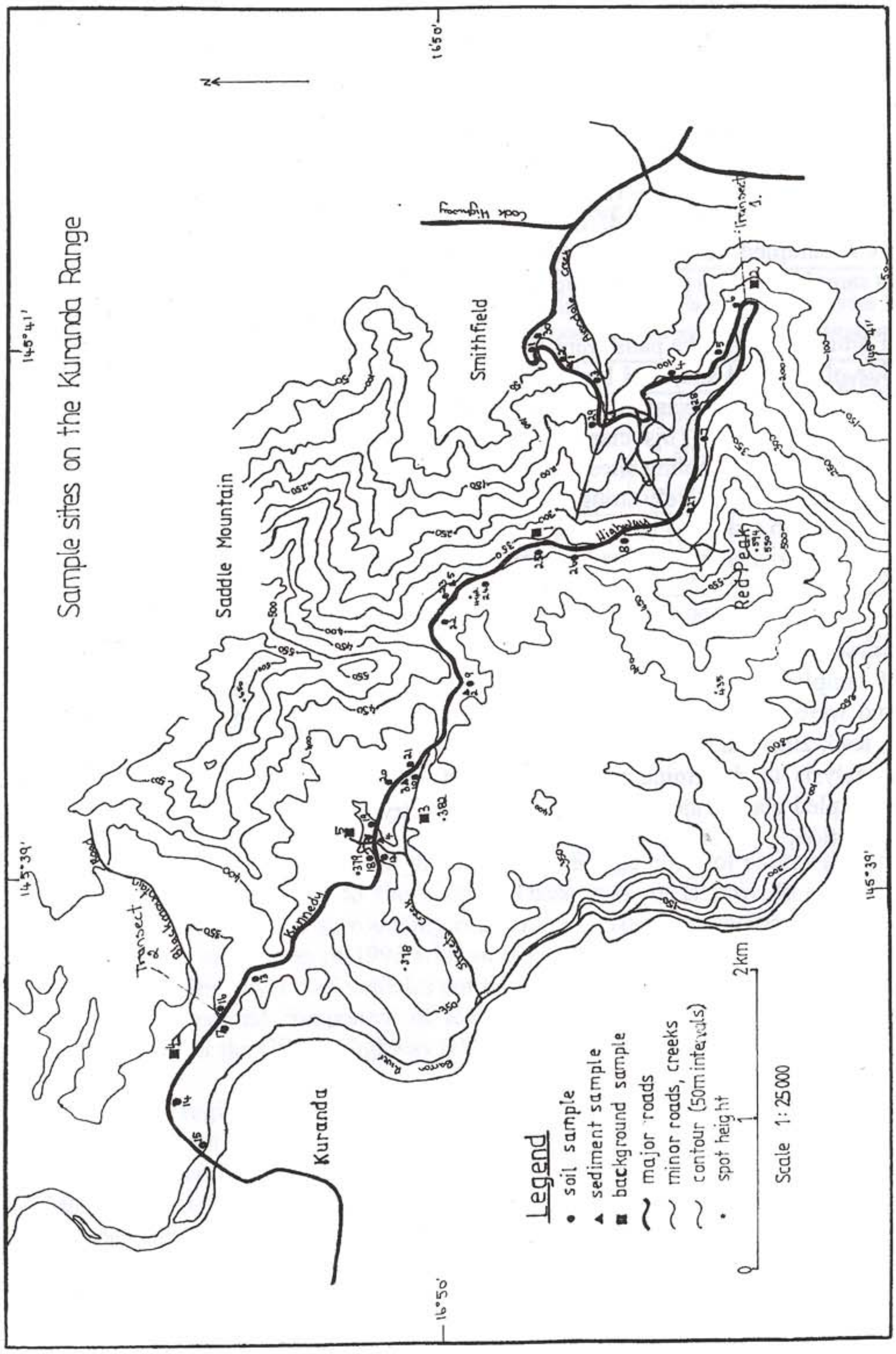
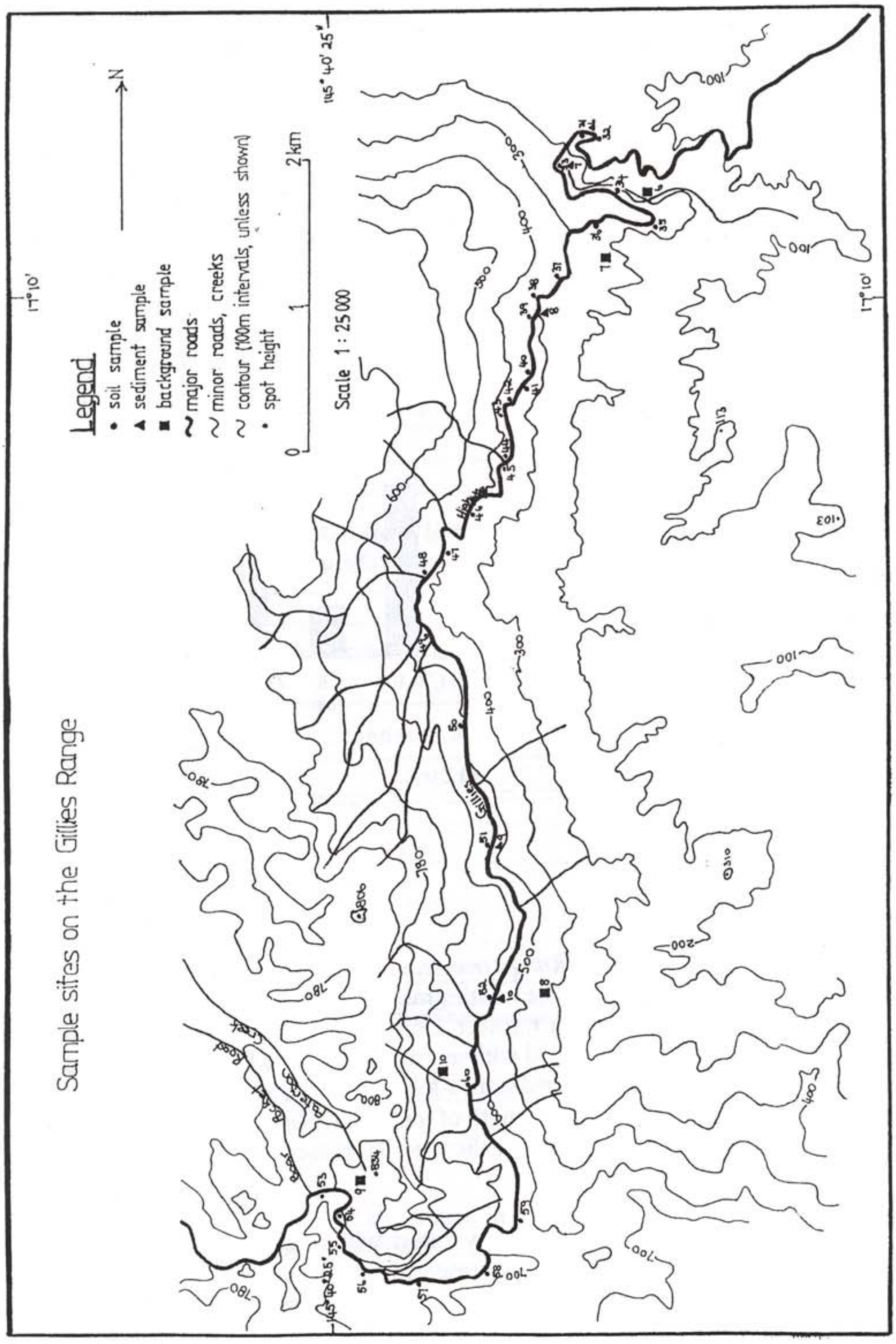


Figure 4.2 Soil, sediment and background sample sites on the Gillies Range Road.



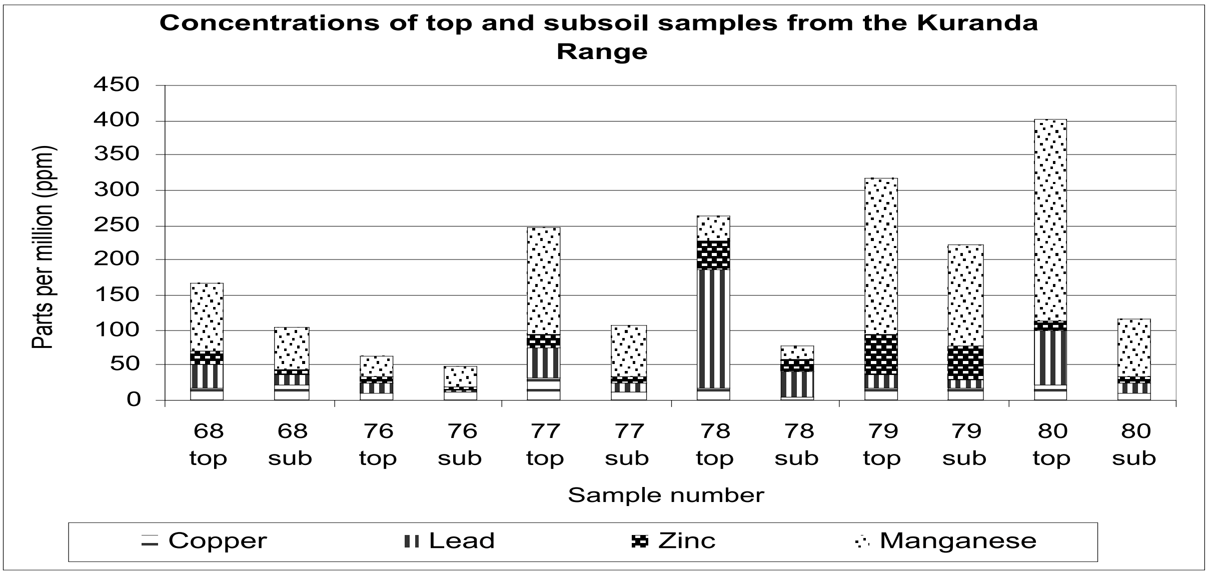
4.3 Results

Patterns of Heavy Metal Distribution and Penetration

Concentration of heavy metals through soil profile

Concentrations of four heavy metals in topsoil (top 5 – 10 cm) and subsoil samples are plotted in Figure 4.3. Copper, lead, zinc, nickel and manganese concentrations generally decreased down the soil profile. Cadmium concentrations varied little through the soil profile while iron concentrations were generally higher in subsoil samples than in topsoil samples.

Figure 4.3. Concentrations of manganese, zinc, lead and copper in top and sub soil samples from the Kuranda Range.



Concentration of heavy metals on Kuranda Range transects

Transect 1 was laid out in a relatively open area with grass to a height of one metre, adjacent to a sharply curved section of road, samples from transect 1 are presented in Figure 4.4. Generally, the measurements of copper, lead and zinc decreased with increasing distance from the road along transect 1. Nickel appeared to increase with increasing distance from the road, and iron and cadmium levels appeared to remain relatively constant along the length of transect 1. Higher concentrations of zinc and copper appeared to occur to a distance of 30m from the road on transect one, after this distance levels of these heavy metals occurred at lower levels.

Transect 2 was laid out in an area of closed canopy forest with thick undergrowth, adjacent to a straight section of road, samples from transect 2 are presented in Figure 4.5. Generally, concentrations of copper, lead and zinc decreased with increasing distance from the road. Cadmium, iron and nickel concentrations remained relatively constant throughout transect 2. Along transect two higher concentrations of zinc, copper, and nickel appeared to occur to a distance of 10m from the road, after this distance levels of these heavy metals deceased and remained relatively constant at lower levels.

Figure 4.4. Heavy metal concentrations in topsoils versus distance from Kuranda Range Road on a transect commencing in a grass verge (grass to 1 metre high) on a sharp curve (transect 1).

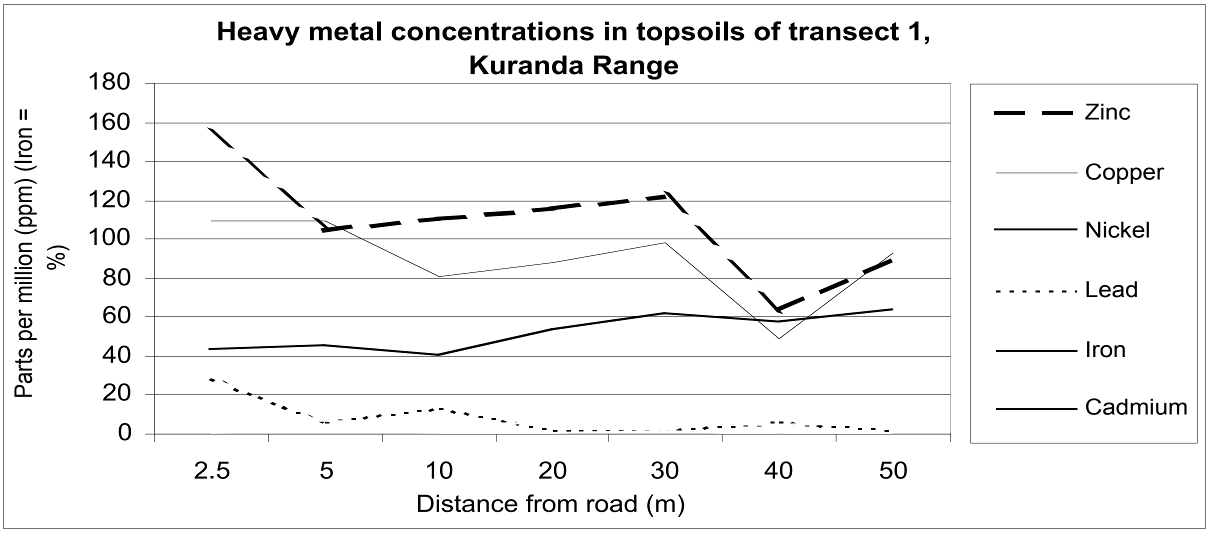
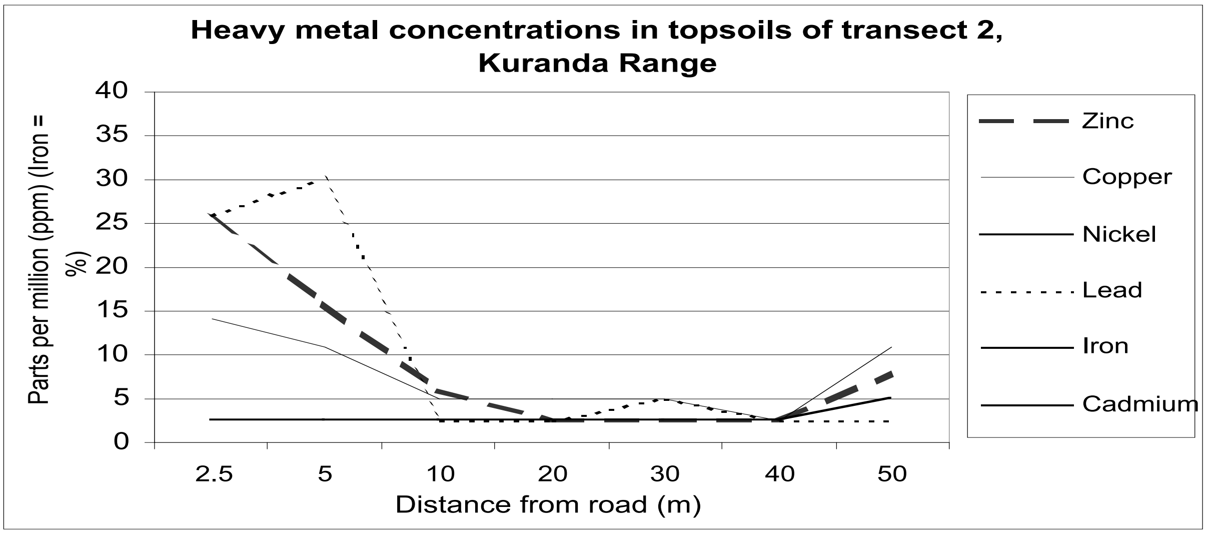


Figure 4.5. Heavy metal concentrations in topsoils versus distance from Kuranda Range Road commencing in closed canopy rainforest with dense shrub and groundcover on a straight road section (transect 2).

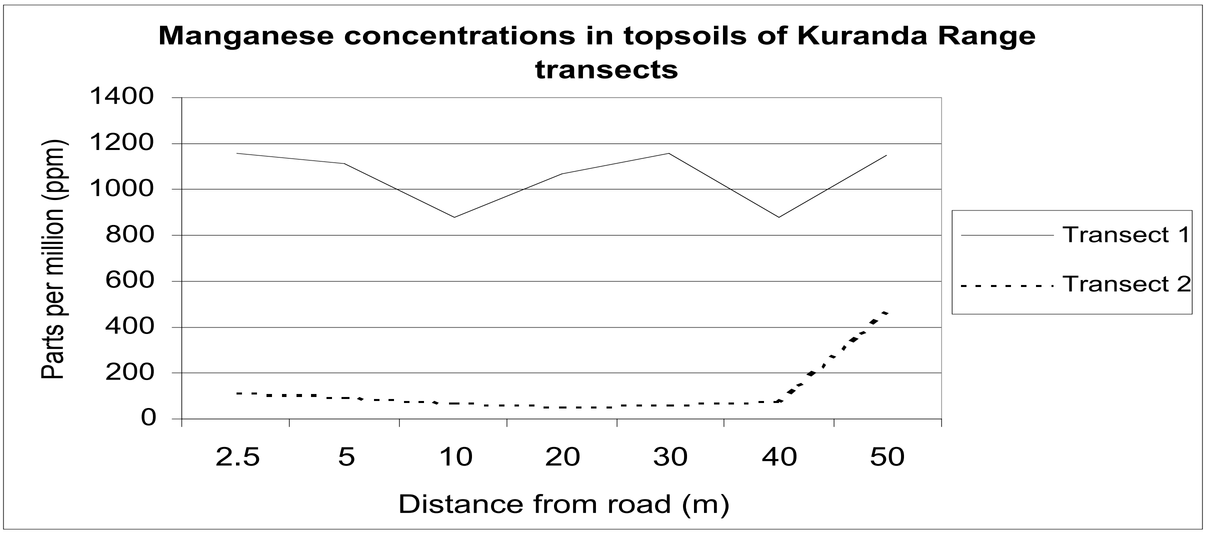


Manganese levels for both transects are plotted in Figure 4.6. While no pattern was discernible over distance from the road, differences in manganese concentrations between transects were apparent.

The penetration of the heavy metals zinc, copper, nickel and lead into soils appeared to be restricted by thick rainforest vegetation in comparison to grassy verges. However, this result can only be considered a preliminary indication, due to differing characteristics of the road adjacent to the transect (one on sharp curve and one on straight road section). Variations in bedrock and sampling and analytical processes may also have occurred, so that more comprehensive and extensive sampling and analyses are required for statistical validity.

Zinc, copper, nickel and manganese occurred at substantially higher concentrations along transect 1 (adjacent to a curved section of road), in comparison to transect 2 (adjacent to a straight section of road). Concentrations of lead, iron and cadmium however were relatively similar across both transects. This may be a result of the degree of curvature of the road. However, lack of replication means that curvature is only one potential causative factor influencing the concentrations of heavy metals. The differences may also be (in part) the result of differences in bedrock, and sampling and analytical processes.

Figure 4.7. Concentration of manganese over distance for transects 1 and 2 on Kuranda Range.



__Levels of Heavy Metal Concentrations__

Heavy metal concentrations in soil samples

The mean concentration levels of heavy metals (copper, lead, zinc and nickel) in the topsoil, sediment and background samples are shown in Figure 4.8 for the Kuranda Range and Figure 4.9 for the Gillies Range. Mean levels of cadmium across both the Kuranda and Gillies Ranges were one or less than one part per million (ppm) and mean levels of manganese were substantially higher than other heavy metals. For reasons of scale, mean levels of cadmium and manganese are presented in Tables 4.3 (Kuranda Range) and 4.4 (Gillies Range) rather than displayed on the graphs.

On the Kuranda Range all mean heavy metal levels except nickel were found in higher concentrations in the topsoils (adjacent to the road) than in the background samples (taken away from the road). Mean levels of copper and lead in the sediments were less than in topsoils but higher than background levels. Mean manganese and nickel levels were lower in sediments than both topsoil and background samples, whilst mean zinc levels appeared to be highest in sediment samples. Concentrations of copper, lead, zinc, manganese and nickel in some topsoil samples were substantially higher than mean background levels. For example, two samples exhibited concentrations of lead at 165ppm and 149ppm, compared with a mean background concentration of 8.4ppm (Appendix 4, Table 1 lists the metal concentrations of all Kuranda Range samples). In addition to the variation in heavy metal levels between background, topsoil and sediment samples, concentrations of heavy metals varied within these three sample groups. The range of background, topsoil and sediment heavy metal samples for Kuranda Range is presented in Table 4.3.

Figure 4.9. Comparison of topsoil, background and sediment soil samples taken on the Kuranda Range Road.

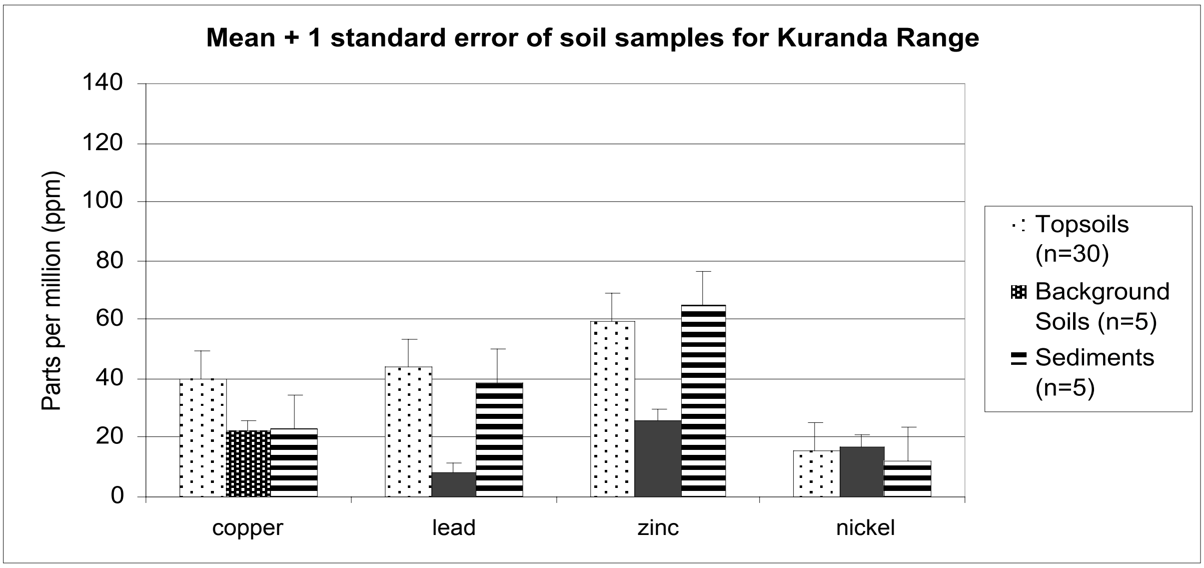


Figure 4.10. Comparison of topsoil, background and sediment soil samples taken on Gillies Range.

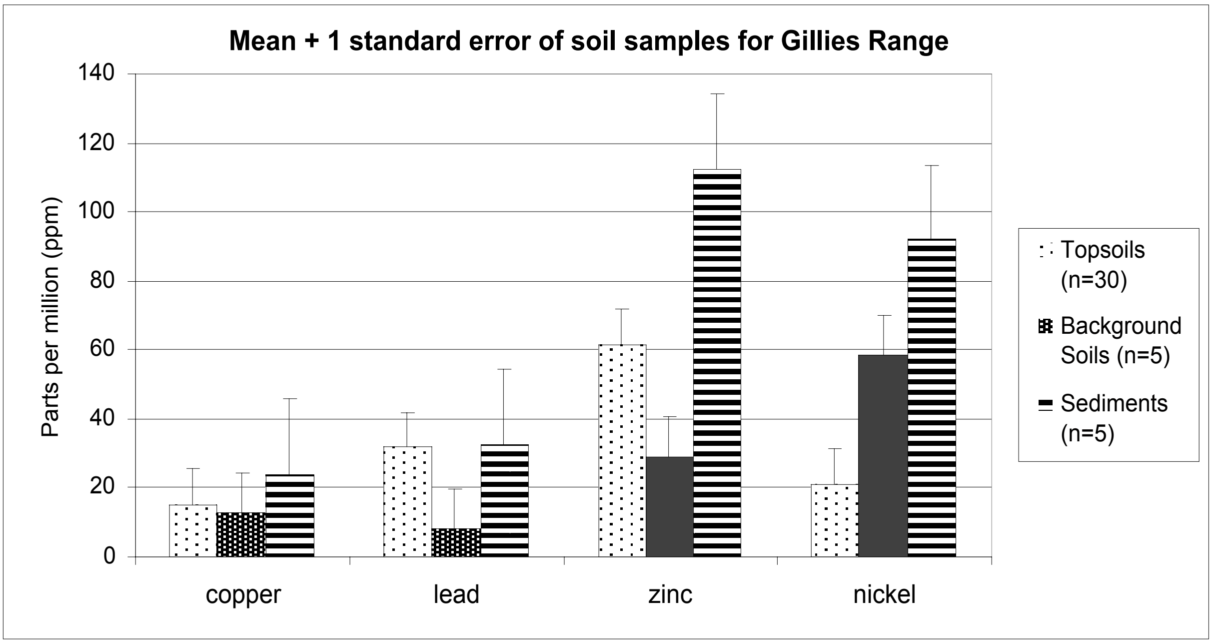


Table 4.3. Mean and range of background topsoil and sediment heavy metal levels for Kuranda Range.

Sample		Concentration of Heavy Metals (ppm)					
		Copper	Lead	Zinc	Cadmium	Manganese	Nickel
Background	Mean (N = 5)	23	8.4	26	1	304	18
	Range	<5-71	<5-15	5-69	<1-1	25-991	<5-71
Topsoil	Mean (N = 30)	40	44	60	1	506	16
	Range	5-208	5-165	5-169	1-2	10-1960	5-58
Sediment	Mean (N = 5)	23	39	65	1	250	12
	Range	11-63	24-91	17-220	<1-1	119-501	7-30

On the Gillies Range mean copper, lead, and zinc levels were found to be higher in topsoils than in background samples while mean manganese and nickel levels were lower than background levels. The mean levels of heavy metals found in the sediment samples were generally greater than both the topsoil and background samples with zinc, manganese and nickel being particularly higher. Concentrations of copper, lead, zinc, manganese and nickel in some topsoil samples were substantially higher than mean background levels. For example, two samples exhibited concentrations of lead at 221ppm and 88ppm, compared with a mean background concentration of 8ppm (Appendix 4, Table 2 lists the metal concentrations for all Gillies Range samples). In addition to the apparent variation in heavy metal levels between background, topsoil and sediment samples, concentrations of heavy metals varied within these three sample groups. The range of background, topsoil and sediment heavy metal samples for Gillies Range is presented in Table 4.4.

Table 4.4. Mean and range of background topsoil and sediment heavy metal levels for Gillies Range.

Sample		Concentration of Heavy Metals (ppm)					
		Copper	Lead	Zinc	Cadmium	Manganese	Nickel
Background	Mean (N=5)	14	8	29	1	451	60
	Range	<5-32	5-12	8-63	<1-1	30-980	<5-272
Topsoil	Mean (N=30)	16	32	62	1	430	22
	Range	5-44	8-221	16-166	1-2	39-3560	5-183
Sediment	Mean (N=5)	24	32	112	1	500	92
	Range	9-31	6-72	26-180	<1-1	170-1030	33-245

Potential Sources of Heavy Metal Contamination

Analysis of the bitumen sample indicated higher concentrations of lead and zinc than mean background levels of both the Kuranda and Gillies Ranges (Table 4.5). The bitumen sample also showed concentrations of manganese and nickel approximately 50% higher than mean background levels for Kuranda Range. Analysis of the brake pad sample demonstrated significantly higher concentrations of copper, lead, zinc, nickel and possibly cadmium in comparison to mean background levels of both the Kuranda and Gillies Ranges (Table 4.5). Pearson correlation analysis of the concentrations of heavy metals found in the Kuranda Range topsoils showed highly significant correlations between copper, zinc, cadmium, manganese and nickel, whereas lead was not correlated with the other metals. This suggested that the source of lead may be different from the source of the other metals. Pearson correlation analysis of concentrations from the Gillies Range topsoils also showed significant correlations between cadmium, manganese and nickel. Lead, zinc and copper were not significantly correlated with the other metals. Therefore it appeared that sources of cadmium, manganese and nickel may be similar.

Table 4.5. Concentrations of heavy metals in bitumen and brake pad samples.

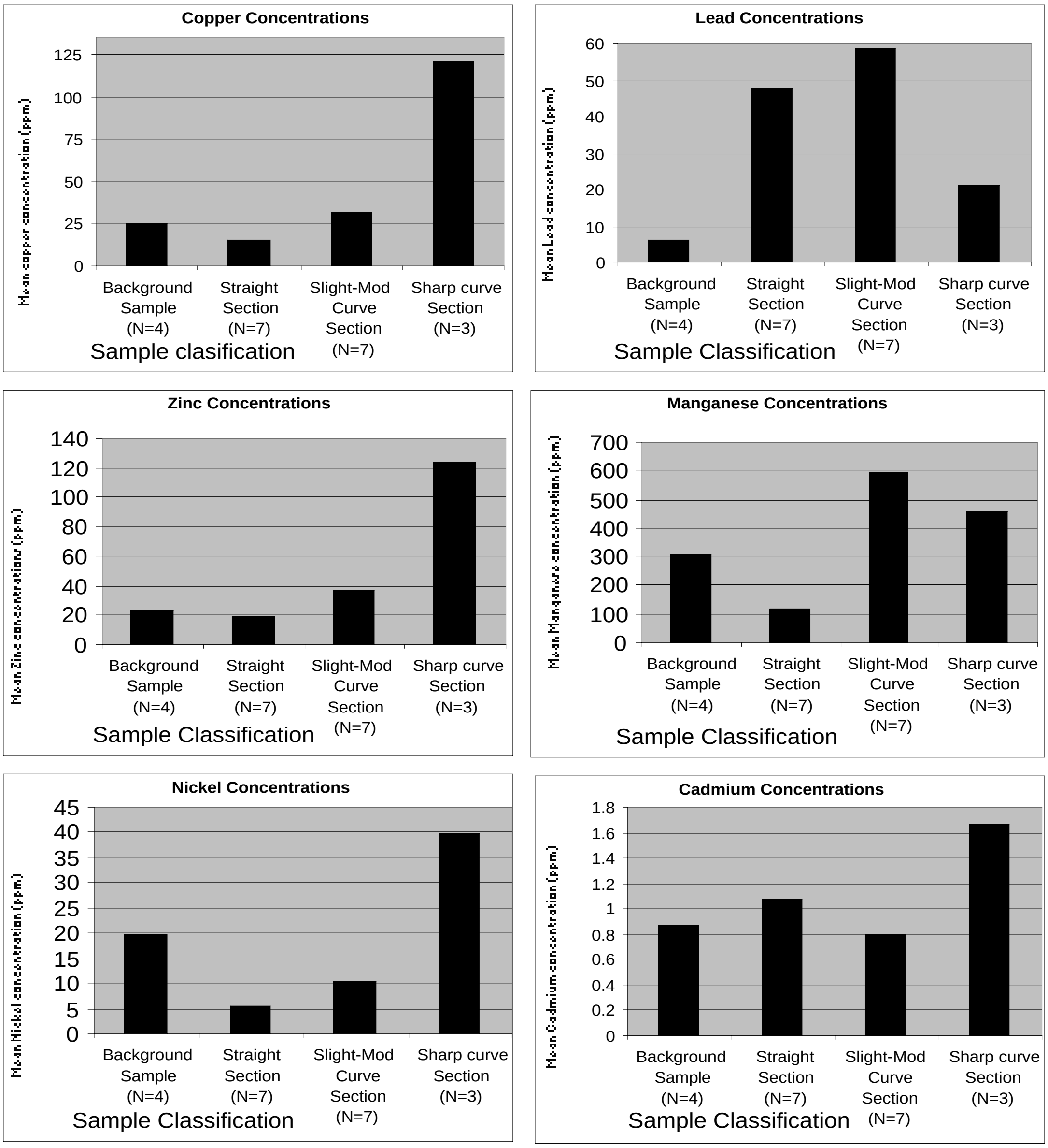
Levels	Heavy Metals					
	Copper (ppm)	**Lead (ppm)**	**Zinc (ppm)**	**Cadmium (ppm)**	**Manganese (ppm)**	**Nickel (ppm)**
Mean Background levels Kuranda Range (N= 5)	23	8.4	26	1	304	18
Mean Background levels Gillies Range (N= 5)	14	8	29	1	451	60
Bitumen sample (N=1)	22	20	88	2	461	38
Brake Pad sample (N=1)	9 213	385	5 790	4	271	582

Lead isotope ratio analysis suggested a similar origin of lead contamination in the samples with high concentrations but comparison with published values for lead used in petrol manufacture (Gulson *et al.* 1981) did not strongly indicate that leaded petrol was the source of lead. Lead in these higher concentration samples appeared to originate from a younger lead source than that typically used in petrol manufacture (Gulson *et al.* 1981). However, this analysis is not conclusive as the number of samples was small and no detailed analysis was carried out on background samples.

Degree of Road Curvature

Examination of the relationship between road sections adjacent to Kuranda Range sampling sites (on Hodgkinson formation) and the concentrations of heavy metals indicated that mean concentrations of manganese, zinc and copper were higher in samples classified as adjacent to slight - moderately curved and sharply curved sections than straight sections of road. Conversely however, the mean concentration of lead was lowest in samples adjacent to sharply curved sections of road. These results were in accord with the observations of the researcher, that samples adjacent to sections of road where motorists accelerated had higher lead concentrations, whilst samples adjacent to sections of road where motorists are required to brake had higher concentrations of zinc and copper. This supported the contention that leaded petrol may be the origin of lead in the higher lead concentration samples. Further lead isotope analysis and research into origins of lead in petrol is required. Zinc and copper origins are likely to be from wear of brake pads. However, analysis of tyres is also required as wear from these sources is suggested to be a likely source of zinc, lead and copper and tyre wear is likely to be greatest where vehicles are braking at sharp curves.

Figure 4.7. Influence of Degree of Curvature and Heavy Metal Concentration (Kuranda Range)



Concentrations of Kuranda Range Samples compared with Environmental Investigation Levels

Total heavy metal concentration analysis (using ICPAES method IC587) was performed on one background sample and 11 topsoil samples from the Kuranda Range. The concentrations of all heavy metals in the background sample did not exceed the environmental investigation levels (Table 4.6). Seven topsoil samples however, exhibited concentrations of copper and manganese which exceeded (and were up to more than three times) the environmental investigation levels, and three of these samples also contained concentrations of nickel which exceeded environmental investigation levels (Table 4.6). The mean topsoil concentration of copper and manganese also exceeded environmental investigation levels.

Table 4.6. Total heavy metal concentrations in samples taken from the Kuranda Range (using ICPAES method IC587)

Sample Identification	Concentrations of Heavy Metals (ppm)					
	Copper	Lead	Zinc	Cadmium	Manganese	Nickel
Environmental Investigation Level	60	300	200	3	500	60
Background sample 1	31	17	30	<5	172	17
Topsoil sample 1	37	106	50	<5	267	20
Topsoil sample 2	57	183	83	<5	398	9
Topsoil sample 3	10	19	15	<5	83	5
Topsoil sample 4	21	181	45	<5	81	10
Topsoil sample 5	123	32	170	<5	1760	49
Topsoil sample 6	126	10	114	<5	1660	53
Topsoil sample 7	93	21	124	<5	1380	44
Topsoil sample 8	98	16	130	<5	1600	57
Topsoil sample 9	108	14	130	<5	1650	63
Topsoil sample 10	59	15	82	<5	1320	70
Topsoil sample 11	109	20	108	<5	1650	68
Mean Topsoil Concentrations	76.45	56.09	95.55	<5	1077.18	40.72

Note: shading indicates samples and mean levels of samples equal to or above the Environmental Investigation Levels (ANZECC / NHMCR, 1992).

4.4 Discussion

Patterns of heavy metal distribution and penetration

It appeared from this study that zinc accumulated at sharp corners on the Kuranda Range, whilst lead accumulated on straight sections and at slight to moderate curves. It is likely that this may be related to the driving conditions of the road. For instance more petrol is used when accelerating and high concentrations of zinc may result from the use of brakes on some corners. Although the traffic volumes of the Kuranda and Gillies Range roads are less than roads previously studied elsewhere, contamination by heavy metals may result from transport activities due to the steep and curved nature of the roads and resultant driving conditions requiring changes in speed with braking and acceleration.

Levels of heavy metal concentrations

Identification of artificially inflated levels of heavy metals in soils and determination of an anthropogenic source is difficult. Specific vehicle-related sources for heavy metals include:

1) tyre wear (zinc, lead, chromium, copper and nickel) (Singh and Stinnes, 1994);
2) wear of studded tyres (iron, nickel, molybdenum, tungsten, chromium, cobalt, cadmium, titanium and copper);
3) corrosion of bushings, brake wires and radiators (copper, iron, nickel, chromium and cobalt);
4) wear of brake linings (nickel, chromium and lead);
5) wear of brake pads (copper, zinc and manganese):
6) leaded petrol (lead) (Viklander 1998).

Heavy metals also sometimes occur naturally in soils in high concentrations due to the breakdown of parent material. A higher number of samples and more detailed analyses are required to determine the source/s (the natural environment or the range of anthropogenic activities) of the heavy metal concentrations observed in this research. Lead isotope ratio analysis can allow sources of lead to be identified. Results from this study did not strongly indicate that petrol is the source of the lead found in the topsoil samples from the Kuranda Range although again, larger numbers of samples are required.

Comparison of concentrations of heavy metals in soil samples with background levels is the first and screening stage in determining if soils are contaminated. Heavy metal concentrations must be greater than background levels (Barzi *et al.* 1996). Analysis of heavy metal concentrations in topsoils indicated that mean copper, lead, zinc and nickel levels were above background levels on the Kuranda Range and that mean copper, lead and zinc levels were above background levels on the Gillies Range. The second criteria for the classification of soils as contaminated is that heavy metal concentrations are over the environmental investigation levels established by regulatory authorities. This second stage, the comparison of heavy metals with environmental investigation levels requires a total heavy metal concentration analysis. Although further sampling is required, the results of the total heavy metal concentration analysis of samples from Kuranda Range indicates that topsoils would be classified by regulatory authorities as contaminated with copper (and potentially nickel). Manganese in many cases is also higher than the environmental investigation level and in several cases higher than mean background level. This indication has considerable implications for both humans and the biophysical environment and monitoring and management of heavy metal concentrations is required. With the forecasted increases in traffic on both the Gillies and Kuranda Range transport corridors this monitoring and management is critical.

The transect data suggested that denser vegetation may restrict the penetration of heavy metal contamination. Although limited in scope, further research in this area is warranted. Restriction of heavy metal contamination to the narrowest zone possible is obviously of benefit to flora and fauna, particularly relatively immobile species.

The majority of the heavy metals were relatively immobile in the topsoil. However, the topsoil is also the part of the soil most used by flora and fauna and therefore contamination of this section of the soil profile is of great concern. Wildlife species may bioaccumulate heavy metal toxins with a pathway recognised from contaminated soil commencing with earthworms.

4.5 Conclusions

It was not possible to determine the effect of vegetation on heavy metal concentrations from the two transects established in this study.

- Lead, zinc and copper concentrations in topsoils decreased with increasing distance from the road.

Lead isotope analysis suggested that high lead concentrations in samples were not always related to lead from exhausts.

- Samples contained a mixture of natural lead and vehicle exhaust lead.

Generally the average heavy metal concentration in topsoils adjacent to both roads was below the environmental investigation limit proposed by ANZECC / NHMRC though some individual samples exceeded the limits.

- Copper levels were higher than environmental investigation limits in many topsoil samples.
- Some topsoil samples showed heavy metal concentrations considerably higher than background samples.
- Manganese was also higher than environmental investigation limits, although also high in background samples.
- Lead was enriched in topsoils on the Kuranda Range. Concentrations were found to accumulate around straight stretches where vehicles tended to accelerate. High zinc concentrations were found accumulated on corners requiring the use of brakes.

- Topsoil and subsoil sampling and analysis indicated that all heavy metal concentrations except iron decrease down the soil profile.

4.6 Recommendations

- More comprehensive sampling of soils at study sites, especially on the Gillies Range, to enhance data analysis.
- Further investigation of the effect of road design and driving conditions on the amount of heavy metals emitted from vehicles.
- Research the effect of wind on the deposition and distribution of heavy metals especially in contained areas.
- A more extensive study into the effects of vegetation on heavy metal distribution.
- A more extensive study of the distribution and penetration of heavy metals in soil samples and sediments adjacent to roads and relationship of this distribution and penetration to the bioavailability of heavy metal pollutants to flora and fauna (choosing indicator species).
- Consideration and development of pragmatic management and engineering techniques to restrict movement and distribution of metal pollutants.

4.7 Management Implications

- Heavy metal distribution in soils appeared to be related to road use for several heavy metals.
- Prevention of such contamination could best be achieved by avoidance of natural areas during construction of new roads.
- For extant roads, distribution of heavy metals into soils may be restricted by thick vegetation (however further research is required). It is therefore recommended that the maintenance or reestablishment of roadside vegetation be a requisite component of road upgrading and construction. This strategy is in accord with recommendations developed from research examining linear barrier impacts on small mammals and arboreal mammals (see sections 1, 6, 7 of this report).
- Consideration should be given to methods for restricting heavy metal contaminants on roadways from entering waterway sediments.
- Locations susceptible to heavy metal contamination are also associated with wildlife mortality, for these reasons consideration and management of plant species used to revegetate road corridors is essential. This strategy is in accord with recommendations developed from research examining road crossing behaviour of rainforest possums, gliders and tree kangaroos (see section 7 of this report).

4.8 Future Research

- A Doctor of Philosophy candidate in Earth Sciences, Mr Bradley Drabsch, supervised by Dr Bernd Lottermoser, will undertake more extensive studies on this subject during 2000 - 2003. The title of his thesis is proposed to be:

  "The dispersal, bioavailability and impact of automotive emissions and metal pollutants in the Wet Tropics of Queensland World Heritage Area".

  Proposed methodology includes:

  a) collection and analysis of topsoil and subsoil samples adjacent to roads in the Mossman and Daintree areas, the Kuranda, Gillies and Palmerston highways. Copper, lead, zinc, cadmium, manganese, nickel, iron and arsenic levels will be examined.
  b) assessment of microclimate, road base composition, topography at sample collection sites.
  c) collection and analysis of vehicle components including brake pads and tyres.

d) analysis of platinum and palladium concentrations in selected samples.
e) analysis of bioavailability of heavy metals in topsoils through EDTA extractions.
f) analysis of biological uptake of metals by earthworms.
g) stream sediments from waterways crossing major roadways will be analysed for heavy metals.
h) lead isotope analysis will be utilised to determine the origin of any elevated lead levels.
i) GIS and statistical analysis of distributions.
j) consideration of clear guidelines and practical engineering solutions to aid in restriction of mechanical metal transfer within the rainforest.

IMPACTS OF ROADS AND POWERLINES

Section 5: Vehicular Noise Disturbance in Rainforest

5. Vehicular Noise Disturbance in Rainforest

Sharon Marks and Steve Turton

Summary: *Vehicular noise and its effect upon humans is a road impact that has been well investigated in rural and urban settings. In fragmented natural regions such as the Wet Tropics of Queensland World Heritage Area (WTQWHA) the effect of vehicular noise on conservation values has not been previously researched. This project examined vehicular noise as an abiotic edge effect that penetrates into rainforest habitat.*

The main objective of this project (Marks 1999) was to accumulate baseline data on vehicular noise and its penetration characteristics into wet tropical rainforest.
The specific aims were:

1) *Quantification of the level and penetration distance of noise generated by a vehicle in a rainforest setting;*
2) *Determination of the effect of type of road surface and / or the presence of a grassy verge on the level and penetration distance of vehicular noise; and*
3) *Observation of actual traffic noise levels on two highways traversing the Wet Tropics and the effect of landscape and road design variables on these noise levels.*

Data from this research provides a general indication of possible levels of vehicular noise on roads in the WTQWHA and the distance this noise may penetrate into the rainforest. Information on the hearing range and noise disturbance behaviour of fauna in this region is lacking therefore the effect of this noise on conservation values is unknown.

Marks's (1999) research indicates that vehicular noise penetrates well over 100 m into the rainforest at levels that may contribute to the degradation of habitat for some species of fauna. As the relationship between noise and faunal behaviour is uncertain, the precautionary principle has been invoked to suggest that a minimum 200 m buffer zone could be modelled in the Wet Tropics Management Authority (WTMA) geographical information system (GIS) to delineate a possible disturbance zone. Fauna of interest occurring within this zone could be studied to determine the potential for vehicular noise impacts.

Note – Initially this project also aimed to assess the penetration of vehicular light into the rainforest. It was found that the available light measurement equipment was not sufficient to provide accurate appraisal of light from vehicles in this situation. The light data collected was therefore unsuitable for analysis and was omitted from the thesis.

5.1 Introduction

Development of roads and transport corridors through wilderness regions is an area of major public concern, especially with regard to conservation. The majority of road impacts are seen as potentially negative with one of the most serious threats being their contribution to the fragmentation and isolation of habitats. Other effects of roads include habitat transformation, linear barrier effects, altered and enhanced edge effects, wildlife mortality, predator and pest invasion, pollution and hydrological and soil erosion problems. One way that roads contribute to altered and enhanced edge effects is through noise. Machinery used for construction and maintenance of roads and the vehicles travelling on roads are sources of noise disturbance. In this case 'disturbance' is the emission of stimuli, which may cause animals to avoid the vicinity of the road (van der Zande *et al.* 1980). Research into vehicular noise disturbance has shown that there is a correlation between traffic levels and the reduction of population density of fauna, including birds and amphibians in areas abutting roads. Most investigations have been carried out in open field or deciduous habitats in countries such as the Netherlands, Denmark and Canada, which have a high density of heavily utilised roads. As with much of the research on the ecological effects of roads, vehicular noise disturbance studies have been site and species specific and have little applicability to wet tropical habitats such as the WTQWHA.

5.2 Materials and Methods

There were two components to this study. The first component involved quasi-experimental measurement of the level and penetration of vehicular noise into wet tropical rainforest. The second component involved the collection of observational data in relation to the effect of topography and road design on noise penetration characteristics. This was obtained by sampling actual traffic noise levels on two highways in the Wet Tropics of Queensland World Heritage Area.

Quasi-experimental quantification of vehicular noise level and penetration

Site description
The quasi-experimental measurement sites were situated along Danbulla State Forest Road, an unsealed road following the outskirts of Lake Tinaroo, and sealed roads within Lake Eacham National Park and the fragment of State Forest containing the Curtain Fig Tree. Sites were located in flat regions with basaltic soils and vegetation classified as Complex Mesophyll Vine forest or Complex Notophyll Vine forest (Webb 1959). Criteria for the selection of each site included similarity of vegetation structure, road and forest topography and safety.

Measurement procedure
A repeated measure sampling design was chosen in which sampling was repeated and nested for each factor of sealed and unsealed road, verge and no verge (Figure 5.1). At each site two parallel transects 100 m long and between 8 – 92 m apart were established perpendicular to the road (Figure 5.2). As a 4WD vehicle was driven past the transect a Rion sound meter was used to take measurements of the maximum sound pressure level (in decibels - L_{max} dB) at set distances of 0 m (road edge), 1 m, 2 m, 5 m, 10 m, 20 m, 50 m and 100 m. The maximum of natural background noise level (dB) was recorded at the 0 m and 100 m. Measurements of the maximum frequency (in kilohertz – kHz) of noise were also taken of the ambient noise and vehicular noise at 0 m and of vehicular noise at 100 m.

Figure 5.1. Experimental design for quantification of vehicular noise level.

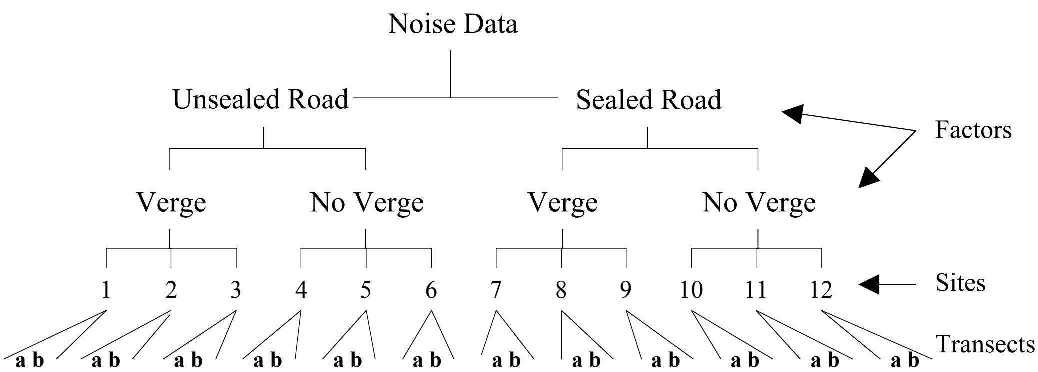
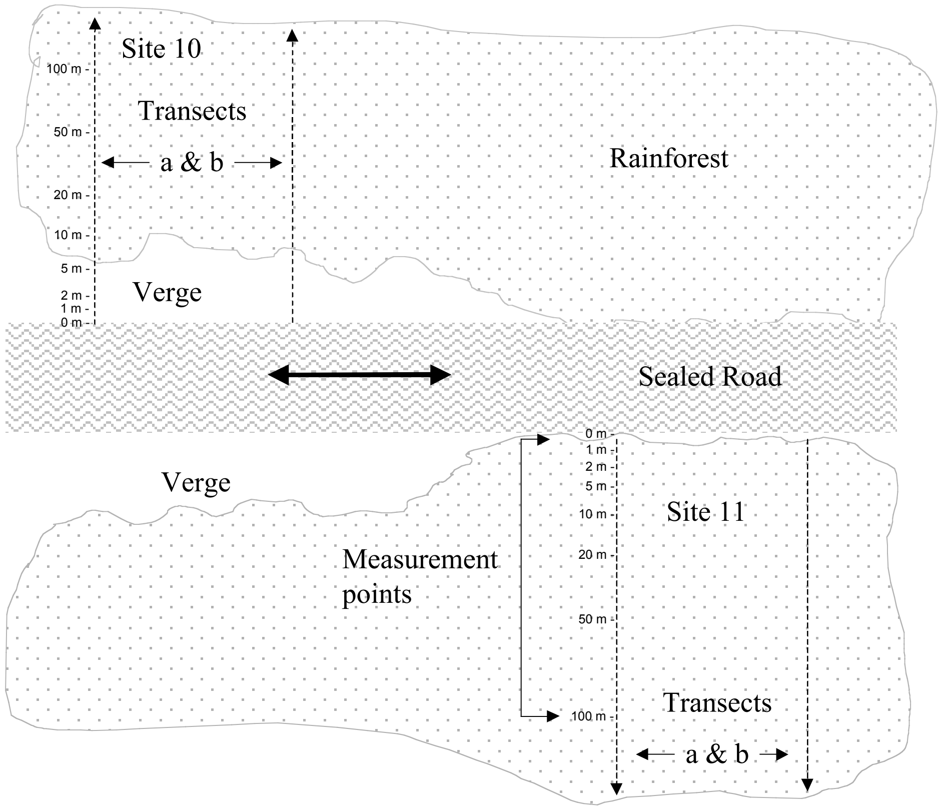


Figure 5.2. Diagrammatic example of site layout.



To investigate differences in the average noise measurements between factors the following hypotheses were constructed:

- $H1_0$: That there is no significant difference in the mean values of noise level (L_{max} dB) at each measurement point between sealed and unsealed roads. (1)
- $H1_A$: That there is a significant difference in the mean values of noise level (L_{max} dB) at each measurement point between sealed and unsealed roads.
- $H2_0$: That there is no significant difference in the mean values of noise level (L_{max} dB) at each measurement point between roads with verges and those without. (2)
- $H2_A$: That there is a significant difference in the mean values of noise level (L_{max} dB) at each measurement point between roads with verges and those without.

Statistical analyses
Repeated Measures Analysis of Variance was used to investigate interactions between the main factors of sealed and unsealed road, with and without a verge and the effect of distance within each factor.

Paired sample tests were used to assess the difference between noise levels measured at 0 m and 100 m for ambient noise (dB), and between ambient noise and vehicular noise (dB), levels and the frequencies (kHz).

Observation of actual traffic noise level

Site description
Actual traffic noise levels were observed at five sites along the Palmerston Highway and three sites on the Kuranda Range Road. Selection of the sites was based on safety for field researchers and the arrangement of variables such as slope, sinuosity of the road, vegetation type, and proximity to stream crossings, gullies and cuttings. The characteristics of each site are summarised in Table 5.1.

Measurement procedure
The same Rion sound meter, used for the quasi-experimental measurements, was used to take sound pressure measurements with the receiver height at approximately one metre. Most measurements were of cars (sedans, 4WDs, small vans) and trucks (diesel semi-trailers and large pantecs) with ambient noise measures only being taken at some positions. Target vehicles for measurement were identified either by sight or with the aid of walkie-talkies. The maximum decibel (L_{max} dB) reading was noted as vehicles passed the position on the edge of the road and then at various distances along landscape variables as summarised in Table 5.1. To assess the cumulative effects of the sound from traffic, multiple-event sound equivalent level (L_{eq}) measurements were taken for a period of 10 minutes. With these measurements the sound pressure level of the passing traffic was summed over the fixed time then averaged by the total duration in seconds. This provided a noise level (dB) that would have had to be present during the 10 minutes at a continuous, steady intensity in order to be equivalent to the total amount of sound energy actually present. Noise(s) that were of either a steady or irregular level of intensity can then be comparable (Kryter 1994). The instrument also provided the maximum decibel level (L_{max}) and frequency (kHz) during the 10 minute period. Most of these measurements were taken 2 m from the edge of the road, with others at 10, 25, 50, and 100m. As many vehicles as possible, travelling either up or down hill, within the time available were assessed at each site to a maximum of 9 vehicles per position.

Table 5.1. Summary of observational sites.

Site	Slope	Road Description	Additional measurements
Kuranda Range Road	Heavily travelled (~6000 vehicles/day, pers. comm. Main Roads) road with almost constant traffic. Traffic speed range ~ 50-80 km/hr.		
1 WT Sign	4°	Sinuous, fast	Down steep slope and up a shallow gully
2 S Sign	6°	Sinuous, slow	Up steep overgrown gully and both sides of the road
3 Powerlines	3°	Straight, fast	Road edge only
Palmerston Highway	Intermittent traffic (~980 vehicles/day, pers. comm. Main Roads) with regular use by cane trucks during cutting season. Traffic speed range ~ 70-100 km/hr.		
1 Safety grid	4°	Straight, fast	Up steep gully and adjoining steep cutting
2 Drive entry	1°	Straight, fast	Both sides of road
3 Sign	1°	Straight, fast	100 m into level rainforest
4 Pull out	4°	Straight, fast	Down steep gully
5 Goolagan	1°	Bridge, fast	At culvert and 100 m up creek

Analyses
It is difficult to control all variables in this situation and thus it was not possible to test any actual hypotheses relating to the observational data. This is descriptive information only to provide baseline data on actual levels of traffic noise experienced close to highways and to provide some indication of

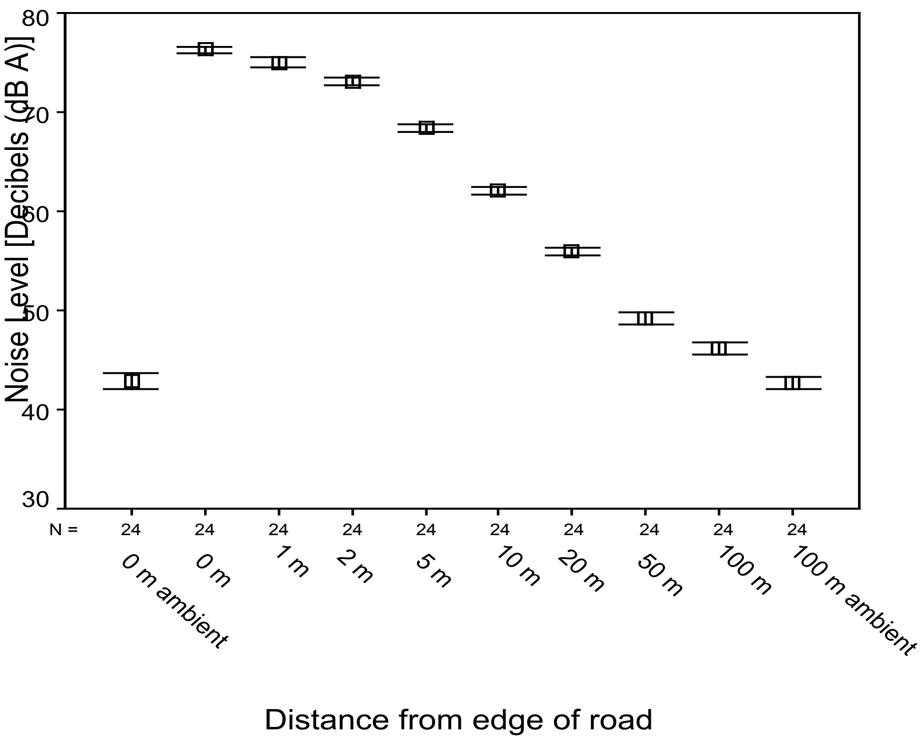
the possible effect of different variables on noise characteristics. Means and standard errors of vehicular measurements were calculated for the observational data. Statistical comparison between sites was not possible due to the highly variable nature of the observations.

5.4 Results

The level and penetration of vehicular noise

Figure 5.3 presents the means ± 1 standard error (S.E.) for all vehicular noise measurements and the ambient (background) noise measurements at 0 m and 100 m. The reliability of the means is established by the very small standard errors. Average maximum vehicular noise level generated by the 4WD used in the quasi-experimental component was 76.23 dB at the road edge (0 m) and significantly decreased with increasing distance from the road to 46.14 dB at 100 m inside the rainforest. At 100 m this level approached the background ambient noise level but the difference is still significant when compared to the ambient noise level at 100 m ($t = 4.862$, $df = 23$, $P<0.001$).

Figure 5.3. Relationship between mean vehicular noise (±1 S.E.) and distance from the road edge into adjacent rainforest. Mean values for background (ambient) noise levels at 0 m and 100 m are also shown (all values are in decibels).



The contrast of ambient noise and vehicular noise means is presented in Figure 5.4. Ambient noise levels at the edge of the road (0 m) and 100 m within the interior of the rainforest were not significantly different ($t = 0.167$, $df = 23$, $P>0.05$). Ambient noise level at 0 m and the vehicular noise level was significantly different at 0 m ($t = 35.636$, $df = 23$, $P<0.001$) and 100 m ($t = 2.572$, $df = 23$, $P<0.05$).

Figure 5.4. Comparison of mean ambient and vehicular noise pressure levels (L_{max} dB) at edge of road (0 m) and in the forest interior (100 m).

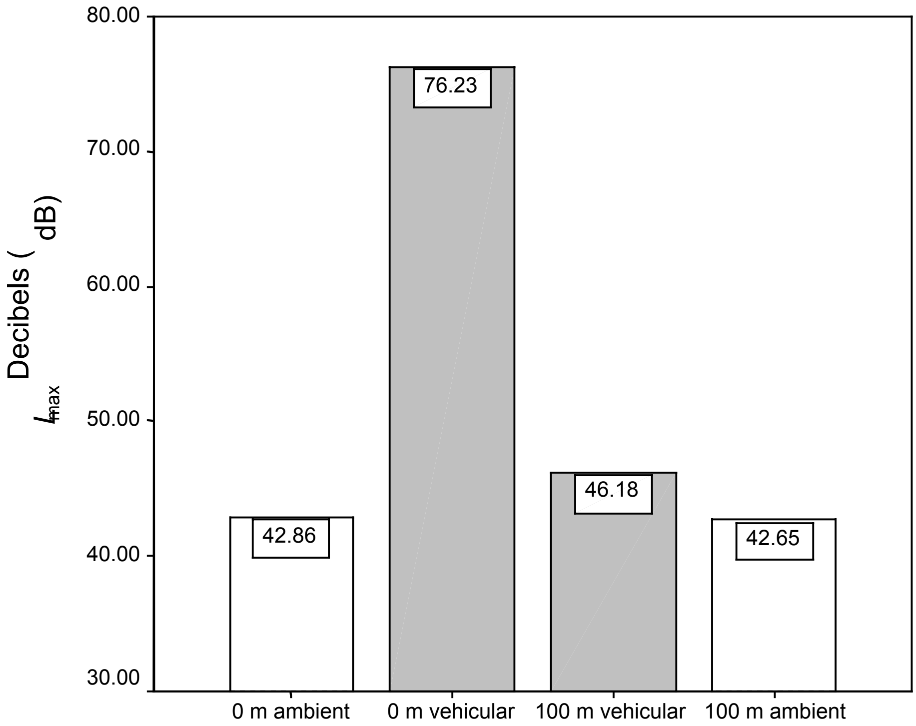
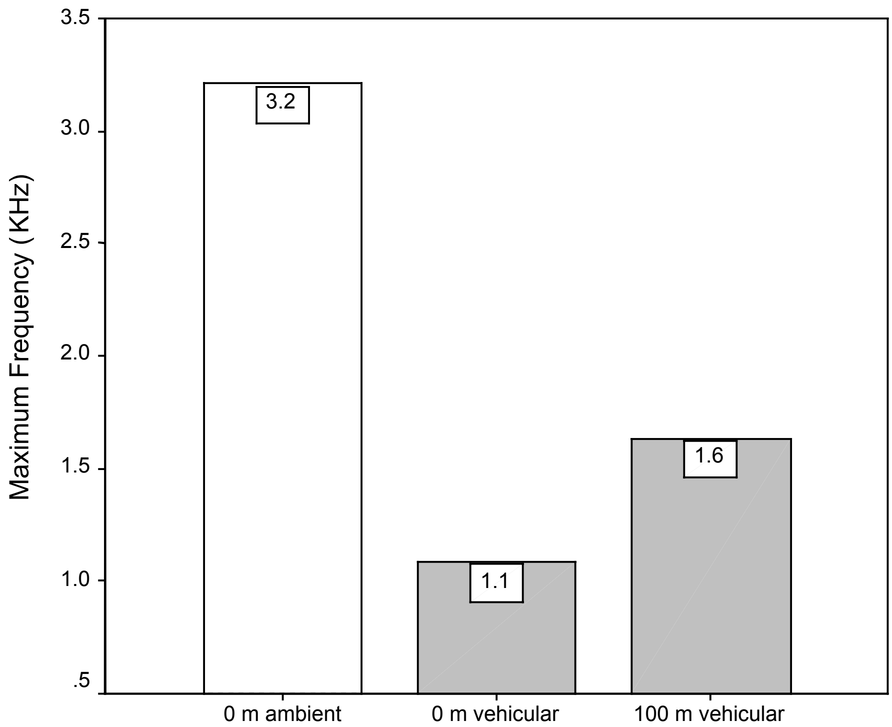


Figure 5.5. Mean of frequency in kilohertz for the ambient noise at 0 m and vehicular noise frequency at 0 m and 100 m into the rainforest.



As shown in Figure 5.5, the peak frequency level of background ambient noise was dissimilar to the peak frequency of noise generated by the test vehicle. The difference between the mean frequency level of ambient noise at 0 m and the frequency level of vehicular noise was significant at 0 m ($t = 6.092$, $df = 11$, $P<0.001$) and 100 m ($t = 3.582$, $df = 11$, $P<0.005$).

In Table 5.2 the results of the repeated measures of analysis of variance (ANOVA) examining the effects of noise level over distance are shown. Distance was found to be the most significant factor ($df = 7$, $F = 725.856$, $P<0.001$) affecting the level and penetration of vehicular noise while road surface and verge type had no significant effect ($P>0.05$) on the relationship of noise over distance.

Table 5.2. Results of General Linear Model repeated measures ANOVA [a] of the interactions of distance with road surface type and road verge type [b].

Source	Degrees of freedom (df)	Mean Square	F value	Significance (P)
DISTANCE	7	1667.187	725.856	.000
DISTANCE * ROAD SURFACE	7	2.052	.894	.518
DISTANCE * VERGE TYPE	7	1.834	.798	.592
DISTANCE * ROAD SURFACE * VERGE TYPE	7	.937	.408	.893
Error (DISTANCE)	56	2.297	-	-

a. Within-distance effects b. Computed using alpha = .05

The effect of road surface and verge on vehicular noise patterns in rainforest

Table 5.2 shows that the road and verge treatments do not have a significant effect ($P>0.05$) on the noise levels over distance. Table 5.3 presents the results of the ANOVA between-subjects test, which examines relationships between the treatments. There were no significant effect ($P>0.05$) of road surface type (sealed or unsealed), nor verge type (grassy or no verge) nor interactions between the road surface and verge treatments.

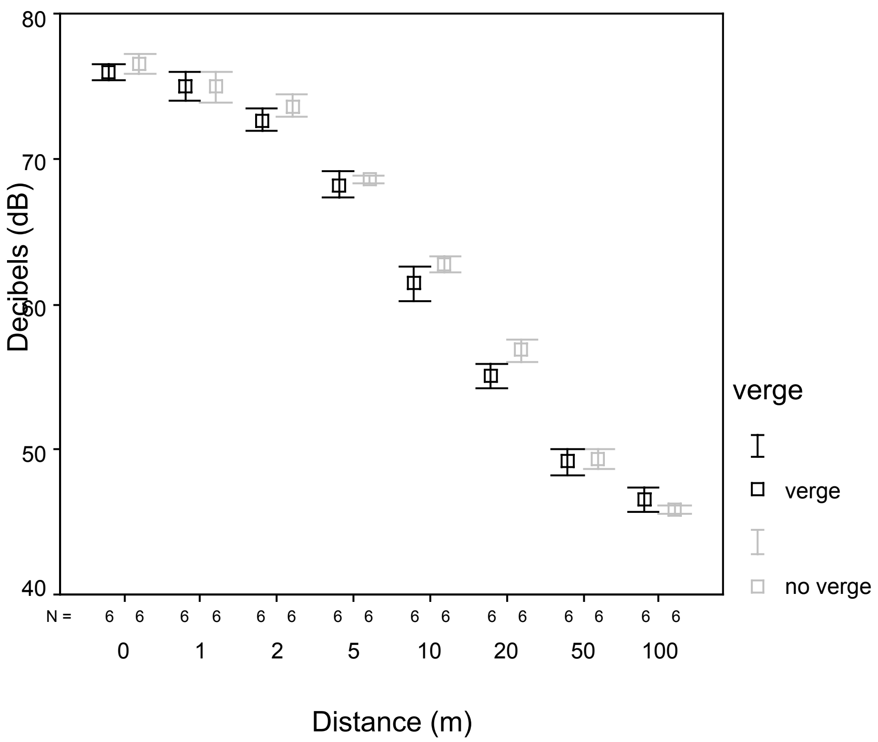
Table 5.3 Results of General Linear Model repeated measures ANOVA [a] of road surface type (sealed or unsealed), road verge type (grassy or no verge), and the interaction between road surface and verge [b].

Source	Degrees of freedom (d.f.)	Mean Square	F value	Significance (P)
ROAD SURFACE	1	.161	.086	.776
VERGE TYPE	1	.880	.474	.511
ROAD SURFACE * VERGE TYPE	1	2.926	1.575	.245
Error	8	1.857	-	-

a. Between-subjects effects b. Computed using alpha = .05

Figures 5.6 and 5.7 show relationships between mean vehicular noise levels and distance into rainforest for each verge type (grassy verge and no verge), and each road surface type (sealed and unsealed). It can be seen that the error bars for each treatment overlap indicating that differences between treatments were insignificant (refer to Tables 5.2 and 5.3).

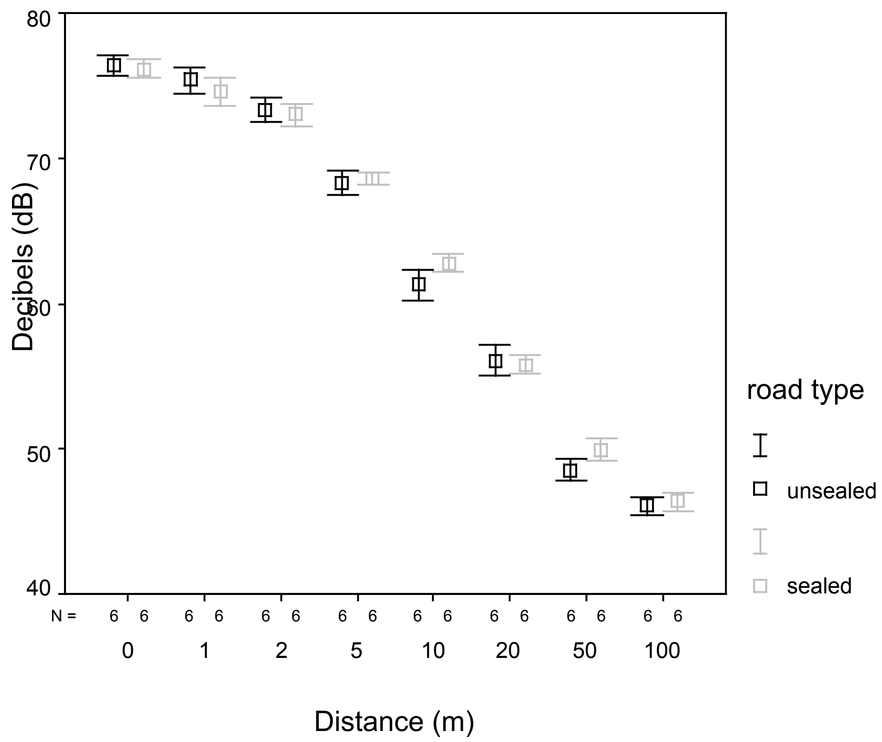
Figure 5.6. Mean ± 1 standard error of vehicular noise level measurements (dB) taken on roads with a grassy verge and those without a verge.



Observation of actual traffic noise levels
Observation of actual traffic levels on the Kuranda Range Road and the Palmerston Highway produced baseline data on the possible effects of different road design and adjacent landscape characteristics. Measurements were not standardised between sites due to the variability of road slope, traffic speed, vehicle type, vegetation structure and the side of the road safest for field operatives. For this reason the results of traffic observation at each site are tabled individually and the thesis (Marks 1999) should be referred to for more information.

Cautious generalisations from the observational data include:
- Trucks generated more noise than cars
- Fast traffic generally generated more noise than slow traffic
- Penetration of traffic noise was less on the downward side of a steep slope
- Vehicular noise may penetrate further along the clearing created by a creek than directly into unbroken rainforest.

Figure 5.7 Mean ± 1 standard error of vehicular noise level measurements (dB) taken on sealed roads and unsealed roads.



5.5 Discussion

This study has shown that the maximum average sound level from one single 4WD vehicle in a rainforest setting was found at the edge of the road, and was almost 35 decibels louder than the background ambient noise. This sound pressure level decreased over the 100 m transects to an average that was still significantly higher than the 100 m ambient reading. It needs to be remembered that sound pressure level is measured on a logarithmic scale. An increase of 1 dB is just perceptible and an increase of 10 dB is experienced by the average human listener as a doubling of loudness. Table 5.4 gives an indication of the decibel level of some typical sounds, juxtaposed with readings obtained in this study.

When comparing this study with others, it appears that within tropical rainforest habitat the potential disturbance distance would be less than that found in open or woodland habitat (Madsen 1985; Reijnen *et al.* 1995; van der Zande *et al.* 1980). This may be due to attenuation of the noise by the dense rainforest vegetation. Examination of the population abundances of fauna that may be affected by traffic noise was beyond the scope of this study. Traffic levels in the WTQWHA, especially in sensitive areas, are very low compared to other studies. It may, therefore, be more practical to define the penetration extent of the possible disturbance zone.

From examination of the results of sound penetration into rainforest over a distance of 100 m, it is proposed that the measurable sound from one vehicle would merge with the background noise within 150 – 200 m. Vehicular noise, especially in some frequencies, may be detectable over greater distances than this, particularly by fauna sensitive to noise frequency. The human ear is more responsive to some frequencies in the sound spectrum than other frequencies. With the complex array of auditory arrangements in faunal groups it could be expected that response to noise and various frequencies within that noise would vary greatly from one species to another.

Table 5.4. Noise level of sounds (Source: Watkins 1981). Measurements from this study are shown in bold.

Noise source or environment	*Sound level, dB (A)*
Room in quiet dwelling at night	32
Ambient noise in rainforest	**33-43**
Soft whisper at 2 m	34
Clothing department in a large store	53
Ambient noise next to rainforest creek	**55**
Busy restaurant or canteen	65
Truck at 25 m from highway	**60-71**
Vacuum cleaner at 3 m	69
Inside small car at 30 mph	70
Inside electric train	76
4WD passing on rainforest dirt road	**76**
Ringing alarm clock at 1 m	80
Loud music in large room	82
Truck at 2 m on rainforest highway	**82-92**
Printing press, medium size	86
Heavy diesel vehicle at 8 m	90

As fauna reside in all levels of the rainforest investigations of noise characteristics (both sound pressure level and frequency) at different levels of the rainforest may produce more information than was possible in this small study. Future investigations should include quantification of the reverberation and attenuation characteristics of the major vegetation / habitat classes of the WTQWHA.

Mitigation of traffic noise in urban settings has been extensively researched. Some methods of traffic noise reduction that may be applicable to natural settings include quiet vehicle development; the building of roads either below or above the landscape element, covered roads, and acoustic barriers. Hard engineering solutions are neither compatible with the aims of WTMA nor appropriate to traffic levels in the region, which except for a few major highways are generally low. Road development must take into account a range of possible negative impacts. The broadening of a road to carry more and faster traffic with a wider verge for safety may produce a range of inter-related effects including: reduced canopy connection, enhanced linear barrier effects, microclimatic changes, increased wildlife mortality, erosion, weed and pest intrusion, as well as edge effects such as vehicular noise.

5.6 Conclusions

The noise from one 4WD vehicle in a rainforest setting was significantly higher than the background ambient noise for all positions along replicated 100 m transects.

- The average of natural rainforest noise was 42.8 dB and the average maximum of vehicular noise at 0 m was 76.2 dB and at 100 m it was 46.2 dB.
- At 0 m (the road edge) the vehicular noise was six times louder than the ambient noise. At 100 m into the forest the vehicular noise approached but was still significantly above ambient.
- Vehicle noise may merge with the background noise between 150 - 200 m from the road edge.
- The maximum peak frequency of vehicular noise was significantly different at 0 m and 100 m.

Neither the type of road surface, sealed or unsealed, nor the presence of a grassy verge had a statistically significant effect on the level and penetration of noise.

- Distance was the only factor that affected the level and penetration of vehicular noises within rainforest habitats.

- Habitat characteristics affect the reverberation and attenuation of the vehicle noise pressure over distance.

Observational data suggested that different traffic, landscape and road design variables affected the level and penetration of vehicular noise into adjacent forest.

- Trucks generated more noise than cars
- Fast traffic generally generated more noise than slow traffic
- Penetration of traffic noise was less on the downward side of a steep slope
- Vehicular noise may penetrate further along a creek than into closed rainforest.
- The type of vehicles, travelling speed of the traffic, how intermittent or constant the traffic flow is and the total number of vehicles affects the average daily noise load.

This study involved pilot research on which further study can be based. The effect of vehicular noise disturbance on fauna in the WTQWHA was not examined. It is hoped that the preliminary findings of this first quantification of vehicular noise in a rainforest setting will assist in the identification of negative impacts from roads, and enable WTMA and other management authorities to make sustainable decisions about the use and location of roads in the WTQWHA.

5.7 Recommendations

- Development of a vehicular noise disturbance zone of 200 m in the WTMA GIS to be modelled in conjunction with traffic, road, topography and habitat data.
- Identification of fauna within this zone that may be susceptible to noise disturbance and commencement of fauna studies to determine if there are identifiable negative impacts.
- Implementation of a more comprehensive study of actual traffic noise levels and the effect of landscape and road design variables on noise level and penetration.
- Quantification of the reverberation and attenuation characteristics of vegetation / habitat classes within the WTQWHA.
- Where negative impacts are identified relevant authorities should implement traffic management and road design changes, such as the elevation of the road above the area of concern, where applicable.

IMPACTS OF ROADS AND POWERLINES

Section 6: Evaluation of Overpasses as Crossing Routes for Arboreal Species

6. Evaluation of Overpasses as Crossing Routes for Arboreal Species

Nigel Weston and Miriam Goosem

Summary: *Rainforest ringtail possums have utilised a canopy overpass erected by QPWS personnel (Rupert Russell) for the Wet Tropics Management Authority. The Lamb Range structure (on the B or Kauri Creek Road) has been used by lemuroid ringtail possums (Hemibelideus lemuroides), Herbert River ringtail possums (Pseudochirulus herbertensis) and green ringtail possums (Pseudochirops archeri). Photographic evidence has been obtained for use by the lemuroid and green ringtails. Scat analysis has demonstrated use of the canopy overpass or an underhang slung below the overpass by lemuroid ringtails, Herbert River ringtails and the scansorial rodent, Melomys cervinipes. No evidence has yet been obtained for tree-kangaroos using the overpass or of predation of canopy overpass users. The canopy overpass appears to cause little disturbance effect to wildlife crossing the road surface.*

6.1 Introduction

On a landscape scale, road reserves have an important role to play in conservation biology. In agricultural areas they encompass a large amount of land, some of which provides excellent representations of vegetation and ecosystems that have since been locally cleared or degraded (Napier 1997). Farmar-Bowers (1997) observed that road reserves may represent Australia's richest biodiversity reserve. However, in the Wet Tropics World Heritage Area, roads subdivide areas of core habitat although road reserves still contain substantial areas of uncleared vegetation.

Impacts on the environment are unavoidable in the construction, use and maintenance of road reserves (Bates 1997), not least because they expose animals to the hazards of traffic. In the United States it has been estimated that vehicular traffic may kill a million vertebrates a day (Lalo 1997). Certainly, in the case of rare or threatened species, road mortality is considered a threatening process (Goosem 1997). This was reiterated by the Queensland Department of Main Roads (1998):

> Of critical significance in the wet tropics region is the effect roads have on endangered species, for example the Cassowary. Roadkills are one of the key threatening processes resulting in declining populations in their remaining habitat.

Roads (and powerline clearings) have a variety of effects on native fauna in addition to increased mortality due to traffic. These include:

- disturbance, especially the closed rainforest canopy and road shoulders (Forde and Frankcombe 1999), and
- habitat fragmentation, as they act as linear barriers to the passage of wildlife (e.g. Mader 1984, Bennett 1991, Burnett 1992, Goosem 1997, Goosem and Marsh 1997, Forde and Frankcombe 1999).

Many studies have examined the effects of linear clearings on vertebrate populations. Most demonstrated a barrier effect in which animals are inhibited from crossing linear clearings (Mader 1984, Bennett 1991, Burnett 1992, Goosem 1997, Goosem and Marsh 1997). Even roads with minimal traffic and narrow clearing widths can strongly inhibit fauna crossings (Mader 1984).

When a barrier completely inhibits faunal movements, subdivided populations may become increasingly prone to local extinction and the loss of genetic variability. Goosem (1997) found that linear clearings had already alienated 0.2% of the total habitat of the Wet Tropics World Heritage Area (a total of 1 316 ha in 324 km of powerline clearings and 608 ha in 1 427 km of roads and highways). This finding is particularly significant given the special conservation values of the region.

One method of determining whether roads cause a linear barrier effect is to assess the incidence of wildlife mortality due to vehicle-wildlife collisions (Goosem 1997). If an animal has attempted to cross the road, it can be concluded that the road is not perceived as a complete barrier. Species not found as road kills may be using alternative crossing routes; may be fast or intelligent traffic avoiders; or may simply avoid roads altogether. It is the last group that could be cause for conservation concern.

In a recent study, more than 4000 vertebrates of over 100 species were recorded as roadkills on a 2 km stretch of the Kennedy Highway in the wet tropics region, (Goosem 2000b). A number of species known to occur in the study area were underrepresented in or absent from these statistics. Many of these were of special conservation or evolutionary interest, such as arboreal marsupials. It was postulated that these species were using the few remaining canopy connections as crossing points or avoiding the road altogether (ibid.). Canopy connections are probably crucial for arboreal mammals such as the Lemuroid ringtail possum (*Hemibelideus lemuroides*), a species that almost never ventures to the ground (Laurance 1990) and is the least able of the rainforest leaf-eating possums to survive in remnant patches (Winter & Goudberg 1995).

It has been suggested that sufficient knowledge now exists to allow manipulation of fauna habitat to proceed in the form of experiments in adaptive management (Cork and Catling 1997). Richard Levins, an ecologist at the Harvard School of Public Health, created the first mathematical model of what he called a 'metapopulation': a set of linked local populations of a species, each in its own separate patch of habitat (Mann and Plummer 1995). In Levins' formulation, the population of any given patch rises and falls over time; there is always a small chance that the population on any given patch can vanish. But the empty habitats can be repopulated if the metapopulation has sufficient connectivity.

Metapopulation theory has become the basis for conservation corridors and other management techniques that increase movement among populations (Hess 1996). Goosem & Marsh (1997) advocated the establishment of new canopy connections across clearings to enable this dispersal. While artificial constructions have been successful elsewhere in allowing wildlife to cross linear barriers by providing links with areas of suitable habitat, these have generally been designed for terrestrial fauna (Leighton 1988, Mansergh and Scotts 1989, Harvard Graduate School of Design 1998). The effectiveness of artificial canopy linkages at mitigating the effects of linear clearings on movements by arboreal wildlife is entirely unknown.

The Wet Tropics are the principal or only habitat for numerous species of threatened wildlife, many of which have small, fragmented distributions. There are at least 54 species of vertebrate animals that are regarded as very rare, found only in small areas or in danger of extinction (Ritchie 1995). These include the rainforest ringtail possums. One of these, the Lemuroid ringtail possum (*Hemibelideus lemuroides*) appears especially sensitive to habitat disturbance (Winter and Goudberg 1995, Laurance 1997).

Population growth in the Wet Tropics bioregion and the growth of tourism within the Wet Tropics WHA which attracts over five million tourist visits each year (Hitchcock *in* Ritchie 1995), places pressure on infrastructure and particularly roads in the region. For example, integrated land use and transport studies were recently commissioned by the Queensland Department of Main Roads (DMR) for Southern Cairns and the Kuranda Range to facilitate this growth. Bates (1997) found that:

> …Road authorities (state and local government) and service providers such as energy, water supply and sewerage authorities, as the statutory bodies in whom management and

> control of roads and infrastructure laid in road reserves is vested, undoubtedly have a legal responsibility as well as powers in respect of the environmental effects of their activities. They must comply not only with the statutory directions contained in a wide range of environmental legislation but also be aware of the legal right of land and riparian owners to enforce common law claims for damages for interference with property rights occasioned by environmental degradation.

As the authority responsible for major road infrastructure, the DMR developed a *Planning, Design, Construction, Maintenance and Operation Best Practice Manual* for roads in the Wet Tropics. The manual aimed at integrating environmental, transportation, engineering, social and economic considerations for protecting the natural and cultural values into the planning of road corridors within the Wet Tropics region (DMR 1998).

It is generally conceded that wildlife values of road corridors generally decline as a direct and indirect result of road construction and operation. Notwithstanding, CRC-TREM (1997b) hypothesised that road impacts could be mitigated by the implementation of innovative road design strategies. The *Planning, Design, Construction, Maintenance and Operation Best Practice Manual* subsequently recommended that these elements be evaluated for their possible incorporation (DMR 1998):

> …In order to enhance the connectivity of wildlife corridors and promote the safe crossing of road corridors investigate potential use of canopy bridges, where suitable/appropriate.
>
> Undertake trials of new technology (eg. …canopy bridges) to determine if these were effective in reducing road kills and habitat fragmentation…

In 1994 the Wet Tropics Management Authority funded the construction by Department of Environment personnel (Rupert Russell) of an arboreal crossing route across the “B” Road (Kauri Creek Road) in the Lamb Range road network. There has been little monitoring of the efficacy of the construction in its objective of providing a crossing route for arboreal species such as the Lemuroid ringtail possum and Herbert River ringtail possum, species which seldom come to the ground (Goosem and Turton 1999).

Aims
This research aims to assess the potential use of artificial canopy linkages to enhance habitat connectivity and promote the safe crossing of road corridors by arboreal fauna. Use of the arboreal crossing route in the Lamb Range by arboreal species of the Wet Tropics that have special conservation significance, in particular the rainforest ringtail possums will be monitored. Implications for road user safety, maintenance and presentation will also be discussed. Consequently, it is hoped that strategies will be developed to maximise the effectiveness of new technology in road corridors with respect to conservation.

6.2 Methods

Site description
It is intended that a total of 24 visits will be made to the study site, located at approximately 800 metres elevation in the Danbulla State Forest, on the B Road (Kauri Creek Road) in the Lamb Range. Often rendered unnavigable in the wet, the track has been traversed by foot in the event of closure. The existing canopy bridge (Figure 6.1) is located in notophyll vine forest (Type 8 *sensu* Tracey 1982).

Figure 6.1. Study site. The existing canopy bridge was erected by Department of Environment personnel (Rupert Russell) on the B road (Kauri Creek Road) in the Lamb Range road network using funding provided by the Wet Tropics Management Authority.

Underhangs (Figure 6.2) designed to intercept scats deposited by arboreal fauna utilising the canopy crossing route have been erected for several days each month. The contents of the underhang have been collected each month. The underhang has been erected at several heights from the road surface, both close to the ground and close to the canopy overpass. Scats have been analysed by Barbara Triggs, an authority on the identification of mammalian traces. Scats have also been collected from the road surface and its verge for comparative purposes.

In addition to scat collection, monitoring has involved the use of an infra-red triggered camera (Buckshot 35A) which is installed inside the entrance to the canopy overpass. The 35 mm autofocus camera is enclosed in a waterproof, airtight housing with an infrared detector that senses heat and motion (Figure 6.3). A 30 ft extension ladder donated by Environment North is used to reach the canopy overpass during installation and retrieval of the camera. The camera has been installed for periods of a weekend or a month. Film has then been retrieved and photographs developed.

Monitoring of the use of natural canopy connections has also been undertaken by spotlighting. Prior to installation of the camera, spotlighting was also used to monitor overpass use. In addition, incidental observations of potential predators in the vicinity has occurred.

Figure 6.2. Installation of an underhang immediately below the canopy overpass on the Kauri Creek Road to allow collection of scats from arboreal species using the canopy overpass.

Figure 6.3 a. The infrared-triggered autofocus camera (buckshot 35a) which is installed inside the entrance of the canopy overpass. The camera has a waterproof housing and is triggered by heat and motion.

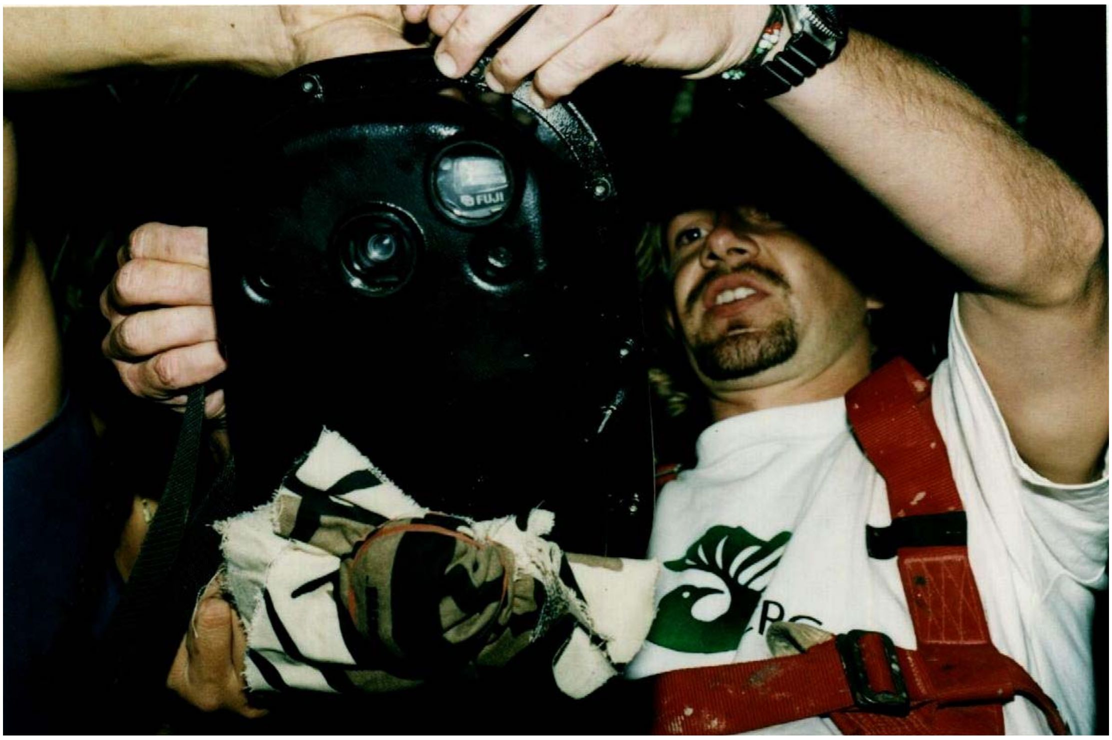


Figure 6.3 b. The infrared-triggered autofocus camera (buckshot 35a) which is installed inside the entrance of the canopy overpass. The camera has a waterproof housing and is triggered by heat and motion.

6.3 Preliminary Results

Infrared Photographic Monitoring

The study is beginning to show that arboreal and scansorial animals such as rainforest ringtail possums and rodents of various species will use simple aerial connections or ‘canopy bridges’ as a crossing route above the road surface.

The infrared-triggered camera has captured images of a rainforest ringtail possum (almost certainly the lemuroid ringtail possum, *Hemibelideus lemuroides,* Figure 6.4) on the existing structure. Several images of a green ringtail possum, *Pseudochirops archeri*, using the canopy overpass have also been captured (Figure 6.5). Species identifications have been confirmed by M. Trenerry (EPA wildlife expert) R. Wilson (Rainforest CRC arboreal expert) and G. Werren (ACTFR wildlife expert).

Figure 6.4. Photograph of a green ringtail possum, *Pseudochirops archeri*, taken inside the canopy overpass by the infrared-triggered camera.

Figure 6.5. Photograph of a green ringtail possum, *Pseudochirops archeri*, taken inside the canopy overpass by the infrared-triggered camera.

Scat Analysis
The net installed beneath the bridge has collected scats from the following species:

- *H. lemuroides,*
- *Pseudochirulus herbertensis,* and
- *Melomys cervinipes.*

M. cervinipes is a rodent that utilises the ground layer and understorey as well as climbing further up into the overstorey. Scats of this species were only collected when the underhang was installed relatively close to the road surface (~1.8 m) which may indicate that these animals used the underhang, rather than the canopy bridge, as a crossing route.

Scats from the following species have been collected from the road surface in the vicinity of the bridge:

- *H. lemuroides,*
- *P. herbertensis,*
- *Pseudochirops archeri,*
- *Dendrolagus* sp. and
- *Hypsiprymnodon moschatus.*

This would appear to indicate that arboreal, scansorial and terrestrial species movement is not greatly inhibited by the installation of the artificial structure.

Spotlighting and Incidental Observations
Observations have been made of *P. archeri* using natural canopy connections to cross a 10 m wide road. Rupert Russell (QPWS) has previously observed *P. herbertensis* utilising the canopy overpass to cross the road (R. Russell, pers. comm.)

A road-killed *Uromys caudimaculatus* was found on a road with very low traffic volumes (1-2 vehicles/hr at most).

A neat pile of 7 *Dendrolagus* sp. (tree-kangaroo) pellets were located centrally on a 6 metre-wide road indicating that the animal paused in the middle of the road as it moved across the ground.

No evidence of predation of animals using the bridge has been observed to date, with hair samples analysed from scats passed by a single large amethystine python *Morelia amethistina*, found near the bridge belonging to a red-necked pademelon, *Thylogale stigmatica*.

6.4 Discussion

Results to date indicate that all three rare rainforest ringtail possums of the Lamb Range area of Wet Tropics are able to utilise the existing canopy bridge constructed by Rupert Russell for WTMA. Photographs of a lemuroid ringtail and a green ringtail show the animals moving within the structure. Rupert Russell had previously recorded a Herbert River ringtail using the structure when spotlighting. Additionally, scat analysis from the underhang show that either the overpass or the underhang is being used by lemuroid and Herbert River ringtails. Scansorial rodents also appear capable of using one of these structures for movements. At present it is impossible to be certain that the possums are crossing the road via the overpass, although the weight of evidence suggests that this may be the case. It is hoped to install a second camera at the other entrance to the canopy overpass to allow further monitoring of crossings.

One consideration that is presently being evaluated is the possibility of the flash from the camera disturbing the animals. The green ringtail possum shown in Figure 6.4 showed no evidence for this – a series of photographs of the animal was taken, whilst it moved around in the vicinity of the camera. However, an attempt is presently being made to obtain film which will record photographs without the aid of the flash, or to use a less bright flash. Digital cameras with an infrared option are presently being purchased for another project (East Evelyn underpass monitoring project, partially sponsored by Department of Main Roads). It is hoped to trial one of these cameras within the overpass.

The existing overpass was designed to prevent predatory flying species such as owls from using the overpass as an easy prey source. It therefore was designed so that the mesh would protect the animals inside, with the hope that vines would eventually cover the outside of the structure, creating a more natural crossing route. Evidence that the possums are moving inside the structure is encouraging. However, this would not form a protection against arboreal predators such as pythons. To date, no evidence of predators using the overpass as a funnel for prey has been found, with no predator situated at the entrances and the one python found close by not having consumed arboreal species.

Wilson (2000) attempted to create linkages across narrow roads with canopy gaps using vines, but was not able to establish that the vine linkages successfully enhance movements of the rainforest ringtail possums. Natural vine linkages were observed in use twice, once by a Herbert River ringtail and once by a lemuroid ringtail with a pouch young in 25 hours of spotlighting observations. In contrast, vines erected across the gap were not used in 25.5 hours of spotlighting observations. Wilson (2000) suggested that if these linkages were not being used, competition with conspecifics, lack of cover or the presence of canopy linkages already known to the possums may have restricted their use. The canopy overpass monitored in this study is a larger construction which provides a degree of cover for the animals that have been observed using it. Interestingly, Herbert River ringtails were able to use barbed wire fences in a grassy powerline clearing as a movement route (Wilson 2000). It is hoped to trial a number of less elaborate constructions including some form of cover from aerial predators in the future.

The overpass is unlikely to be used by tree-kangaroos. No evidence has been obtained of use by this species. None of the respondents to the arboreal survey had observed tree-kangaroos using canopy connections (see report Section 7). Therefore, an overpass cannot be expected to prevent road mortality of this species. Underpasses may be more effective for tree-kangaroos.

6.5 Management Implications

- It appears that canopy overpasses are utilised by arboreal rainforest possums. It is as yet uncertain as to whether the possums cross the road using the existing structure.
- It is possible that subdivision of rainforest possum populations by roads may be ameliorated by overpasses. However more research using overpasses across wider road clearings needs to be undertaken before the effectiveness of these structures in reducing linear barrier effects across larger roads and highways is able to be determined.
- Further research with respect to predation of animals using such structures is also required.

Section 7: Road Crossings by Arboreal Mammal Species Questionnaire

7. Road Crossings by Arboreal Mammal Species Questionnaire

Miriam Goosem

Summary: *A questionnaire was developed to collate experience and knowledge of researchers and managers, spotlighting tour operators and naturalists / wildlife rescuers with respect to arboreal species and their road crossing habits. The questionnaire was conducted with thirty-three respondents through telephone surveys. The results confirm experience of many researchers and naturalists in the Wet Tropics who have concluded that the lemuroid ringtail, Hemibelideus lemuroides, is the species most susceptible to fragmentation of habitat, including that from linear environmental discontinuities such as roads and powerlines. The data also highlights the importance of vehicle collisions in mortality of species such as Lumholtz's Tree-kangaroo, Dendrolagus lumholtzi, and the striped possum, Dactylopsila trivirgatus. Many respondents have described the utility of canopy connections as crossing points for the rare possums. We have also collated suggestions from respondents of tree species for roadside revegetation that may provide effective canopy connections for arboreal species and yet not attract Endangered species such as the southern cassowary to feed near the roadside.*

7.1 Introduction

Natural habitat fragmented by networks of roads and powerline clearings may cause subdivision of populations of many faunal species (Oxley *et al.* 1974; Goosem and Marsh 1997, Goosem 2000, Section 1 of this report). Many arboreal species such as possums and gliders avoid moving across terrain at ground level (Pahl *et al.* 1988, Laurance 1990, Wilson 2000). The problem of fragmentation of habitat by linear barriers therefore is exacerbated for strictly arboreal species as compared to ground-living species (Wilson 2000). However, some arboreal species are known to utilise canopy connections as crossing points.

Several possum and tree-kangaroo species of the Wet Tropics are not strictly arboreal, being prepared to come to ground level for dispersal movements (Tree Kangaroo and Mammal Group, pers. comm.). A few species are commonly observed on the ground. Such species may be subject to road mortality when attempting to cross roads during dispersal movements, in the breeding season, or during normal foraging movements (Goosem 2000). It is likely that particular sections of road may form 'roadkill hotspots' where animals are more likely to be killed due to a particular combination of road design and habitat factors (Goosem 2000).

Objective and Aims

The objective of this study was to collate and interpret experience and knowledge from researchers, tourism operators, management organisation personnel, field naturalists and conservation and wildlife rescue groups with respect to the road crossing ability and habits and road mortality of arboreal species.

The aims of this study included:

- To collate experience of the above groups as to which species will use canopy connections as road crossing routes or alternatively which species will only cross over the road surface.
- To collate expert knowledge with respect to which plant species may provide suitable road crossing points for arboreal species, particularly those thought to be 'strictly arboreal'.
- To collate data with respect to roadkills of arboreal mammals in order to determine any particular 'roadkill hotspots'.

7.2 Methodology

A questionnaire was developed and initially trialed on research personnel. The questionnaire was then modified to facilitate data collection using the telephone survey technique. Telephone surveying was selected as the measurement technique as it allows selection of respondents according to their experience in the subject, does not require research travel, is inexpensive and facilitates a high response rate. The questionnaire was conducted with researchers and managers, spotlighting tour operators and naturalists / wildlife rescuers between July 1998 and May 2000. The questionnaire examined knowledge and expertise with respect to 15 rainforest arboreal species including possums, tree-kangaroos and gliders (Table 7.1), and specifically examined the following factors to develop a "road crossing summary" for each species:

- Spotlighting frequency and location/s;
- Arboreal species observed;
- Vegetation type/s and plant species where arboreal mammal species were observed, including tree species at road edge;
- Details of observations of species crossing roads:
  - Species;
  - Location/s;
  - Width of road clearing;
  - Type of road verge;
  - Method of crossing i.e. road surface, through a culvert, using a canopy connection, gliding or leaping;
  - Comment of the use of tree species by arboreal and other fauna;
  - Location of observed roadkills.

Table 7.1. Rainforest arboreal species examined by the questionnaire.

Species Types	Species Name	Common Name
Possums (Ringtail)	*Hemibelideus lemuroides*	Lemuroid Ringtail Possum
	Pseudochirulus herbertensis	Herbert River Ringtail Possum
	Pseudochirulus cinereus	Daintree Ringtail Possum
	Pseudochirops archeri	Green Ringtail Possum
Possums	*Cercartetus caudatus*	Long-tailed Pygmy Possum
	Trichosurus vulpecula johnstoni	Coppery Brushtail Possum
	Dactylopsila trivirgatus	Striped Possum
Tree-kangaroos	*Dendrolagus lumholtzi*	Lumholtz’s Tree-kangaroo
	Dendrolagus bennettii	Bennett's Tree-kangaroo
Gliders	*Petaurus breviceps*	Sugar Glider
	Petaurus norfolcensis	Squirrel Glider
	Petaurus australis reginae	Yellow-bellied Glider
	Petauroides volans	Greater Glider
	Petaurus gracilis	Mahogany Glider
	Acrobates pygmaeus	Feather-tailed Glider

7.3 Results

Respondents

Thirty-three people have been interviewed (Table 7.2). Respondents include 23 researchers and managers, 6 spotlighting tour operators and 4 naturalists / wildlife rescuers. Respondents include arboreal experts such as John Winter, Robyn Wilson, John Kanowski, Rupert Russell, Nicky Goudberg and Graham Newell. Many field observations have been made by research and management organisation personnel including Mike Trenerry, Darryn Storch, Les Moore, Steve van Dyck, Steve Comport, Chris Clague, Scott Burnett and Bill and Sue Laurance. One source of much experience that is not often tapped is the tourism operators who run spotlighting tours. These people have been most helpful. People from wildlife rescue groups and field naturalists have also shared their knowledge and expertise.

Table 7.2. Respondent profile.

Classification of Respondents	Respondents	Text Identifier	Number of Respondents
Researchers and Managers	John Winter	JW	23
	Robyn Wilson	RW	
	John Kanowski	JK	
	Rupert Russell	RR	
	Nicky Goudberg	NG	
	Mike Trenerry	MT	
	Darryn Storch	DS	
	Les Moore	LM	
	Steve van Dyck	SD	
	Graham Newell	GN	
	Steve Comport	SC	
	Steve Williams	SW	
	Andrew Krockenberger	AK	
	Chris Clague	CC	
	Scott Burnett	SB	
	Bill Laurance	BL	
	Sue Laurance	SL	
	Nigel Weston	NW	
	Keith Smith	KS	
	Mick Godwin	MG	
	Andrew Dennis	AD	
	Nigel Tucker	NT	
	Garry Werren	GW	
Spotlighting tour operators	Bob Morrison	BM	6
	Alberto Vale	AV	
	Dave Armbrust	DA	
	John Strutton	JS	
	Grei Stokes	GS	
	Charlie Hawkins	CH	
Naturalists / wildlife rescuers	Margit Cianelli	MC	4
	Beth Stirn	BS	
	Rob Whiston	RW	
	Jean Horton	JH	
		Total Respondents	**33**

Species Habitat and Distribution and Road Crossing Summaries

The data collected through the questionnaire has been collated and is presented as a "road crossing summary" for each species (Appendix 7). These results identify the number of respondents who have spotlighted, seen species crossing roads and the observed roadkills of each species. The results also detail locations, types and methods of road crossings, tree species used for crossing and locations of roadkills, together with comment made by respondents with respect to road crossings by species. In addition, "habitat and distribution summaries" for each of the 15 species have been compiled from literature (Appendix 7).

Plant Species Useful in Mitigating Road Impacts for Arboreal Species

A list of plant species and communities which respondents had observed being used at the road edge for crossing, or that are used by arboreal species for foraging or other daily activities and with the potential to be used for crossing by arboreal species was established from those plant species identified by managers, researchers, spotlighting tour operators and naturalist / wildlife rescuers (Table 7.3). This collation of plant species can only be considered as a preliminary inventory, which can be expanded as new information is provided.

Table 7.3. Plant species identified by respondents' experience as potentially useful in mitigating road impacts by arboreal species.

Group of Arboreal Species identified as using Plant community or group	Plant communities or species identified by respondents as used by the arboreal species	Frequency of identification of plant groups as used in road crossings
Possums	*Acacia* spp.	4
	Alphitonia spp.	38
	Calamus spp.	-
	Coastal mosaic	7
	Dendrocnide spp.	2
	Elaeocarpus spp.	5
	Laurels	1
	Eucalypts	2
	Figs	2
	Flindersia spp.	-
	Helicia spp.	1
	Lianas	2
	Mature rainforest	15
	Melaleucas	2
	Omalanthus sp.	2
	Polyscias spp.	-
	Solanum spp.	1
	Syzygium spp. (mature)	-
	Tall open forest	1
Gliders	Dry Eucalypt woodland	4
	Eucalypts	1
	Acacia regrowth	1
	Tall open forest	1
	Melaleucas	1
	Mature upland rainforest	2
Tree Kangaroos	Cluster figs	-
	Polyscias spp.	-

7.4 Discussion

Each arboreal species for which responses were received are discussed separately. The species fall into three groups with respect to vulnerability to road impacts:

1) species which avoid coming to the ground and are therefore vulnerable to fragmentation by linear barriers;
2) species that are little affected by linear clearings with respect to habitat fragmentation as they are comfortable on the ground, but when crossing are subject to road mortality, which may be a threatening process for particularly vulnerable species; and
3) species that lie between these two extremes of behaviour i.e., avoid the ground layer but are willing to cross linear clearings when necessary for dispersal purposes, but do not form a high proportion of roadkill statistics.

Road Crossing Behaviour: Possums

Lemuroid Ringtail Possum, *Hemibelideus lemuroides*

Some very interesting conclusions can be drawn from this pooling of expert knowledge. The long-held belief that the Lemuroid Ringtail does not come to the ground (John Winter, *pers. comm.*) has largely been backed up by this collation of data. Only one roadkill of this species was recorded and only 3 respondents replied that they had observed the Lemuroid crossing on the road surface. All noted that this was a very rare occurrence and in the hundreds of hours of spotlighting they had undertaken, these were the few results. In addition one respondent (MT) believed that the only reason he had observed the animals on the ground was that there was no canopy connection within a reasonable distance to be used as a crossing point. Another arboreal expert noted that the species would come down to the ground to cross under the duress of being taken outside its normal home range to the other side of a linear barrier (RW).

The lack of mobility of the Lemuroid away from its arboreal habitat explains the species susceptibility to habitat fragmentation. The species is very unlikely to travel between habitat fragments. Pahl *et al.* (1988) in a study of remnant rainforest patches on the Atherton Tablelands found the Lemuroid Ringtail to be absent from 7 of 11 remnant patches and only present in greatly reduced abundances in those four remnants where it remained. The next worst affected of the four large rainforest possums was the Herbert River Ringtail which was present in six remnants but in similar abundances to that of continuous forest. The Coppery Brushtail on the other hand was little affected and may even have benefitted because it was present in all rainforest patches at densities greater than in continuous forest. Similarly, Laurance (1989) demonstrated that the Lemuroid was the most vulnerable of the nocturnal mammals to local extinctions within habitat fragments. Corridors of secondary vegetation helped to mitigate the effects of fragmentation for some species, but not for the vulnerable Lemuroid (Laurance 1989). In a study of selective logging effects on arboreal marsupials, Laurance and Laurance (1996) again found that the Lemuroid was the most vulnerable to disturbance, declining markedly in logged forest. In contrast, Wilson (2000) found that where canopy connections existed, Lemuroids were likely to use both sides of a narrow road. The distribution of time on either side of the road could be equal where the canopy connection was present in the middle of the animal's home range (Wilson 2000). However, where canopy connections were not available in the vicinity of a home range, the animals tended to align their home ranges along the linear clearing (Wilson 2000).

For the Lemuroid, the presence of a road, highway or powerline corridor which lacks any canopy connection may be a complete barrier to any movements, unless under the severe stress of being moved away from their home range (Wilson 2000). The species would move on the ground when forced by translocation. When translocated across a clearing, the width of the clearing became a factor – more animals would return across a narrow road (3 of 7 translocations) than across a 60 metre wide powerline clearing (1 of 8). Therefore provision of canopy connections over roads (and powerline clearings) in areas where the Lemuroid occurs is of great importance. Data collation here shows that the Lemuroid crosses roads via canopy connections quite easily (13 respondents having observed at least one crossing). The species can leap short distances (JK, JW) and are agile on thin branches and vines (MT).

Herbert River Ringtail, *Pseudochirulus herbertensis*

The Herbert River Ringtail was also felt to very seldom come to the ground, and also probably be susceptible to fragmentation. Pahl *et al.* (1988) found that the Herbert had disappeared in 5 of the 11 remnant patches but still retained its abundance levels where it remained. Laurance (1989) found that the Herbert exhibited a negative response to rainforest fragmentation, although it was not as vulnerable as the Lemuroid. Although Laurance and Laurance (1996) noted that the species is exclusively arboreal and therefore clearings and wider logging roads may present a barrier to movements, they did not find any reduction of abundance after logging. They ascribed this population constancy to the range of their preferred food species which include secondary successional plants and also to their den requirements which are not as strict as the hollow tree dens of the Lemuroid.

The data from this survey shows that the Herbert River Ringtail will come to the ground which seems to occur much more often than previously thought and certainly much more often than the Lemuroid Ringtail. Six respondents have observed the species crossing roads on the ground and quite a number of locations are mentioned as crossing points on the road surface. The species prefers to use canopy connections where available but will use the road surface when there is no other avenue. Wilson (2000) observed Herbert River ringtails crossing a single-lane sealed road on 5 of 38 nights even though canopy connections were available and has observed one using the road as a walkway for a distance of 20 metres. She has often sighted the species crossing from fragments to continuous forest blocks (Wilson 2000). Roadkills of the Herbert have been observed in a number of Tablelands areas, as would be expected with such movements. This does not necessarily mean that fragmentation of habitat by linear barriers is not a threatening process. As we have seen in Section 1, even mobile generalist mammals can be inhibited in their movements by the presence of a linear environmental discontinuity.

Provision of canopy connectivity for the Herbert River Ringtail is actually more difficult than for the Lemuroid. Respondents noted that the Herbert requires more solid canopy connections because they can't leap and are less agile when it comes to vines and thin branches (JW, MT). However they have been observed using barbed wire as a means of moving in a powerline clearing (Wilson 2000). There is also the problem mentioned by one respondent (NG) that more than one or even two crossing points in an area would be necessary due to the species being susceptible to bullying from the Coppery Brushtail. However, it was noted that Herberts will use their own weight to create links across the canopy by weighing down the ends of branches (MT).

Daintree Ringtail Possum, *Pseudochirulus cinereus*

Observations of managers, researchers, spotlighting tour operators and naturalist / wildlife rescuers suggest that the Daintree Ringtail Possum is very similar to Herbert River Ringtail Possum in behaviour (BM, MT). However, observations of the species are limited in comparison with the Herbert River ringtail, as the species is only found north of the Daintree and in the Carbine Tableland, where fewer researchers and spotlighting tours visit in comparison with the Atherton Tablelands. The literature and observations of respondents suggest the Daintree Ringtail Possum very rarely descends to ground level, the one respondent who had observed the species at ground level stated that they had "only observed one animal walking on a road (and) assumed it was because the animal was sick" (RR). Only two roadkills have been observed by one researcher – at the top of the Rex Range and at Mt Lewis. The movement patterns of the Daintree Ringtail Possum indicate that the species is susceptible to fragmentation with linear clearings such as roads probably representing a fairly severe barrier to movements where canopy connections do not exist.

Green Ringtail Possum, *Pseudochirops archeri*

The literature, together with observations of respondents to the survey suggests that although markedly arboreal ("have not seen on ground" (SW) and "don't often come down to ground" (MC)), the Green Ringtail Possum will descend to ground to cross small clearings. One respondent indicated that they had seen Green Ringtail Possums "crossing between trees over a gap" (RR), and that they "often spot them 0.5 – 1m off the ground which have just run to a sapling" (RR). Whilst the literature suggests that Green Ringtails avoid leaping, a respondent suggested that the species "can leap and so (potentially) don't need a good (canopy) connection" (JW). Many respondents have observed roadkills of this species, highlighting the fact that Green Ringtails will descend to the ground to cross roads. Roadkill locations are distributed across the Atherton and Evelyn Tablelands, Kuranda area and Julatten areas. The species is often observed on road edges in species such as *Alphitonia* which have the potential to form canopy connections. It has been observed using the artificial canopy overpass in the Lamb Range.

Coppery Brushtail Possum, *Trichosurus vulpecula johnstoni*

The Coppery Brushtail uses the road as a means of access to new areas, travelling through pasture and urban areas easily. Consequently road crossings on the road surface are commonly recorded and few crossings using a canopy connection have been noted. However, this lack of inhibition by roads does place the species at risk of wildlife mortality, with many roadkill locations recorded and many respondents just replying to the question of location of roadkills as 'all over the Tablelands'.

The main problem for canopy connections posed by the Coppery is the species potential to bully other possums and prevent them from crossing (NG). A fairly solid branch would be required to allow them to cross by a canopy connection but they can swing across gaps less than 0.5 metres (RW). A large number of plant species appear to be suitable sources of canopy crossing points for the Coppery Brushtail.

Long-Tailed Pygmy Possum, *Cercartetus caudatus*

As with the Green Ringtail Possum, the Long-tailed Pygmy Possum is reported by respondents to be markedly arboreal with most reporting to have "never seen (the species) on the ground" (DS, RR). Other respondents indicated that they had observed the species "on the ground" (SC), "down near the ground on fallen logs (used as runways)" (RR), and "on the side of the road, on the ground at Mt Lewis and Mt Baldy" (BM). The road crossings summary collated from responses to the survey indicates that 4 respondents had observed the species crossing roads (2 respondents had observed crossings on the road surface), whilst some respondents had not observed the Long-tailed Pygmy Possum "crossing roads" (DS), (RR), (SC). The lack of responses with respect to road crossings is not unexpected for this cryptic species, as it is also seldom observed. It may also indicate road avoidance due to disturbance. However, the two locations of roadkills suggest that, on occasion, the species will descend to the ground to cross roads and may then be fairly susceptible to mortality due to their small size and restricted mobility.

Striped Possum, *Dactylopsila trivirgatus*

In contrast to the rainforest ringtails and Long-tailed Pygmy Possum, the Striped Possum is not considered strictly nor markedly arboreal. Literature suggests this species (whilst usually arboreal), uses all layers of the rainforest, with observations of managers, researchers, spotlighting tour operators and naturalist / wildlife rescuers indicating that individuals "have been seen wandering down a road" (RR) and are "often see near ground level on fallen logs" (DS). The ability of Striped Possums to leap and catapult documented in the literature is also supported by the field observations that "Striped Possums are very good at leaping – can jump 10m vertically to cross a 4m road" (RR), "Striped possums will jump across a gap 1-2m wide"(JW). This ability to leap, is combined with the observations that they "land on the ground and are very mobile on the ground" (RR) and "prefer to come to ground to cross roads – are often sighted on road surface in lowland rainforest areas and coastal mosaics" (MT). Whilst the small size of the species is identified in the literature as a factor potentially affecting the impact of roads as barriers, field observations and expert comment suggests that roads are less of a barrier to movement for this species than other strictly and markedly arboreal species. A large number of respondents (10) indicated that they had observed roadkills of Striped Possums and one respondent reported that "roadkills are often seen on roads after new developments and clearing in the coastal mosaic" (MT).

General Crossing Behaviour of Possum Species

The results suggest that for most arboreal rainforest possum species canopy connections are critical to allow movements across roads and other linear clearings and to prevent road mortality. For the Lemuroid ringtail crossings are almost unknown where canopy connections do not exist. However, a Lemuroid has been photographed using an artificial canopy overpass. Several other species e.g. Long-tailed Pygmy Possum are markedly arboreal and may be at a disadvantage if forced to the ground to cross roads. Several of these, including the Striped possum, feature regularly as roadkill statistics. Another group includes the Coppery Brushtail possum which appears to have little problem with fragmentation but a much greater problem with road mortality.

The likelihood that canopy connections form well-known runways for arboreal animals was suggested by the observation from one respondent (SL):

> ‘Lemuroids and other arboreals were always observed in one particular place on a road on the Tablelands where there was a canopy connection. It appeared that all the arboreals in the area knew where the overpass was situated and often concentrated in the area.’

Conversely, perhaps the predators of the area also knew of the ‘arboreal highway’ because it was noted that the only observation of a Rufous Owl was made perched right in the middle of the canopy connection.

A similar observation was made by the same respondent for a different area:

> ‘I observed a Herbert River Ringtail and a Green Ringtail follow the same trail through the rainforest towards a canopy connection and eventually use it as an overpass.’

Therefore it appears that the value of canopy connections over roads is well known to the fauna that use them.

Road Crossing Behaviour: Tree-kangaroos

Lumholtz’s Tree-kangaroo, ***Dendrolagus lumholtzi***

Connectivity through the canopy does not pose a problem for Lumholtz’s Tree-kangaroo. The species comes to the ground readily and has been seen in areas isolated from rainforest by several kilometres during dispersal, particularly of juvenile males. However, settled groups of animals are sedentary (GN) and do not normally attempt to cover the large areas that some of the dispersal records demonstrate. This was demonstrated by the group of five animals that did not cross a road although they were relatively restricted in areal extent of habitat (GN).

The major threat of roads to the Tree-kangaroo is due to collisions with vehicles. The large database of road-killed Tree-kangaroos currently compiled by the Tree Kangaroo and Mammal Group (MC) calls into question current management of this Rare species. Canopy connections do not appear to be a viable option to encourage movements and prevent mortality of Tree-kangaroos as they were very seldom utilised. Provision of sub-road crossing points which are aligned with the surrounding topography of the landscape may be an option to be tested. Such a question may be able to be resolved by examination of the use of purpose-built culverts with infrared-triggered cameras as is proposed in the next few years during monitoring of the East Evelyn road upgrade project. One individual has been observed using a rail tunnel of similar dimensions for movements (JK). Additionally the TKMG database can be spatially analysed to provide information about roadkill hotspots and potential corridors for dispersing animals between fragments with resident tree-kangaroos. This would aid in maintenance of the species and determination of where potential conflicts with vehicles may arise and potentially be ameliorated.

Bennett's Tree-Kangaroo, *Dendrolagus bennettianus*

Expert comment indicates that Bennett's Tree Kangaroos, although seen on the ground (DS) and along the side if a road (once) (GW), have not been seen crossing roads (RW). This is not surprising as the species is rarely observed. The observations of managers, researchers, spotlighting tour operators and naturalist / wildlife rescuers suggest that, whilst this rare species is not strictly arboreal and will descend to the ground readily, roads may constitute a barrier to movement, with road noise, headlights and disturbance potentially sources of disturbance and road mortality a serious threat. The average weight of Bennett's Tree-Kangaroos, 13 kg (compared to Lumholtz's Tree-kangaroo with an average weight of 7kg), indicate that solid canopy connections would be required for this species. Although the species is fairly agile and able to swing between branches (MT), the absence of any observations of utilisation amongst respondents of this survey, suggest that canopy connections may not be an effective method of mitigating road impacts on this species. Consonant with Lumholtz's tree-kangaroos, roadkills of Bennett's Tree-Kangaroos represent a major threat to the species and research involving trial of mitigation measures is required.

General Crossing Behaviour of Tree-Kangaroo Species

The results suggest that both Lumholtz’s and Bennett’s Tree-Kangaroos come to the ground to cross roads and that neither species commonly use canopy connections, (only one observation of a Tree-Kangaroo using a canopy connection was recorded). These results together with the knowledge that road mortality is a significant threat to both species of Tree-Kangaroos, mean that trials of effectiveness of sub-road crossing points which are aligned with the surrounding topography is considered essential. The effectiveness of fencing in preventing road crossing attempts away from faunal underpasses is another area of mitigation that needs urgent examination.

Road Crossing Behaviour: Gliders

Sugar Glider, *Petaurus breviceps*, Squirrel Glider, *P. norfolcensis*, Yellow-Bellied Glider, *P. australis reginae*, and Greater Glider, *Petauroides volans*

The literature suggests that Sugar, Squirrel, Yellow-Bellied and Greater Glider species are highly mobile and agile and are able to glide between 30m (easily) and 100m (Dept Main Roads, Manual, 1998) and comment from managers, researchers, spotlighting tour operators and naturalist / wildlife rescuers predominantly supports this indication. Greater gliders have been observed gliding 40-50m (AD), and one respondent suggested that Sugar, Squirrel, Yellow-Bellied and Greater Glider species have "no trouble crossing roads except for two or four lane highways" (JW). Other respondents indicated that they had not observed sugar gliders crossing roads (RWh), that they had observed a Greater Glider land in the middle of a road with a width of between 0 and 5m (SC) and that during flooding a squirrel glider had been observed walking along the road (MG). These results suggest that although Sugar, Squirrel, Yellow-Bellied and Greater Glider species are able to glide between 30 and 100m, roads, particularly 2 lane highways and wider road clearings may restrict movements.

Mahogany Glider, *Petaurus gracilis*

The endangered Mahogany Glider is described in the literature as highly mobile, able to glide up to 50m (Dept Main Road Manual 1998). Response with respect to this endangered species was limited to three respondents. Whilst one respondent observed a Mahogany Glider "successfully crossing (a road) by hopping and gliding" (KS), the four observed roadkills of this species suggests that road mortality is a significant threat to the survival of this species.

Feather-Tail Glider, *Acrobates pygmaeus*

The literature indicates that the Feather-Tail Glider is highly mobile and agile, and able to glide or leap up to 20m (Dept Main Roads manual, 1998), however, the road crossing observations reported through this questionnaire suggest that roads may constitute a severe barrier to this small glider. One respondent indicated that they had "never seen (a Feather-Tail Glider) glide, (and that the species) may have trouble crossing" (JW), another respondent reported they had observed a Feather-Tail Glider "land on the ground" (SW).

General Crossing Behaviour of Glider Species

Glider species were predominantly observed gliding across roads, with the Sugar Glider the only species observed crossing using canopy connections. These results suggest that canopy connectivity may not be as critical to glider species as to arboreal possum species. However, the presence of trees adjacent to roads of sufficient height to enable long glides above vehicle height must be considered critical in encouraging glider movement across roads, whilst preventing road mortality. Consideration also needs to be given to the type of fencing adjacent to roads – gliders becoming caught in barbed wire fences is recognised as a threatening process in some parts of the region, particularly for Mahogany and Yellow-bellied gliders.

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Plant Species Useful for Canopy Connectivity

The appropriate selection of plant species remains a critical aspect in the revegetation of roadsides, particularly when considered from the point of view of canopy connectivity for arboreal wildlife. Another aspect that must be considered is the attractiveness of the plants to species for which road mortality forms a threatening process. For example, fruiting species attract the Southern Cassowary, *Casuarius casuarius johnsoni* (NG), whereas certain foliage is more attractive to Tree-kangaroos, particularly when producing a new flush of leaves, and attracts the species across roads (MC).

Contrary to expectations that the architecture and thin branches of *Alphitonia* spp. were not likely to form canopy connections that could be utilised by arboreal rainforest species, Sarsaparilla was the species most often mentioned as forming a crossing pathway. Although this may well be a function of the presence of this secondary rainforest species along the edges of many roads on the Atherton and Carbine Tablelands, it demonstrates that the plants serve a useful function. One respondent suggested that it may actually pose a threat to some of the possums by attracting them to the roadside (SW).

In contrast, *Acacia* spp., which also line many Wet Tropics roads due to previous disturbance, were summarily dismissed as being of little, if any, use to any arboreal species.

Several very useful suggestions were received with respect to plant species that may form viable canopy connection. Suggestions included *Alphitonia* spp*., Flindersia brayleana* and *F. pimenteliana* and *Elaeocarpus* spp. due to their architecture that provides lateral and relatively horizontal branches (NG). Other species with this architecture include *Omalanthus* sp., but the branches may not prove as sturdy. *Polyscias* spp. were also suggested as an alternative because, although the species do not have spreading lateral branches, branches when they do touch do so at high levels in the canopy (BM). One problem with planting of *Elaeocarpus* spp. close to the road was the likelihood of attraction of Endangered Cassowaries to the roadside with the potential for vehicle mortality (NG). *Flindersia* spp. was suggested as an alternative, being a prime food tree for Lemuroids and not producing the fruit so attractive to Cassowaries (NG).

7.5 Conclusions

For many arboreal rainforest possum species, canopy connections are important to allow movements across roads and other linear clearings and to prevent mortality. Canopy connections are particularly critical for the Lemuroid ringtail, for which road crossings are almost unknown where canopy connections do not exist and which uses canopy connections readily. All rare rainforest ringtails have been observed using canopy connections and the three in the vicinity of an artificial canopy overpass will also use it to cross a narrow road. Canopy connections appear to be well known by arboreal individuals in their vicinity. A number of possum species are vulnerable to road mortality, particularly the Coppery Brushtail and the Striped Possum. A requirement to cross roads from habitat fragments or from recently cleared areas to reach continuous forest appears to be a factor for these species.

Tree-kangaroos do not appear able to use canopy connections effectively, but are prepared to come to the ground. This behaviour places them at risk of road mortality which appears likely to be a significant threatening process.

Gliders normally do not experience narrow roads as a complete barrier, but movements may be severely restricted by roads with clearings greater than 20-30 metres (i.e. wide 2-lane highways and 4-lane highways). Road mortality may become a factor where the width of the road exceeds the distance the species is able to glide. The maintenance of tall vegetation on either side of a road clearing may encourage crossing movements.

A number of plant species or community characteristics have been identified as encouraging canopy connectivity for strictly or markedly arboreal species whilst discouraging species that may be attracted to the roadside by food species and thus join the mortality statistics

7.6 Recommendations

- Maintain canopy connections across roads to cater for arboreal species and encourage new connections wherever possible.
- Consider the possibility of bridges with high spans that allow maintenance of canopy connectivity below the bridge.
- Examine the effectiveness of canopy overpasses connecting rainforest in highway areas where it is not feasible to maintain or create canopy connections.
- Rehabilitation of grassy and weedy road verges will help prevent the intrusion of predators such as feral cats which prey on smaller arboreal species.
- Roadside revegetation should consider the wildlife occurring in the vicinity and make provision for canopy connections where possible whilst avoiding fruiting species where Cassowaries occur or trees with extremely attractive young foliage where Tree-kangaroos are common.
- Undertake research into the effectiveness of faunal underpasses for use by Tree-kangaroos.
- If underpasses are used by Tree-kangaroos, examine the effectiveness of 'floppy fencing' in preventing Tree-kangaroos from crossing at situations other than where underpasses are provided.
- Traffic calming measures including rumble strips, and slow-speed designs that include chicanes and curves may aid in prevention of mortality at known 'roadkill hotspots'.

- Maintain roadside tall trees by the roadside in glider habitat areas to allow maximum glide distances above vehicle height to be achieved.
- Replace barbed wire fencing of the road with other fencing strategies in areas of glider habitat.

7.7 Management Implications

Maintenance or creation of canopy connections above roads will aid management in maintaining populations of many rainforest and open forest arboreal possum and glider species, through avoidance of linear barrier effects and road mortality. Alternatively high bridges can maintain canopy connectivity below the road surface. Artificial canopy overpasses have been used by some obligate rainforest species that are strictly or markedly arboreal and may provide an option where canopy connectivity cannot be maintained. However more research into the effectiveness of longer overpasses is still required.

Tree-kangaroos and several possum species appear to be particularly subject to road mortality. Provision of faunal underpasses may aid in prevention of Tree-kangaroo mortality but research and monitoring is required. Trials of the effectiveness of various designs of ‘floppy fencing’ for prevention of movements of Tree-kangaroos outside of faunal underpasses is also required, particularly in ‘roadkill hotspots’. Identification of potential faunal corridors between fragments on the Atherton Tablelands should aid in determining the best positions for these measures. Alternatively, traffic calming methods could be examined.

In tall open forest and eucalypt and melaleuca woodlands, maintenance of tall trees in roadside vegetation and removal of barbed wire fencing should encourage safe glider road crossings.

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Appendix Section 2: Edge Effects of Roads and Powerlines on Rainforest Microclimate

Appendix Section 2: Edge Effects of Roads and Powerline Clearings on Rainforest Microclimate.

Table 1: Physical Characteristics of the Study Sites

Average Physical Characteristics of each Treatment					
Treatment	**Aspect**	**Average Clearing Width**	**Average Site Slope**	**Average Tree Height at the Forest Edge**	**Time of Day Sites are Most Affected by Sunlight**
Closed canopy	NE to N	7m	10?	32m	mid-morning to midday
Open canopy	NE to NW	9m	5?	29.5m	mid-morning to mid-afternoon
Powerline corridor	NE to N	100m	5?	38m	mid-morning to midday

The physical characteristics of each treatment site with respect to location (aspect), site topography (slope) and potential penetration of sunlight, wind and momentum into each linear clearing (average clearing width, average tree height and the time of day that sites were most directly affected by solar radiation). It is possible that one or more of these factors may have influenced the microclimate of each treatment; in addition, the combined influences of aspect and slope may have had an effect on site hydrology and drainage.

While all three sites did not differ greatly in aspect, and it can be seen that all three were affected by solar radiation primarily from mid-morning to midday, the open canopy experienced a longer exposure to sunlight from mid-morning to mid-afternoon. Mean clearing widths and mean tree heights were similar for the open canopy and closed canopy sites, while the powerline corridor was ten times wider than either of these.
Additionally, the open canopy and powerline corridor sites had similar slopes while the closed canopy site had a greater mean slope.

Table 2. Descriptive statistics for photosynthetically active radiation

	Photosynthetically Active Radiation (PAR µmol.m $^{-2}$.s^{-1})					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	5.7	24.3	23.8	62.3	72.5	55.4
Standard Deviation	8.3	63.8	36.8	144.7	262.8	198.1
Standard Error	(±)1.072	(±) 8.239	(±) 4.76	(±)18.684	(±) 33.93	(±) 25.581
Minimum	0.3	1.1	1.3	1.1	0.7	0.5
Maximum	41.7	344.2	139.4	914.4	1821.8	1486.7

- Compiled from data collected on the all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- The closed canopy site had the lowest mean photosynthetically active radiation in both the wet and the dry season.

Table 3. Descriptive statistics for soil surface temperature

	Soil Surface Temperature (? C)					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	18.1	15.7	18.0	16.3	19.7	16.0
Standard Deviation	1.2	1.6	1.1	1.0	1.9	1.1
Standard Error	(±) 0.159	(±)0.208	(±) 0.136	(±) 0.132	(±) 0.252	(±) 0.136
Minimum	15.3	12.7	16.5	14.7	17.4	14.5
Maximum	21.1	19.8	21.4	20.5	25.3	20.1

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- There was little variation in soil surface temperature between the wet and dry seasons across the three treatments
- However, the powerline corridor site had the highest soil surface temperature during the wet season.

Table 4. Descriptive statistics for soil temperature at 10 cm depth

	Soil Temperature (? C) at 10 cm depth					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	18.5	15.3	17.8	15.6	19.9	15.4
Standard Deviation	0.8	0.8	0.8	0.9	1.4	0.4
Standard Error	(±)0.108	(±)0.108	(±) 0.103	(±) 0.113	(±) 0.181	(±) 0.052
Minimum	17.1	13.6	16.8	14.5	18.0	14.9
Maximum	20.1	17.8	20.7	20.1	23.3	17.0

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- Soil temperature at 10 cm depth did not vary between the three treatments in the dry season.
- However, the powerline corridor site had the highest wet season soil temperatures at 10 cm depth.

Table 5. Descriptive statistics for ambient temperature at 20 cm height.

	Ambient Temperature (? C) at 20 cm					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	18.6	16.7	19.1	17.1	20.1	16.4
Standard Deviation	1.2	1.8	1.4	0.7	1.2	1.3
Standard Error	(±) 0.163	(±) 0.234	(±) 0.182	(±) 0.09	(±) 0.157	(±) 0.163
Minimum	17.4	14.0	17.1	16.1	17.5	14.5
Maximum	20.8	19.6	22.8	18.4	23.0	19.8

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- The powerline corridor had the highest mean ambient temperature at 20 cm in the wet season, while the closed canopy site had the lowest.

Table 6. Descriptive statistics for ambient temperature at 150 cm height

	Ambient Temperature (?C) at 150 cm					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	18.3	16.6	18.9	17.1	18.5	17.0
Standard Deviation	1.0	2.0	1.4	1.0	1.0	1.4
Standard Error	(±) 0.128	(±) 0.263	(±) 0.185	(±) 0.124	(±) 0.127	(±) 0.184
Minimum	17.3	13.0	16.3	15.8	16.5	14.5
Maximum	21.0	19.3	21.8	19.8	21.8	20.3

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- Very little variation in mean ambient temperature at 150 cm was exhibited between the three treatments in the wet season,.
- However, the closed canopy site had the lowest temperature in the dry season.

Table 7. Descriptive statistics for vapour pressure deficit at 20 cm height

	Vapour Pressure Deficit (VPD in Pa) 20 cm					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	248.3	428.5	415.2	134.1	330.1	94.0
Standard Deviation	193.8	199.2	229.5	65.2	250.5	11.8
Standard Error	(±) 25.023	(±) 25.717	(±) 29.622	(±) 8.418	(±) 32.34	(±) 1.527
Minimum	99.4	102.5	109.1	91.5	99.4	54.6
Maximum	678.9	768.1	940.5	340.7	892.7	151.3

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- Although the closed canopy site had the lowest VPD 20 cm in the wet season, it was unexpectedly high in the dry season compared to the other treatments.

Table 8. Descriptive statistics for vapour pressure deficit at 150 cm height

	Vapour Pressure Deficit (VPD in Pa) 150 cm					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	379.0	464.0	328.8	243.3	124.8	258.7
Standard Deviation	110.7	154.5	139.0	127.7	72.2	156.8
Standard Error	(±) 14.3	(±)19.954	(±) 17.949	(±) 16.486	(±) 9.323	(±) 20.241
Minimum	192.8	143.2	47.5	73.9	22.3	42.1
Maximum	655.0	783.8	756.6	737.3	283.2	580.1

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- The closed canopy showed the highest VPD at 150 cm in both the wet and dry seasons.

Table 9. Descriptive statistics for wind speed at 150 cm height

	Wind Speed (m/s) at 150 cm					
	Closed Canopy		Open Canopy		Powerline Corridor	
Statistical Parameters	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	0.0	0.0	0.0	0.0	0.0	0.0
Standard Deviation	0.0	0.0	0.1	0.1	0.1	0.1
Standard Error	0.0	0.0	(±) 0.007	(±) 0.007	0.0	0.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	0.0	0.0	0.3	0.3	1.1	1.1

- Compiled from data collected on all study sites at West Palmerston during the wet season (April to early May, 1999) and the dry season (August, 1999).
- Wind speed at 150 cm was not detected on the closed canopy site and was minimal on the open canopy and powerline corridor sites.

Table 10. Descriptive Statistics for Diurnal Temperature at 150cm for each treatment, in both wet and dry seasons and at selected distances from the edge to the forest interior.

	Diurnal Temperatures at 150cm in Wet and Dry Seasons									
	8 metres		12 metres		16 metres		20 metres		100 metres	
Closed Canopy	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Mean	18.5	14.8	18.7	14.7	18.6	14.7	18.6	14.7	18.6	14.7
Standard Error (±)	0.05	0.16	0.04	0.05	0.04	0.05	0.04	0.16	0.04	0.06
Minimum	17.4	11.7	17.7	11.7	17.4	11.7	17.4	11.7	17.4	11.7
Maximum	19.8	15.3	19.8	17.0	19.5	17.0	19.8	15.3	19.5	17.7
Range	2.4	8.7	2.1	5.3	2.1	5.3	2.4	8.7	2.1	6.0
Open Canopy										
Mean	17.9	14.1	17.9	13.9	16.5	13.9	17.8	13.7	17.9	13.7
Standard Error (±)	0.09	0.10	0.09	0.08	0.16	0.08	0.09	0.08	0.10	0.07
Minimum	15.3	9.9	15.3	9.9	12.4	10.2	15.3	9.9	15.3	10.6
Maximum	20.6	20.2	20.6	18.8	20.2	18.4	20.6	17.7	20.6	17.7
Range	5.3	10.3	5.3	8.9	7.8	8.2	5.3	7.8	5.3	7.1
Powerline Corridor										
Mean	26.5	16.2	27.5	16.3	18.4	16.1	18.1	16.0	18.4	15.7
Standard Error (±)	0.08	0.10	0.19	0.09	0.12	0.09	0.11	0.09	0.13	0.08
Minimum	24.8	12.0	23.0	12.4	15.3	12.4	15.3	12.0	14.9	12.4
Maximum	29.2	21.3	32.8	21.3	22.0	20.9	21.6	20.6	22.3	19.8
Range	4.4	9.3	9.9	8.9	6.7	8.5	6.3	8.6	7.4	7.4

- Minimum and maximum air temperatures at 150cm from the edge to the forest interior were constant in both the wet and dry seasons on the Closed Canopy and the Open Canopy- Grassy Verge sites.
- However, the Powerline Corridor showed a strong gradient with very high temperatures up to 12 metres from the edge in the wet season, although mean air temperatures were constant from the edge to the interior in the dry season, as were temperature minima and maxima.

Table 11. Summary results of Spearman's rank correlation between each microclimate variable and distance for all treatments in the wet and dry seasons.

	PAR (PPFD m-2.s-1)	Soil Surface Temp(?C)	Soil Temp (?C) at 10cm depth	Air Temp (?C) at 20cm	Air Temp (?C) at 150 cm	VPD (Pa) at 20cm	VPD (Pa) at 150 cm
Wet Season							
Closed Canopy							
Rho	-0.432	0.004	-0.060	-0.290	-0.111	-0.177	-0.008
P-Value	0.0009*	0.976	0.646	0.0261*	0.395	0.175	0.952
Open Canopy-Grassy Verge							
Rho	-0.510	-0.114	-0.281	-0.182	-0.143	-0.433	-0.402
P-Value	<.0001*	0.381	0.0309*	0.163	0.272	0.0009*	0.002*
Powerline Corridor							
Rho	-0.679	-0.228	-0.268	-0.207	-0.183	-0.250	-0.125
P-Value	<.0001*	0.080	0.0397*	0.112	0.160	0.0545*	0.337
Dry Season							
Closed Canopy							
Rho	-0.208	-0.150	0.036	-0.090	-0.025	-0.134	-0.215
P-Value	0.109	0.250	0.782	0.490	0.845	0.303	0.099
Open Canopy-Grassy Verge							
Rho	-0.540	-0.554	-0.509	-0.318	-0.173	-0.433	-0.233
P-Value	<.0001*	<.0001*	<.0001*	0.0145*	0.184	0.0009*	0.074
Powerline Corridor							
Rho	-0.708	-0.336	-0.474	-0.191	-0.130	-0.183	-0.218
P-Value	<.0001*	0.0099*	0.0003*	0.142	0.317	0.161	0.095

- Spearman's rank correlation tests between microclimate variables and distance for each of the treatments in both the wet and dry season showed a greater number of significant relationships for the Open Canopy-Grassy Verge and Powerline Corridor treatments in both seasons.
- Although the results are quite variable both between and within the treatments, it can be seen that PAR had the most consistently significant relationship with distance. The shaded areas indicate significant results.

Table 12.
Repeated Measures ANOVA summary table for photosynthetically active radiation at 150 cm.

Photosynthetically Active Radiation				
Significance Tests	**Source of Variation**	**d.f.**	**F Values**	**Sig. Values**
Between-Subjects Effects				
Wet Season	Treatment	2	8.228	p = 0.019*
Dry Season	Treatment	2	1.938	p = 0.224
Combined Seasons	Treatment	2	5.779	p = 0.040*
Within- Subjects Effects				
Wet Season	Distance	9	45.437	p = 0.000***
	Distance * Treatment	18	3.690	p = 0.000***
Dry Season	Distance	9	21.671	p = 0.000***
	Distance * Treatment	18	2.541	p = 0.004**
Combined Seasons	Distance	9	49.130	p = 0.000***
	Season	1	86.963	p = 0.000***
	Distance * Treatment	18	3.996	p = 0.000***
	Season * Treatment	2	4.189	p = 0.073
	Distance * Season	9	2.986	p = 0.006**
	Distance* Season * Treatment	18	1.481	p = 0.134

(α= 0.05, * P< 0.05, ** P < 0.01, *** P < 0.001).

- Treatment effects: PAR on the closed canopy was significantly different to that on the open canopy and the powerline corridor in the wet season. However, when treatments were compared within seasons, closed Ccanopy PAR was not significantly different to that of the open canopy.
- Season effects: Wet season PAR was significantly greater than dry season PAR.
- Interaction effects:
  Distance* Treatment: the type of treatment had a significant effect on PAR from the edge to the interior.
  Season* Treatment: the time of year (season) affected PAR on each treatment.

Figure 1: Plotted estimated marginal means for Soil Surface Temperature

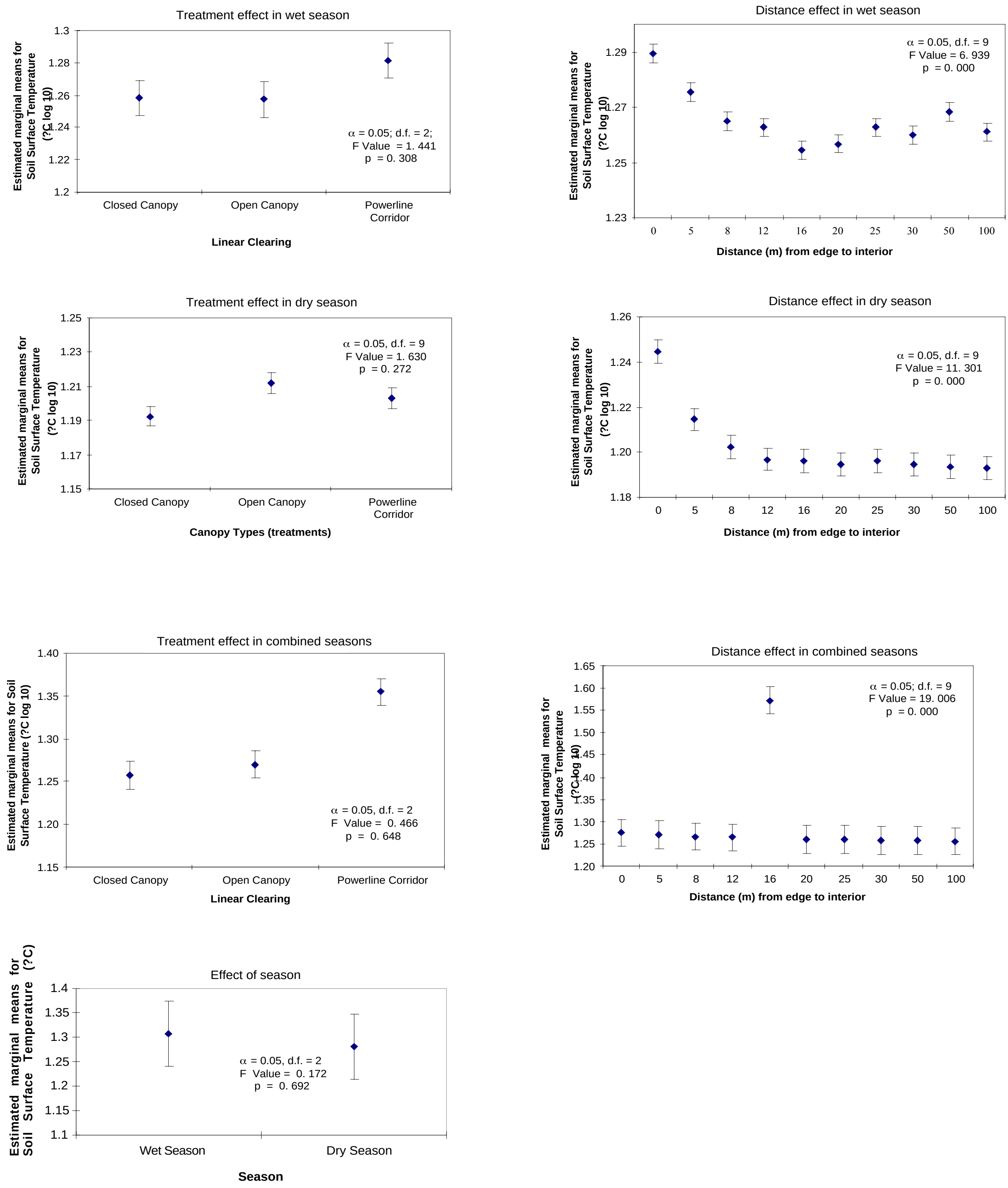


Table 13.
Repeated Measures ANOVA summary table for soil surface temperature.

Soil Surface Temperature				
Significance Tests	**Source of Variation**	**d.f.**	**F Values**	**Sig. Values**
Between-Subjects Effects				
Wet Season	Treatment	2	1.441	p = 0.308
Dry Season	Treatment	2	0.381	p = 0.699
Combined Seasons	Treatment	2	1.355	p = 0.327
Within-Subjects Effects				
Wet Season	Distance	9	6.939	p = 0.000***
	Distance * Treatment	18	1.183	p = 0.308
Dry Season	Distance	9	31.533	p = 0.000***
	Distance * Treatment	18	1.344	p = 0.199
Combined Seasons	Distance	9	0.998	p = 0.453
	Season	1	0.172	p = 0.692
	Distance * Treatment	18	0.997	p = 0.477
	Season * Treatment	2	0.549	p = 0.604
	Distance * Season	9	1.003	p = 0.449
	Distance* Season * Treatment	18	0.997	p = 0.477

($\alpha = 0.05$, * P< 0.05, ** P < 0.01, *** P < 0.001)
Treatment effect: There were no significant differences in soil surface temperatures between the treatments.
Distance effect: There were significant differences in soil surface temperatures at distance from the edge to the interior.
Season effect: There was a significant difference in soil surface temperatures at distance from the edge to the interior in the wet and the dry seasons, however, this was not due to an effect of season or the type of treatment.

Figure 2 : Plotted estimated marginal means for Soil Temperature at 10cm depth.

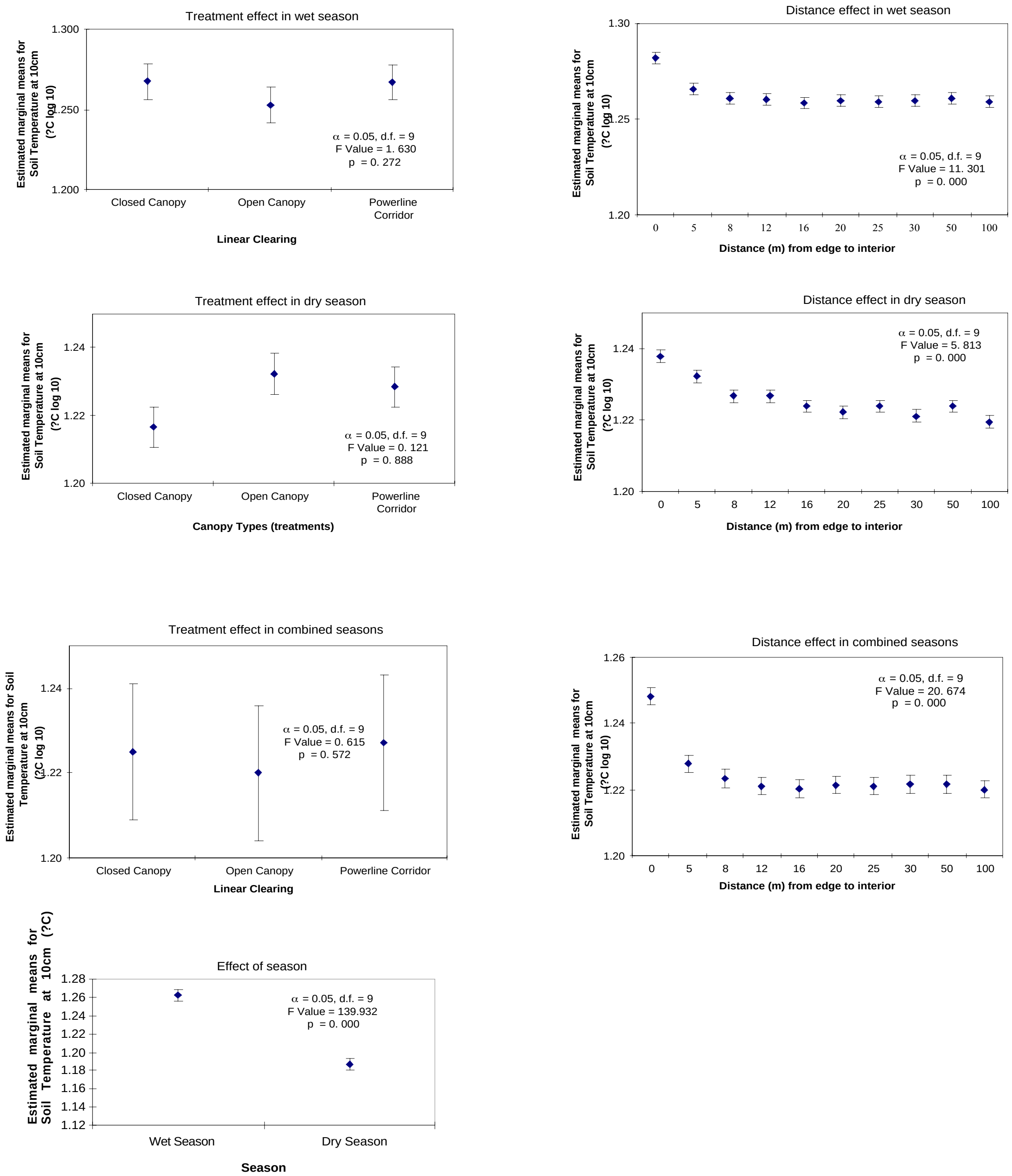
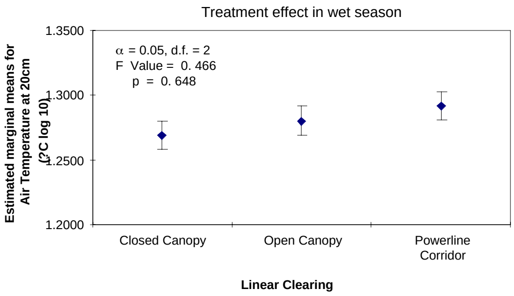


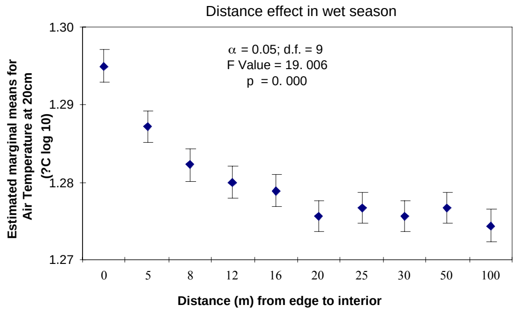
Table 14.
Repeated Measures ANOVA summary table for soil temperature at 10 cm depth.

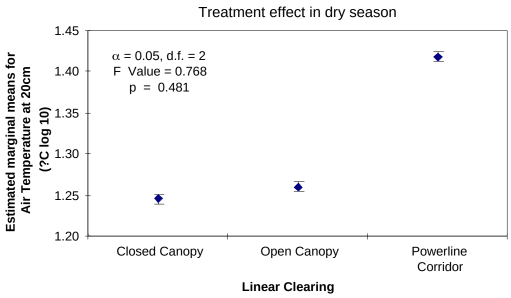
Soil Temperature at 10 cm Depth				
Significance Tests	**Source of Variation**	**d.f.**	**F Values**	**Sig. Values**
Between-Subjects Effects				
Wet Season	Treatment	2	1.630	p = 0.272
Dry Season	Treatment	2	0.121	p = 0.888
Combined Seasons	Treatment	2	0.615	p = 0.572
Within-Subjects Effects				
Wet Season	Distance	9	11.301	p = 0.000***
	Distance * Treatment	18	1.920	p = 0.034*
Dry Season	Distance	9	5.813	p = 0.000***
	Distance * Treatment	18	0.574	p = 0.903
Combined Seasons	Distance	9	20.674	p = 0.000***
	Season	1	139.932	p = 0.000***
	Distance * Treatment	18	3.603	p = 0.000***
	Season * Treatment	2	1.218	p = 0.360
	Distance * Season	9	0.893	p = 0.538
	Distance* Season * Treatment	18	0.357	p = 0.991

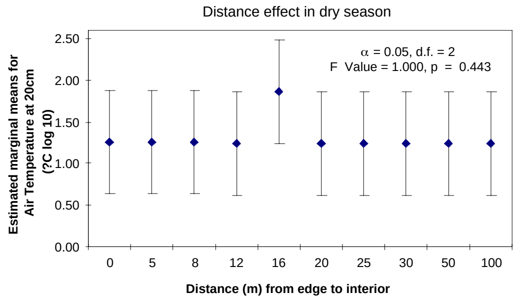
($\alpha = 0.05$, * P< 0.05, ** P < 0.01, *** P < 0.001).
Treatment effects: There were no significant differences in soil temperature at 10cm depth in either the wet or the dry seasons, nor when the treatments were compared between seasons.
Distance effects: There were significant differences in soil temperature at 10cm depth from the edge to the forest interior in both the wet and the dry seasons.
Seasons effects: There was a significant difference in soil temperatures at 10cm depth between the wet and the dry seasons, with higher soil temperatures at 10cm depth in the dry season.
Interaction effects:
Distance*Treatment: the type of linear clearing had an influence on the differences in soil temperature from the edge to the interior when treatments were compared between seasons.

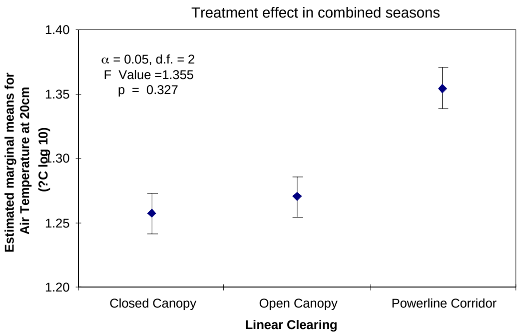
Figure 3 :
Plotted estimated marginal means for Air Temperature at 20cm

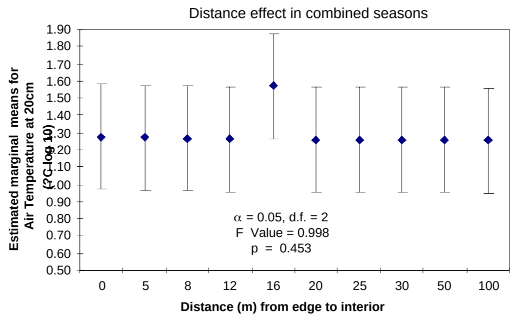












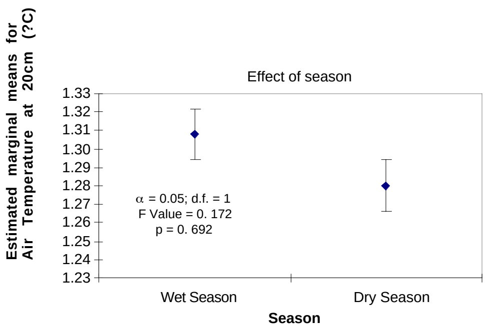


Table 15.
Repeated Measures ANOVA summary table for ambient temperature at 20 cm.

Ambient Temperature at 20 cm				
Significance Tests	**Source of Variation**	**d.f.**	**F Values**	**Sig. Values**
Between-Subjects Effects				
Wet Season	Treatment	2	0.466	p = 0.648
Dry Season	Treatment	2	0.768	p = 0.481
Combined Seasons	Treatment	2	1.355	p = 0.327
Within-Subjects Effects				
Wet Season	Distance	9	19.006	p = 0.000***
	Distance * Treatment	18	0.955	p = 0.522
Dry Season	Distance	9	1.000	p = 0.443
	Distance * Treatment	18	0.998	p = 0.466
Combined Seasons	Distance	9	0.998	p = 0.453
	Season	1	0.172	p = 0.692
	Distance * Treatment	18	0.997	p = 0.477
	Season * Treatment	2	0.549	p = 0.604
	Distance * Season	9	1.003	p = 0.449
	Distance* Season * Treatment	18	0.997	p = 0.477

(α = 0.05, * P< 0.05, ** P < 0.01, *** P < 0.001).

Distance effect: There was a significant difference in air temperature at 20cm from the edge to the interior in the wet season only, with the Powerline Corridor and the Open Canopy-Grassy Verge air temperatures being higher than those of the Closed Canopy.

Figure 4:
Plotted estimated marginal means for Air Temperature at 150cm.

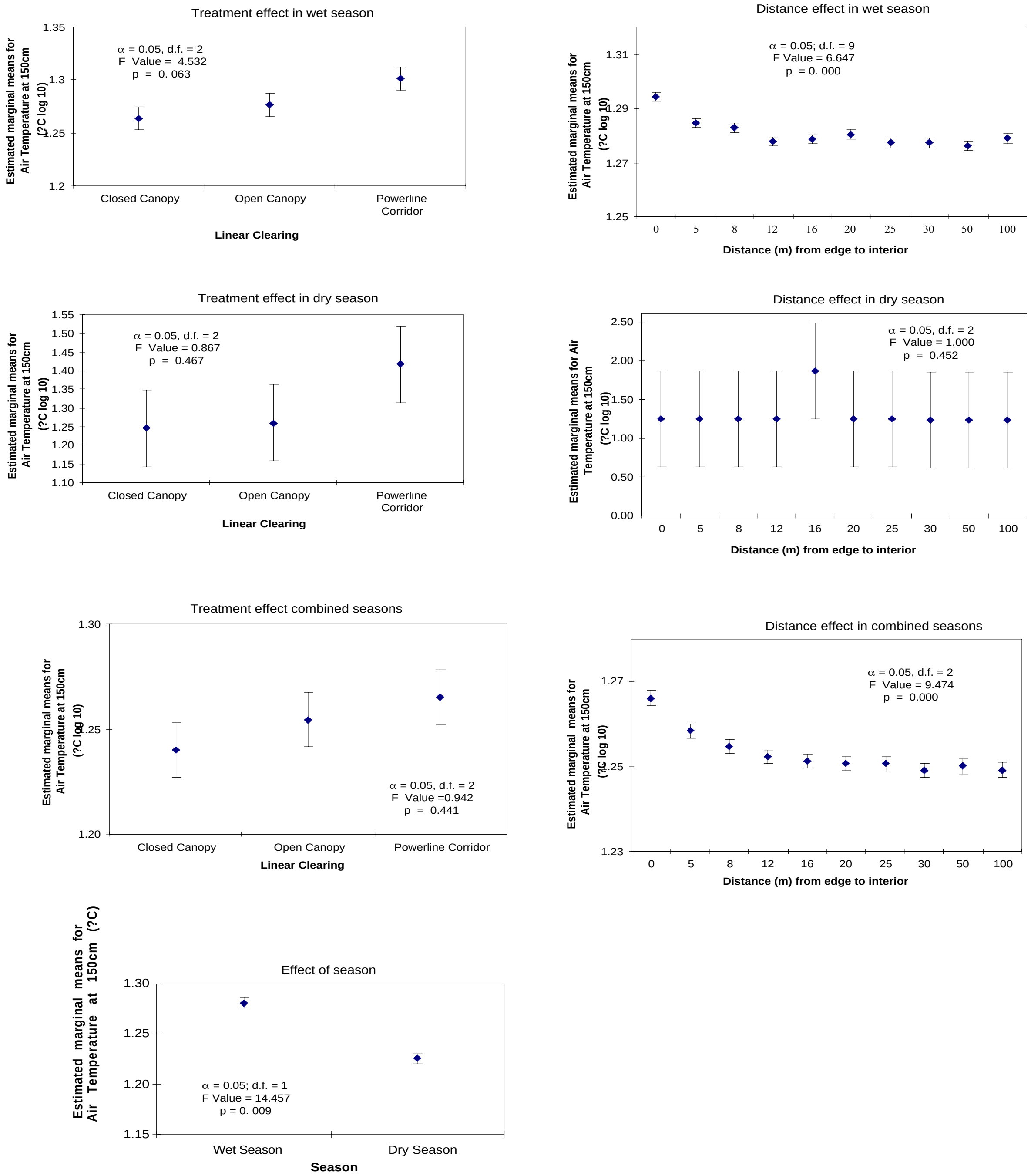


Table 16.
Repeated Measures ANOVA summary table for ambient temperature at 150 cm.

Ambient Temperature at 150 cm				
Significance Tests	**Source of Variation**	**d.f.**	**F Values**	**Sig. Values**
Between-Subjects Effects				
Wet Season	Treatment	2	4.532	p = 0.063
Dry Season	Treatment	2	0.867	p = 0.467
Combined Seasons	Treatment	2	0.942	p = 0.441
Within-Subjects Effects				
Wet Season	Distance	9	6.647	p = 0.000***
	Distance * Treatment	18	1.310	p = 0.219
Dry Season	Distance	9	1.000	p = 0.452
	Distance * Treatment	18	0.997	p = 0.477
Combined Seasons	Distance	9	9.474	p = 0.000***
	Season	1	14.457	p = 0.009**
	Distance * Treatment	18	0.995	p = 0.480
	Season * Treatment	2	0.397	p = 0.689
	Distance * Season	9	0.963	p = 0.480
	Distance* Season * Treatment	18	0.782	p = 0.711

($\alpha = 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).
Treatment effect: There were no significant differences in air temperature at 150cm between the treatments.
Distance effect: There were significant differences in air temperature at 150cm from the edge to the interior when seasons were compared, with lower wet season temperatures.
Season effect: There were significant differences in air temperature at 150cm between the seasons, with the dry season having higher temperatures than the wet season.

Figure 5 :
Plotted estimated marginal means for Vapour Pressure Deficit at 20cm.

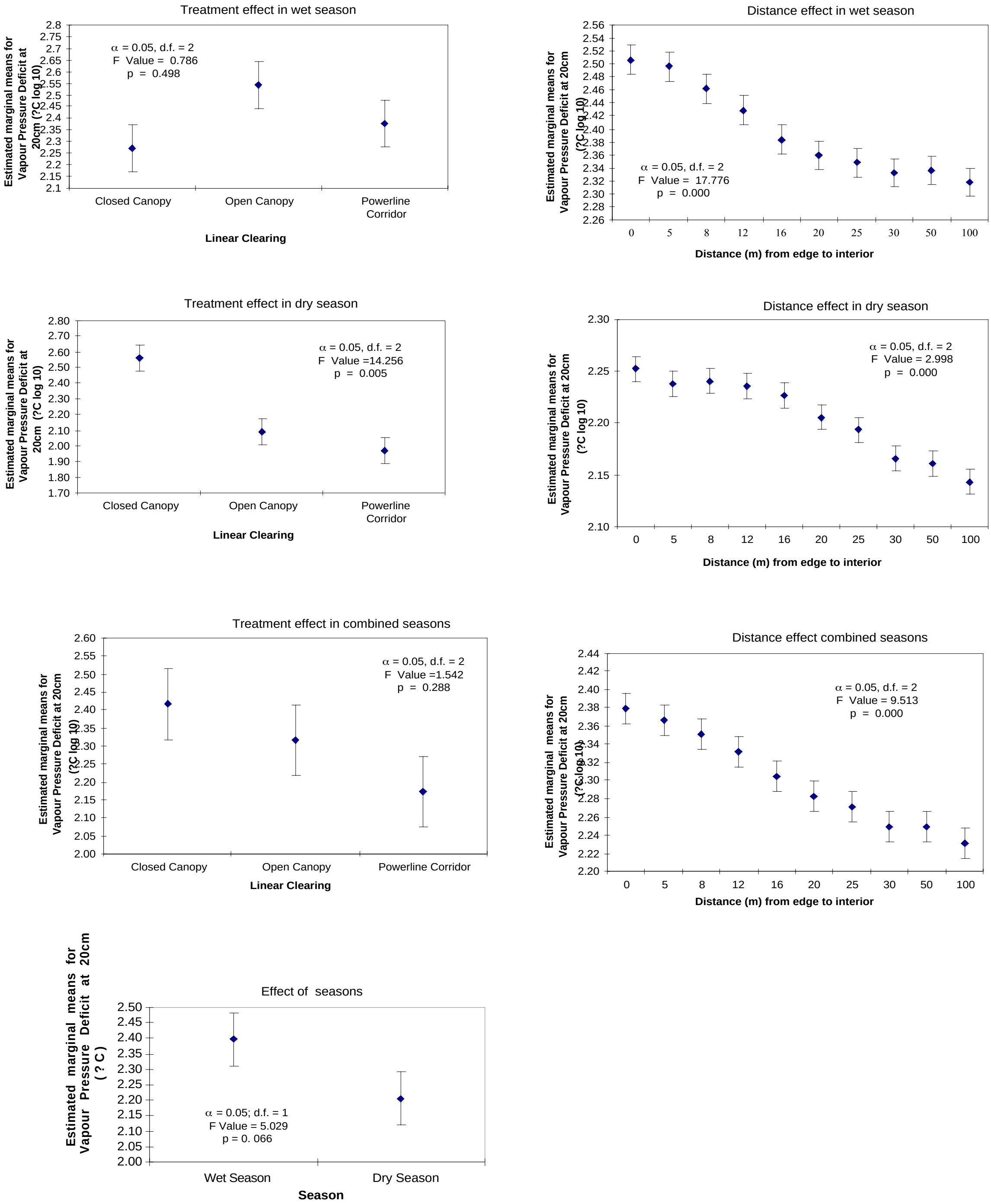


Table 17.
Repeated Measures ANOVA summary table for vapour pressure deficit (VPD) at 20 cm

Vapour Pressure Deficit at 20 cm				
Significance Tests	**Source of Variation**	**d.f.**	**F Values**	**Sig. Values**
Between-Subjects Effects				
Wet Season	Treatment	2	0.786	p = 0.498
Dry Season	Treatment	2	14.256	p = 0.005***
Combined Seasons	Treatment	2	1.542	p = 0.288
Within-Subjects Effects				
Wet Season	Distance	9	17.776	p = 0.000***
	Distance * Treatment	18	4.211	p = 0.000***
Dry Season	Distance	9	2.998	p = 0.006***
	Distance * Treatment	18	1.303	p = 0.223
Combined Seasons	Distance	9	9.513	p = 0.000***
	Season	1	5.029	p = 0.066
	Distance * Treatment	18	2.589	p = 0.004***
	Season * Treatment	2	7.838	p = 0.021
	Distance * Season	9	4.508	p = 0.000***
	Distance* Season * Treatment	18	1.584	p = 0.098

(α = 0.05, * P< 0.05, ** P < 0.01, *** P < 0.001).
Treatment effect: There was a significant difference in vapour pressure deficit at 20cm in the dry season due to higher values on the Closed Canopy treatment.
Distance effect: There were significant differences in vapour pressure deficit at 20cm from the edge to the interior in both seasons, although the effect of the type of treatment was not significant in the dry season.
Season effect: There was no significant difference in vapour pressure deficit at 20cm between the seasons.
Interaction effects:
Distance* Treatment: The type of treatment (Closed Canopy) had a significant effect on differences in vapour pressure deficit at 20cm from the edge to the interior.
Season* Treatment: The type of treatment (Closed Canopy) had a significant effect on differences in vapour pressure deficit at 20cm between the seasons.
Distance* Season: Season (dry) had a significant effect on the difference in vapour pressure deficit at 20cm from the edge to the interior.

Figure 6:
Plotted estimated marginal means for Vapour Pressure Deficit at 150cm.

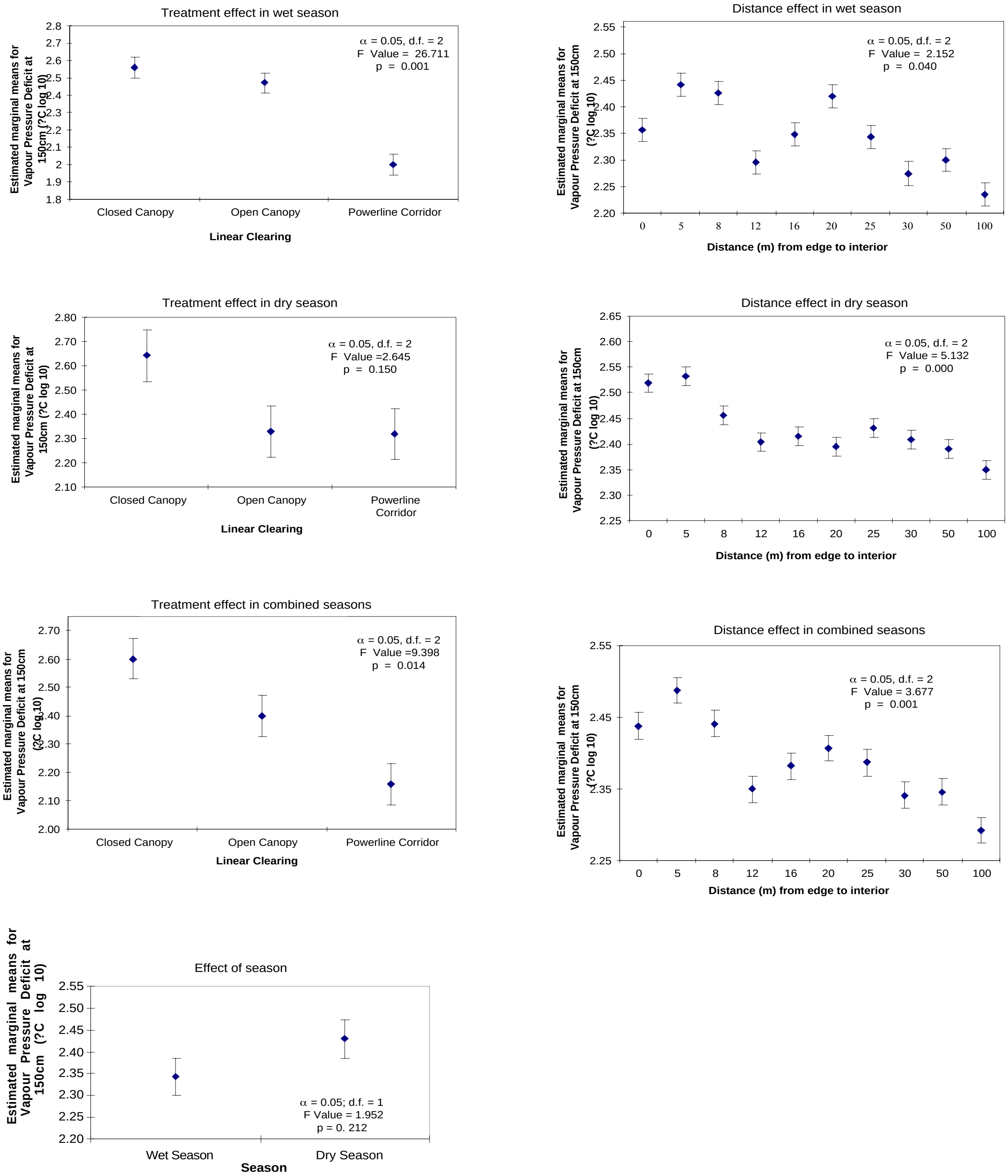


Table 18.
Repeated Measures ANOVA summary table for vapour pressure deficit (VPD) at 150 cm.

Vapour Pressure Deficit at 150 cm				
Significance Tests	Source of Variation	d.f.	F Values	Sig. Values
Between-Subjects Effects				
Wet Season	Treatment	2	26.711	p = 0.001***
Dry Season	Treatment	2	2.645	p = 0.150
Combined Seasons	Treatment	2	9.398	p = 0.014*
Within-Subjects Effects				
Wet Season	Distance	9	2.152	p = 0.040*
	Distance * Treatment	18	2.221	p = 0.012*
Dry Season	Distance	9	5.132	p = 0.000***
	Distance * Treatment	18	0.629	p = 0.861
Combined Seasons	Distance	9	3.677	p = 0.001***
	Season	1	1.952	p = 0.212
	Distance * Treatment	18	1.752	p = 0.058
	Season * Treatment	2	4.694	p = 0.059
	Distance * Season	9	1.353	p = 0.233
	Distance* Season * Treatment	18	2.051	p = 0.022*

(α = 0.05, * P< 0.05, ** P < 0.01, *** P < 0.001).
Treatment effect: There were significant differences in vapour pressure deficit at 150cm between treatments in the wet season, with the Powerline Corridor having the lowest VPD values.
Distance effect: There were significant differences in vapour pressure deficit at 150cm from the edge to the interior in both seasons due to lower VPD values on the Powerline Corridor.
Distance*Treatment effect: The type of linear clearing had a significant effect the differences in vapour pressure deficit at 150cm from the edge to the interior in the dry season only.

Table 20.
Descriptive Statistics for Hemiphot Data by Treatment

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum
% Canopy Openness						
Closed Canopy	4.325	3.775	0.487	60	1.08	15.27
Open Canopy	5.668	8.097	1.045	60	0.24	35.67
Powerline	10.06	15.294	1.974	60	0.13	64.84
Direct Below Canopy PPFD						
Closed Canopy	1.453	1.435	0.185	60	0.02	5.41
Open Canopy	2.641	4.281	0.553	60	0.01	16.65
Powerline	3.775	5.932	0.766	60	0.06	23.08
Diffuse Below Canopy PPFD						
Closed Canopy	0.517	0.43	0.056	60	0.11	1.62
Open Canopy	0.744	0.992	0.128	60	0.05	4.17
Powerline	1.1	1.429	0.185	60	0.02	5.67
Red to Far Red Ratio						
Closed Canopy	0.314	0.102	0.013	60	0.19	0.56
Open Canopy	0.316	0.167	0.022	60	0.11	0.79
Powerline	0.395	0.212	0.027	60	0.08	1.01
Leaf Area Index						
Closed Canopy	4.606	1.389	0.179	60	2.06	7.49
Open Canopy	4.795	2.397	0.309	60	1.11	13.17
Powerline	3.526	1.586	0.205	60	0.32	9.12

Descriptive statistics for each variable generated by analysis of hemispherical photographs for each of the treatments.

- The greatest differences between the treatments were seen in the mean (±1 SE) % canopy openness and in mean direct and diffuse below canopy PPFD, with the powerline corridor treatment consistently demonstrating the highest mean values and the closed canopy treatment the lowest mean values.
- Minimum values indicate the forest interior conditions, whilst maximum values relate to conditions at the edge zone.
- There was little difference in mean red to far red ratios and leaf area indices between the treatments, although the powerline corridor treatment had a lower leaf area index than either of the other two treatments.

Table 22. Summary ANOVA Table for hemiphot variables

	Source of Variation	d.f	F Value	Sig Value
Tests for Between - Subjects Effects				
% Canopy Openness	Treatment	2	9.098	p = 0.003**
Direct Below Canopy PPFD	Treatment	2	7.694	p = 0.005**
Diffuse Below canopy PPFD	Treatment	2	7.538	p = 0.005**
Red to Far Red Ratio	Treatment	2	3.423	p = 0.060
Leaf Area Index	Treatment	2	2.404	p = 0.124
Tests for Within - Subjects Effects				
% Canopy Openness	Distance	9	47.514	p = 0.000***
	Distance*Treatment	18	3.371	p = 0.009**
Direct Below Canopy PPFD	Distance	9	143.386	p = 0.000***
	Distance*Treatment	18	3.029	p = 0.015*
Diffuse Below canopy PPFD	Distance	9	98.979	p = 0.000***
	Distance*Treatment	18	4.183	p = 0.003**
Red to Far Red Ratio	Distance	9	52.363	p = 0.000***
	Distance*Treatment	18	3.17	p = 0.012*
Leaf Area Index	Distance	9	47.205	p = 0.000***
	Distance*Treatment	18	1.012	p = 0.494

(a = 0.05, * P < 0.05; **P<0.01; ***P < 0.001)

- There were significant differences between the treatments for % canopy openness and direct and diffuse below canopy PPFD due to the effect of the powerline corridor.
- However, there was no significant difference in red to far red ratios or leaf area indices between treatments although measured differences were observed.
- Significant differences from the edge to the interior were observed for all the hemiphot variables, with the type of linear clearing having a significant effect on these differences in all cases except leaf area index which was not effected by the type of linear clearing, although it was lower on the powerline corridor.

Appendix Section 3: Edge Effects of Roads and Powerlines on Rainforest Vegetation

Appendix Section 3. Edge Effects of Roads and Powerline Clearings on Rainforest Vegetation

Table 1

Summary Table of Shannon-Weiner Diversity Indices

Treatment	Diversity Index (H)	Evenness Index (J)
Closed Canopy	5.582	1.166
Open Canopy	5.450	1.140
Powerline Corridor	5.686	1.147

Key Points:

- There are differences in species diversity and evenness between each of the treatments.
- The open canopy showed the lowest diversity and evenness indices.
- The powerline corridor showed the highest diversity and second highest evenness indices.
- The closed canopy had intermediate diversity and the highest evenness, therefore, the closed canopy had greater species diversity than the powerline corridor or the open canopy.
- However, these differences were not significantly different, as indicated by the results of the Shannon-Weiner T-Test shown below.

Table 2

Summary Table for Shannon-Weiner T-Test

Ho: There is no difference in species diversity between the three treatments.
H1: There is a significant difference in species diversity between the three treatments.

Source of variation	d.f.	T Value	P Value
Treatments	728	-178.193	P < 0.05
	t0.05 (2),728 = 1.965		

Therefore, accept Ho, there is no significant difference in species diversity between the three treatments.

Table 3: Results of χ^2 Goodness of Fit and Homogeneity Tests

Observed Frequencies for treatment x category

	Pioneer	Rainforest	Vines	Weeds	Totals
Closed Canopy	44	167	41	5	257
Open Canopy	34	141	31	19	225
Powerline Corridor	39	180	56	14	289
Totals	117	488	128	38	771

Expected Values for treatment x category

	Pioneer	Rainforest	Vines	Weeds	Totals
Closed Canopy	39	162.667	42.667	12.667	257
Open Canopy	34.144	142.412	37.354	11.089	225
Powerline Corridor	43.856	182.921	47.979	14.244	289
Totals	117	488	128	38	771

Cell Chi Squares for treatment x category

	Pioneer	Rainforest	Vines	Weeds
Closed Canopy	0.641	0.115	0.065	4.64
Open Canopy	0.001	0.014	1.081	5.643
Powerline Corridor	0.538	0.047	1.341	0.004

Post Hoc Cell Contributions for treatment x category

	Pioneer	Rainforest	Vines	Weeds
Closed Canopy	1.065	0.687	-0.342	-2.706
Open Canopy	-0.032	-0.232	-1.353	2.895
Powerline Corridor	-1.007	-0.451	1.604	-0.084

Chi Square Summary Table

DF	6	a= 0.05, d.f. = 6;
Chi Square	14.13	p= 0.0282
Chi Square P-Value	0.0282	Therefore, reject Ho,
G-Squared	14.518	there is a significant difference
G-Squared P-Value	0.0244	in the number of species
Contingency Coef.	0.134	in each disturbance indicator
Cramer's V	0.096	category within and
		between treatments.

Ho: That there is no difference in the number of species in each of the disturbance indicator categories either within or between the three treatments.
H1: That the number of species in each of the disturbance indicator categories differs within each treatment and between the treatments.

Table 4

Species List for Study Area, West Palmerston

Ageratum houstoniana	Blechnum sp	Darlingia sp
Ageratum sp	Bowenia spectabilis	Davidsonia pruriens
Aglaia brassii	Breynia stipitata	Decaspermum humile
Aglaia meridionalis	Brombrya platynema	Desmodium sp.
Aglaia tomentosa	Bubbia semicarpioides	Dichapetalum papuanum
Alangium villosum ssp. polyosmoides	Bulbites quoniane?	Dinosperma melanophloia
Alocasia sp	Calamus australis	Dinospermum
Alphitonia petrei	Calamus moti	Diospyros sp. (Millaa Millaa)
Alphitonia sp.	Calanthe sp	Diplazium ditellatum
Alphitonia whitei	Caldcluvia australiensis	Doryphora aromatica
Alpinia actiflora	Callicarpa pedunculata	Drynaria rigidula
Alpinia modesta	Capparis moorei	Drypetes sp
Amyema sp	Cardwellia siblimis	Dysoxylum klanderi
Apodytes brachystylis	Castanospora alphandii	Dysoxylum oppositifolium
Apodytes sp	Chionanthus axillaris	Dysoxylum papuanum
Archidendron grandiflorum	Christella dentata	Dysoxylum rufum
Archidendron vaillantii	Cinnamomum baileyanum	Elaeocarpus eumundi
Archidendron whitei	Cinnamomum laubatii	Elaeocarpus largiflorens
Ardisia brevipedata	Cinnamomum sp	Elaeocarpus sp.
Ardisia pachyracchis	Cissus vinosa	Elatostoma stipitata
Argyrodendron sp	Citronella smithii	Elattostachys sp.
Arthropteris palisotii	Clerodendrum sp.	Embelia australasica
Arthropteris sp.	Commelina cyanea	Embelia grayii
Artocarpus sp	Cordyline cannifolium	Embelia sp.
Arytera macrobotys	Cryptocarya corrugata	Endiandra bessaphila
Asplenium australasicum	Cryptocarya grandis	Endiandra leptodendron
Asplenium simpliciformis	Cryptocarya lividula	Endiandra montana
Athertonia diversifolia	Cryptocarya mackinnoniana	Endiandra pubescens
Austrobaileyii scandens	Cryptocarya melanocarpa	Endiandra sp.
Austromyrtus dallachiana	Cryptocarya murrayi	Epipremum sp.
Austromyrtus sp	Cryptocarya pleurosperma	Erythoxylum ecarynatum
Austrosteenisia stipularis	Cryptocarya rhodosperma	Euodia muelleri
Bacopa floribunda	Cryptocarya sp	Eupomatia sp.
Beilschmiedia recurva	Cryptomanes sp	Ficus congesta
Beilschmiedia tooram	Crytocarya rhodosperma	Ficus leptoclada
Belvisia mucronata	Cupaniopsis flagelliformis	Ficus obliqua
Bischofia javanica	Cupaniopsis sp	Flagellaria indica
Bleasdalia bleasdalii	Cyathea cooperi	Flagellaria sp
Blechnum cartilagineum	Daphnandra repandula	Flindersia brayleyana
	Darlingia ferruginea	Flindersia laevicarpa var.laevicarpa

Table 4 continued

Species List for Study Area, West Palmerston

Franciscodendron laurifolium	Pachygone longifolia	Sarcopteryx martyana
Freycinetia excelsa	Palmeria scandens	Sarcopteryx prostata
Freycinetia scandens	Pandanus monticola	Sarcotoechia protracta
Freycinetia sp	Panicum maximum	Scaevola entodaphyllum
Gardenia merikin	Parsonsia latifolia	Schefflera actinophylla
Glochidion hylandii	Parsonsia sp.	Sida retusa
Gonocormus saxafragioides	Phyllanthus amarus	Siegesbeckia orientalis
Guoia lasioneura	Physianthus racemigera ??	Siphonodon membranaceus
Haplostichanthus sp	Pilidiostigma tropicum	Sloanea australis
Haplostichanthus sp (Johnstone River)	Piper caninum	Sloanea australis ssp parviflora
Harpullia rhyticarpa	Piper sp.	Sloanea macbrydei
Helicia lamingtoniana	Plantago majora	Sloanea sp.
Helicia nortoniana	Pollia macrophylla	Smilax australis
Hollandeae sayeriana	Pollia sp	Smilax glyciphylla
Hydrocotyle sp.	Polyosma hirsuta	Smilax sp.
Hypserpa sp.	Polyosma rthytophloia	Steganthera australiana
Laccospadix microcarya	Polyscias murrayi	Steganthera macooraia
Lantana camara	Polyscias sp	Stellaria media
Legnephora moorei	Pothos longipes	Stephania japonica
Lepiderema ixiocarpa	Pouteria brownlessiana	Symplocos hylandii
Levieria acuminata	Pouteria castanospora	Symplocos sp
Litsea leefeana	Prunus turneriana	Synima cordierorum
Macaranga dallachyana	Pseuduvaria mulgraveana var glabrescens	Synoum muelleri
Medicosma fareana	Pseuduvaria villosa	Synoum sp
Meliaceae sp	Psychotria dallachiana	Syzygium gustavioides
Melodinus acutiflorus	Psychotria sp. (Utchee Creek?)	Syzygium johnsonii
Melodinus australis	Pyrrosia sp.	Syzygium sp.
Melodinus sp	Randia hirta	Tetrastigma nitens
Menispermaceae sp.	Randia tuberculosa	Tetrastigma sp.
Microgonum sp	Raphidophora australis	Tetrasynandra longipes
Microsorium australiensis	Raphidophora petriei	Tetrasynandra sp #1
Mischocarpus misarytera	Raphidophora sp	Tetrasynandra sp #2
Mischocarpus stipitata	Ripogonum album	Tetrasynandra sp.
Monimiaceae sp	Ripogonum sp.	Tetrophyllum brighnightiana
Monogrammia sp	Rockinghamia angustifolia	Toechima erythrocarpum
Morinda hypotephera	Rubus procerus	Vittaria elongata
Neolitsea dealbata	Rubus queenslandicus	Wilkea angustifolia
Niemeyera prunifera	Rubus rosifolius	Wilkiea sp
Opisthiolepis heterophylla	Rubus sp. (exotic)	Wilkiea wardellii
Oplis-menus composita	Rubus sp. (native)	Xanthophyllum fragrans
		Zanthoxylum sp.

Table 5 Descriptive Statistics for Seedlings and Saplings

Table of Descriptive Statistics for Seedlings

	Closed Canopy	Open Canopy	Powerline Corridor
Mean Number for distance (N= 60)	42	37	41
Standard Deviation	31.149	22.506	31.73
Standard Error	4.021 (±)	2.906 (±)	4.096 (±)
Coefficient of Variation	0.734	0.608	0.783
Sum	2547	2221	2430
Mean Number for treatment (N= 6)	425	370	405

Table of Descriptive Statistics for Saplings

	Closed Canopy	Open Canopy	Powerline Corridor
Mean Number for distance (N= 60)	12	10	11
Standard Deviation	0.96	0.87	1.14
Standard Error	7.432 (±)	6.697 (±)	8.833 (±)
Coefficient of Variation	0.635	0.695	0.799
Sum	702	578	663
Mean Number for treatment (N = 6)	117	96	111

Key Points:
- The closed canopy had the highest numbers of seedlings and saplings, although there was little difference between each of the treatment means.
- The co-efficient of variation values suggest that there was a high degree of variability within each of the treatment sample populations for seedlings and saplings in this study.

Table 6

Summary ANOVA Table for Seedlings and Saplings

Significance Tests	Source of Variation	d.f.	F value	Significance Value
Seedlings				
Between Treatment Effects	Treatment	2	0.524	0.617
Within Treatment Effects	Distance	9	61.323	0.000***
Interaction Effects	Distance*Treatment	18	1.767	0.055*
Saplings				
Between Treatment Effects	Treatment	2	0.47	0.646
Within Treatment Effects	Distance	9	36.238	0.000***
Interaction Effects	Distance*Treatment	18	1.819	0.047*

(a= 0.05, p <0.01*, p<0.001**, p<0.0001***)

Key Points:
- Although there was no significant difference in seedling and sapling numbers between the treatments, there was a significant difference in seedling and sapling numbers between the edge and the forest interior, and this difference was influenced by treatment. Thus, numbers of seedlings and saplings were shown to have edge effect that varied with treatment type.

Table 7 Spearman rank correlation for seedlings and saplings with distance

	Seedlings	Saplings
Closed Canopy		
Sum of Squared Differences	27014	23025
Rho	0.249	0.36
Z-Value	1.916	2.767
P-Value	0.0554*	0.0057**
Open canopy		
Sum of Squared Differences	19903.5	20413.5
Rho	0.447	0.433
Z-Value	3.433	3.324
P-Value	0.0006***	0.0009***
Powerline Corridor		
Sum of Squared Differences	23775.5	29478.5
Rho	0.339	0.181
Z-Value	2.607	1.39
P-Value	0.0091**	0.1646

(a=0.05, $p < 0.01$*, $p < 0.001$**, $p < 0.0001$***)

Key Points:

- The relationship between seedling and sapling numbers on the open canopy treatment was significantly correlated and showed a moderately steep increase in numbers with increasing distance from the edge.
- The powerline corridor showed a significant correlation with distance for seedlings only with a moderate increase in numbers with increasing distance.
- Seedling and sapling numbers on the closed canopy had significant correlations with distance and a slight increase in numbers from the edge to the forest interior.

Table 8 Summary table for Spearman's rank correlation between seedling numbers and microclimate variables

	Photosynthetically Active Radiation	Soil Surface Temperature	Soil Temperature at 10cm depth	Air Temperature at 20cm	Air Temperature at 150cm	Vapour Pressure Deficit at 20cm	Vapour Pressure Deficit at 150cm
Closed canopy							
Spearman's R Value	-0.315	0.178	0.239	0.156	0.278	-0.277	-0.05
P-Value	0.0154*	0.1704	0.0661	0.2307	0.0327*	0.0334*	0.703
Open canopy-Grassy verge							
Spearman's R Value	-0.393	-0.447	-0.358	-0.292	-0.144	-0.291	-0.196
P-Value	0.0026**	0.0006***	0.006**	0.025*	0.268	0.0253*	0.1314
Powerline Corridor							
Spearman's R Value	-0.332	-0.328	-0.186	-0.188	-0.177	-0.183	-0.133
P-Value	0.0107*	0.0117*	0.1526	0.148	0.1731	0.1609	0.3059

Key Points:

- On the closed canopy, seedling numbers increased as PAR and VPD at 20cm decreased, but increased with increasing air temperature at 150cm. The strongest correlation was between seedling numbers and PAR.
- On the open canopy, seedling numbers increased with decreasing PAR, soil temperatures, air temperature at 20cm and vapour pressure deficit at 20cm. The strongest correlations were for PAR and soil temperatures.
- Seedling numbers on the powerline corridor were only slightly correlated with PAR and soil surface temperature.
- Although the significance and strength of the correlations between microclimate elements and seedling numbers varied between the treatments, it can be seen that PAR, soil temperatures, air temperature at 20cm and VPD at 20cm are more important to number of seedlings on the open canopy, whilst PAR and soil surface temperature are more important on the powerline corridor. In contrast, seedling numbers on the closed canopy treatment are influenced by PAR, air temperature at 150cm and VPD at 20cm.
- Dry season microclimate data was used in this analysis as the seedling census was conducted during June/July 1999.

Table 9. Summary Table for Spearman's rank correlation for numbers of saplings and microclimate variables.

	Photosynthetically Active Radiation	Soil Surface Temperature	Soil Temperature at 10cm depth	Air Temperature at 20cm	Air Temperature at 150cm	Vapour Pressure Deficit at 20cm	Vapour Pressure Deficit at 150cm
Closed canopy							
Spearman's R Value	-0.162	-0.154	-0.075	-0.074	-0.097	-0.039	-0.108
P-Value	0.2136	0.2356	0.5656	0.5719	0.4546	0.764	0.408
Open canopy-Grassy verge							
Spearman's R Value	-0.314	-0.403	-0.347	-0.281	-0.191	-0.271	-0.295
P-Value	0.0159*	0.002**	0.0077*	0.0307*	0.1433	0.0371*	0.0234*
Powerline Corridor							
Spearman's R Value	-0.405	-0.66	-0.47	-0.531	-0.579	-0.553	-0.544
P-Value	0.0019**	<.0001***	0.0003**	<.0001***	<.0001***	<.0001***	<.0001***

Key Points:

- Sapling numbers on the closed canopy were not significantly correlated with the microclimate variables.
- Sapling numbers on the powerline corridor were significantly correlated with all microclimate variables.
- Sapling numbers on the open canopy were significantly correlated with all microclimate variables with the exception of air temperature at 150cm.
- The powerline corridor results suggest that there was a steep increase in sapling numbers as all microclimate variables decreased, whilst PAR and soil temperature had the greatest influence on sapling numbers on the open canopy treatment.
- Dry season microclimate data was used in this analysis as the seedling census was conducted during June/July 1999.

Table 10 Summary table for results of Spearman's rank correlation between seedling numbers and each hemiphot variable.

Closed Canopy	Direct Below Canopy PPFD	Diffuse Below Canopy PPFD	% Canopy Openness	Red to Far Red Ratio	Leaf Area Index
Spearman's R Value	-0.472	-0.536	-0.527	-0.528	0.426
P-Value	0.0003***	0.0001***	0.0001***	0.0001***	0.0011**
Open Canopy					
Spearman's R Value	-0.394	-0.326	-0.281	-0.274	0.592
P-Value	0.0025**	0.0124*	0.0309*	0.035*	<.0001***
Powerline Corridor					
Spearman's R Value	-0.101	-0.1	-0.17	-0.164	0.23
P-Value	0.4364	0.4405	0.1915	0.2068	0.0776

Key Points:
- Seedling numbers on all three treatments were correlated with each hemiphot variable.
- The powerline corridor treatment by itself was not significantly correlated with any hemiphot variable.
- However, seedling numbers on the closed canopy showed correlations with each variable, with highly significant increase in seedling numbers with a decrease in light quantity (direct and diffuse below canopy PPFD) and quality (red to far red ratio) and in % canopy openness and with an increase in canopy thickness (leaf area index).
- The open canopy showed the same trends, although the increase in seedling numbers was not so strongly correlated with the hemiphot variables, except for leaf area index.
- These results suggest that a proportion of the seedlings on the powerline corridor were tolerant of relatively high light levels, a lower proportion of far red light and a more open canopy, whilst the seedlings on the closed canopy and open canopy treatments were less light tolerant and required lower light levels, a greater ratio of far red light and a more closed canopy for their survival.

Table 11 Summary table for results of Spearman's rank correlation between sapling numbers and each hemiphot variable

	Direct Below Canopy PPFD	Diffuse Below Canopy PPFD	% Canopy Openness	Red to Far Red Ratio	Leaf Area Index
Closed Canopy					
Spearman's R Value	-0.196	-0.243	-0.184	-0.175	0.426
P-Value	0.1329	0.0616	0.1566	0.178	0.0011**
Open canopy					
Spearman's R Value	-0.271	-0.274	-0.221	-0.226	0.542
P-Value	0.0372*	0.0355*	0.0897	0.083	<.0001***
Powerline Corridor					
Spearman's R Value	-0.179	-0.221	-0.217	-0.205	0.542
P-Value	0.1689	0.0902	0.0962	0.1155	<.0001***

Key Points:
- Sapling numbers increased with increased canopy thickness (LAI) on all the treatments.
- However, sapling numbers on the open canopy also tended towards a slight increase with decreasing levels of sunlight (direct and diffuse below canopy PPFD).
- These results suggest that increased light levels affect a proportion of the saplings on the open canopy. However, thickness of the canopy influences sapling numbers on all three treatments.

Appendix Section 4: Geochemical Impacts on Roadside Soils in the Wet Tropics of Queensland World Heritage Area as a Result of Transport Activities

Appendix Section 4: Geochemical Impacts on Roadside Soils in the Wet Tropics World Heritage Area as a Result of Transport Activities

Kuranda Range:

Table 1. Background Samples

Background Sample Number & Geology Type	Heavy Metals					
	Copper (ppm)	Lead (ppm)	Zinc (ppm)	Cadmium (ppm)	Manganese (ppm)	Nickel (ppm)
1 = Granite	10	15	39	1	303	7
2 = Hodgkinson	71	10	69	1	991	71
3 = Hodgkinson	19	5	7	1	70	<5
4 = Hodgkinson	<5	<5	5	<1	25	<5
5 = Hodgkinson	8	7	10	1	131	<5

Table 2. Sediment Samples

Sediment Sample Number & Geology Type	Road Classification*	Heavy Metals					
		Copper (ppm)	Lead (ppm)	Zinc (ppm)	Cadmium (ppm)	Manganese (ppm)	Nickel (ppm)
1 = Obs. Hornfels	C	63	91	220	1	501	30
2 = Hodgkinson	SC	11	24	29	<1	213	9
3 = Hodgkinson	S	15	32	21	1	119	8
4 = Hodgkinson	S	14	28	17	1	208	7
5 = Granite	C	13	19	39	1	208	7

*SC = adjacent to a sharp curve; C = adjacent to a moderate – slight curve; S = adjacent to a straight section.

Table 3. Geochemistry of Kuranda Range topsoil samples (using AAS method G102, partial metal concentration)

Topsoil Sample Number & Geology Type	Road Classification*	Heavy Metals					
		Copper (ppm)	Lead (ppm)	Zinc (ppm)	Cadmium (ppm)	Manganese (ppm)	Nickel (ppm)
1 = Obs. Hornfels	SC	35	71	132	1	412	23
2 = Obs. Hornfels	C	60	37	99	1	1950	30
3 = Obs. Hornfels	C	26	36	66	1	346	13
4 = Hodgkinson	C	17	31	59	1	99	9
5 = Hodgkinson	SC	33	40	89	1	252	16
6 = Hodgkinson	SC	122	9	113	2	1100	46
7 = Hodgkinson	S	44	22	64	1	566	19
8 = Hodgkinson	C	105	39	64	1	1960	37
9 = Hodgkinson	C	208	14	169	2	1680	57
10 = Hodgkinson	C	33	89	36	<1	167	14
11 = ?	?	10	40	22	1	27	<5
12 = Hodgkinson	C	48	149	54	<1	202	6
13 = Hodgkinson	SC	11	48	25	<1	28	<5
14 = Hodgkinson	C	<5	5	<5	1	10	<5
15 = Hodgkinson	S	10	14	6	<1	12	6
16 = Hodgkinson	S	5	16	5	1	27	<5
17 = Hodgkinson	S	6	12	<5	1	28	<5
18 = Hodgkinson	S	16	75	18	1	114	5
19 = Hodgkinson	S	8	31	9	1	38	<5
20 = Hodgkinson	S	17	165	28	1	25	<5
21 = Hodgkinson	C	6	47	21	1	51	<5
22 = Granite	C	34	42	45	1	206	7
23 = Granite	C	19	17	65	1	236	11
24 = Granite	S	18	38	71	1	267	9
25 = Granite	S	21	33	70	1	602	7
26 = Hodgkinson	S	46	63	71	2	475	13
27 = Hodgkinson	C	116	24	86	2	1420	58
28 = Hodgkinson	C	84	34	140	1	1680	38
29 = Obs. Hornfels	SC	31	62	111	1	1070	16
30 = Obs. Hornfels	C	15	22	45	1	134	9

*SC = adjacent to a sharp curve; C = adjacent to a moderate – slight curve; S = adjacent to a straight section.

Gillies Range

Table 4. Gillies Range Background and Sediment Samples

Background Sample	Heavy Metals					
	Copper (ppm)	Lead (ppm)	Zinc (ppm)	Cadmium (ppm)	Manganese (ppm)	Nickel (ppm)
6 = Hodgkinson	12	11	37	<1	471	6
7 = Hodgkinson	14	12	28	<1	980	10
8 = Granite	32	7	63	1	711	272
9 = Granite	<5	5	8	<1	30	<5
10 = Granite	<5	6	10	<1	62	<5

Sediment Sample	Road classification*	Heavy Metals					
		Copper (ppm)	Lead (ppm)	Zinc (ppm)	Cadmium (ppm)	Manganese (ppm)	Nickel (ppm)
6 = Hodgkinson	SC	31	72	116	1	593	104
7 = Hodgkinson	SC	29	32	147	<1	375	33
8 = Granite	C	9	6	26	<1	170	36
9 = Granite	S	19	31	180	<1	330	41
10 = Granite	S	31	21	92	1	1030	245

*SC = adjacent to a sharp curve; C = adjacent to a moderate – slight curve; S = adjacent to a straight section.

Table 5. Geochemistry of Gillies Range topsoil samples (using AAS method G102, partial metal concentration)

Topsoil Sample Number & Geology Type	Road Classification*	Heavy Metals					
		Copper (ppm)	Lead (ppm)	Zinc (ppm)	Cadmium (ppm)	Manganese (ppm)	Nickel (ppm)
31 = Hodgkinson	SC	21	52	35	<1	174	<5
32 = Hodgkinson	SC	24	27	34	<1	410	9
33 = Hodgkinson	SC	14	29	64	<1	372	9
34 = Hodgkinson	C	31	25	43	<1	536	16
35 = Hodgkinson	SC	21	40	72	<1	446	13
36 = Hodgkinson	SC	12	18	76	<1	629	10
37 = Granites	SC	17	45	126	<1	253	9
38 = Granites	SC	12	19	55	<1	385	<5
39 = Granites	C	29	24	54	<1	160	<5
40 = Granites	C	10	26	166	<1	237	5
41 = Granites	S	26	18	79	<1	468	47
42 = Granites	SC	28	23	80	<1	118	<5
43 = Granites	C	14	14	43	<1	221	26
44 = Granites	C	16	22	53	<1	226	<5
45 = Granites	SC	10	19	69	<1	340	11
46 = Granites	C	<5	23	88	<1	303	<5
47 = Granites	C	<5	18	61	<1	283	<5
48 = Granites	S	<5	25	81	<1	406	<5
49 = Granites	C	<5	13	54	<1	265	<5
50 = Granites	S	<5	21	53	<1	256	<5
51 = Granites	S	43	22	66	<1	1560	20
52 = Granites	S	33	22	75	2	3560	183
53 = Granites	S	44	13	83	2	420	121
54 = Granites	SC	<5	221	16	<1	39	<5
55 = Granites	SC	8	88	55	<1	195	47
56 = Granites	SC	<5	21	71	<1	181	12
57 = Granites	C	<5	12	22	<1	117	6
58 = Granites	C	<5	27	32	<1	93	<5
59 = Granites	SC	17	13	16	<1	103	<5
60 = Granites	SC	7	8	26	<1	146	54

*SC = adjacent to a sharp curve; C = adjacent to a moderate – slight curve; S = adjacent to a straight section.

Appendix Section 7: Species Habitat and Distribution and Road Crossing Summaries

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES:	***Hemibelideus lemuroides***
COMMON NAME:	**LEMUROID RINGTAIL POSSUM**
CONSERVATION STATUS:	**RARE**
FEATURES:	Dark-coloured (rarely white) possum of upland treetops
HABITAT:	
Vegetation type:	Cool, wet, upland rainforest.
Distribution:	Mt Carbine Tableland south on Atherton Tableland to Cardwell Range.
Macrohabitat:	Upper canopy of rainforest, almost never ventures to the ground.
Microhabitat:	Feeds only at night on leaves of a variety of tree species, spends day in a tree hollow, can leap 2-3 metres from branch to branch.
Altitude:	Above 550 metres
MOVEMENTS:	
Movement Patterns:	Strictly arboreal, almost never ventures to ground.
Method of Movement:	Walking on branches, can leap 2-3 metres from branch to branch.
BREEDING:	
Habitat:	Tree hollow, often sleeps in family groups
Patterns:	A single young in pouch and then riding on mother's back.
Time:	Between August and November
IMPACTS OF ROADS:	Roads constitute a severe barrier where the clearing between canopy trees is greater than 2-3 metres, the distance they can leap between branches, as they do not descend to ground level. Roads allow spotlighting disturbance.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. treetops touching. Construct arboreal walkways between trees with suitable natural vine cover to protect from flying predators, where canopy closure can not be achieved. Monitor use by arboreal species.

Regulate spotlighting tours to ensure animals are not continually disturbed (i.e. more than 3-4 nights per week) and monitor effects on animals habitat use close to road.

Avoid widening of roads in upland rainforest areas.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

LEMUROID RINGTAIL POSSUM *Hemibelideus lemuroides*

No. who **spotlight** or have **spotlighted** the species	regularly:	16
	intermittently:	3

No. who have seen the species **crossing roads**: 14
No. who have seen the species **crossing on the road surface:** 3

Locations crossing on the road surface:
Mt Lewis 2; Kauri Creek Road, Lamb Range 1; Millaa Millaa Falls 1; Curtain Fig 1.

No. who have seen the species **crossing via a canopy connection**: 13

Locations crossed via a canopy connection:
Mt Lewis 3; Kauri Creek Road Lamb Range 2; Mt Baldy 4; Mt Father Clancy 1; Maalan forestry track 1; Tully Falls Road 5; Culpa Road 1; The Crater road 2; Kirrama road 2; Maalan road near Millaa Millaa 2.

Width of clearing crossed on the surface: 0-5m 3; 5-10m 2.
Width of clearing crossed via a canopy connection: 0-5m 9; 5-10m 12.

Tree species at road edge used for crossing: *Alphitonia* spp. 12
Mature rainforest 3

Tree species also used:
Syzygium spp., *Endiandra* spp. *Polyscias* spp.

Plant species with potential to be used for crossing: Alphitonia *spp.*
Elaeocarpus spp.
Flindersia spp.

No. who have seen *roadkills* of this species: 1
Locations where roadkills observed: The Crater near creek crossing on Kennedy Highway.

Comments:
- Have observed one arboreal crossing where the animal leapt between two trees whose canopies were not quite touching (JK)
- Lemuroids will leap to cross between two canopies which are almost touching (JW)
- Have observed on low branches but never on the ground (BM)
- Lemuroids are agile on thin branches and also will use vines between two trees (MT)
- Road crossings on the road surface are extremely unusual and only ever observed where there were no canopy connections in the vicinity (MT)
- Have observed in Bloodwoods on the Mt Haig C road where the canopy was disjunct, therefore must have come to the ground (DS)
- Have never observed on the ground (RR, SW)
- Have observed an animal, possibly a Herbert River Ringtail, but almost certainly a Lemuriod on the ground (GS)
- Only ever observed once on the ground when ill (NG)
- Have twice observed a Lemuroid cross over the road surface, but this is very unusual and occurred where there was no canopy connection at Mt Lewis and Lamb Range (MT)
- Observed on side of the road at Millaa Millaa Falls, seems likely to have crossed (SC)
- Never seen a Lemuroid on a road surface (JW)
- Lemuroids are very agile on thin branches and also use vines to move between two trees (MT)
- Have observed two Lemuroids sitting in the middle of a canopy connection above the road (SB)
- Lemuroids and other arboreals were always seen in the same place on a road where there was canopy connection. It appeared that arboreals in the area all knew where the overpass was situated and often concentrated in the area.

At one time a Rufous Owl was observed sitting on the canopy connection waiting for prey (SL)
- *Elaeocarpus* spp. is a good food tree for Lemuroids and also has good architecture for crossing, but also attracts Cassowaries so is not a good choice for planting near roads. *Flindersia brayleana* or *F. pimenteliana* would be a good choice for planting near roads – they are prime food species for Lemuroids but do not attract Cassowaries (NG)
- Lemuroids like *Polyscias* spp. Which connect high up above the road and could be a good connecting tree for planting (BM)
- *Polyscias,* mature *Syzygium, Endiandra, Flindersia* are all used for feeding near roads, occasionally *Omalanthus.*
- Never observed near *Acacia*.
- Observed using an artificial canopy overpass (NW)
- Some individuals utilise canopy connections as part of their home range which occurs on both sides of a narrow road (RW)
- Will move across the ground when forced to by translocation experiments across a powerline clearing (RW)
- Readily use canopy connections to return to point of capture when translocated across a narrow road (RW)
- Movements of species restricted when canopy connections are absent (RW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Pseudochirulus herbertensis***

COMMON NAME: **HERBERT RIVER RINGTAIL POSSUM**

CONSERVATION STATUS: **RARE**

FEATURES: Black and white rainforest possum. Weight to approximately 1kg

HABITAT:

Vegetation type: Cool, wet, upland rainforest and occasionally tall open Wet Sclerophyll forest at rainforest margins.

Distribution: Atherton Tableland, Bellenden Ker, Cardwell, Walter Hill and Seaview Ranges.

Macrohabitat: Arboreal, middle layers and canopy of rainforest, very rarely descends to the ground.

Microhabitat: Feeds only at night on leaves of a variety of rainforest trees and cadaghi and pink bloodwood in Wet Sclerophyll, occasionally fruits and flowers. Spends day in a tree hollow, large clump of epiphytic ferns or nest if no other alternative, retunrs to den before dawn.

Altitude: Above 600 metres

MOVEMENTS:

Movement Patterns: Arboreal, very rarely descends to ground.

Method of Movement: Climbs cautiously and methodologically.

BREEDING:

Habitat: Solitary species, young left in dens.

Patterns: A single pale brown young in pouch and then riding on mother's back

Time: Mating peak between March and May, pouch young emerge throughout year, peak in October

IMPACTS OF ROADS:

Narrow roads without canopy connections constitute a barrier as they rarely descend to ground level. Barrier effects not as severe as for Lemuroid. Roads allow spotlighting disturbance.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. solid branches touching.

Construct arboreal walkways between trees with suitable natural vine cover to protect from flying predators, where canopy closure can not be achieved. Monitor use by arboreal species.

Regulate spotlighting tours to ensure animals are not continually disturbed (i.e. more than 3-4 nights per week) and monitor effects on animals habitat use close to road.

Avoid widening of roads in upland rainforest areas.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

HERBERT RIVER RINGTAIL *Pseudochirulus herbertensis*

No. who **spotlight** or have **spotlighted** the species	regularly:	14
	intermittently:	2

No. who have seen the species **crossing roads**: 12
No. who have seen the species **crossing on the road surface:** 6

Locations crossing on the road surface:
Mt Baldy 3; Kauri Creek Rd, Lamb Range 2; Longland's Gap 1; The Crater 1; Tully Falls Rd 2; Massey Creek 1; Atherton-Herberton Rd 1; Old Palmerston Highway 1; Palmerston Highway 1, Kennedy Hwy, Malaan Rd, Teresa Ck Rd, Mt Father Clancy, top of Gillies Hwy

No. who have seen the species **crossing via a canopy connection**: 10

Locations crossed via a canopy connection:
Mt Fisher 1; Kauri Creek Road, Lamb Range 2; Mt Baldy 5; Massey Ck 1; Longland's Gap 4; Maalan forestry track 1; Tully Falls Road 1; Danbulla Forest Drive 1; The Crater road 2; Gillies Highway 1; Maalan Rd 2; Palmerston Highway near South Johnstone 1; Bailey Rd 1.

Width of clearing crossed on the surface: 0-5m 0; 5-10m 3
Width of clearing crossed via a canopy connection: 0-5m 2; 5-10m 16; 10-15 2

Tree species at road edge used for crossing:

Alphitonia spp.	12
Mature rainforest	1
Elaeocarpus spp.	4
Omalanthus sp.	1
Calamus spp.	1

Tree species also used:
Syzygium spp., *Polyscias* spp., fruiting species

Plant species with potential to be used for crossing:
Alphitonia spp.
Elaeocarpus spp.
Flindersia spp.
Polyscias spp.

No. who have seen *roadkills* of this species: 6
Locations where roadkills observed: Longland's Gap; Old Palmerston Highway near Beatrice R., Herberton-Atherton Rd; old Maalan Rd.

Comments:
- Herbert River Ringtails need more solid canopy connections than do Lemuroids because they can't leap and are less agile (JW)
- Observed using a dead branch to cross overhead (RR)
- Often seen in dense clumping vegetation such as mistletoe and vines hanging over the road (MT)
- Observed using *Elaeocarpus* sp as a crossing point (NG)
- A few overhead crossing connection points in the same area would be required because Herbert River Ringtails are attacked and overpowered by Coppery Brushtails so if there were only one or two crossing points, the Herberts would not be able to use them (NG)
- Herberts will use their weight to move branches down till they touch in order to effect a crossing and will have another branch elsewhere where they can use their weight again to cross back (MT)
- Observed a Herbert and a Green follow the same trail through the forest towards an arboreal canopy connection and then use it as an overpass (SL)
- Very common canopy crosser, but never seen on ground (BM)

- Use *Alphitonia* spp. both for feeding and road crossing (AV)
- Have observed crossing on road surface but a very rare occurrence (AV)
- Have observed on ground but was injured - on the Atherton-Herberton Road where a canopy connection had recently been thinned out (CH)
- Never observed crossing on the road surface (JW)
- Never observed on ground, but often low in trees (DS)
- Observed on the ground in wet sclerophyll forest, a long way from rainforest (SW)
- Observed on road edges in *Alphitonia* spp*., Polyscias* spp. and *Omalanthus* sp (RW)
- Have only ever seen on ground in July and August when they get a muscle-wasting disease or when fighting caused a fall (the goal of the fight), then they will stagger disorientated on ground passing possible climbing trees until recovered (RR)
- Have observed on ground in pasture, moving between isolated *Polyscias* spp. (RW)
- Use *Alphitonia* spp. all the time and are greatly attracted to *Polyscias murrayi* (JK)
- *Alphitonia* spp. and *Elaeocarpus* spp. are popular as feeding trees (NG, DS, SW, BM)
- Herberts seen in many tree species at road edge (MT)
- *Alphitonia* spp. make good potential crossing trees (RR)
- *Alphitonia whitei* and *Flindersia* spp. might be a good choice for plantings to enable crossings, being lower growing and less attractive to Cassowaries than *Elaeocarpus* spp. (NG)
- Wattles do not have potential because they pose road safety problems because of being prone to borer and are not used much as a crossing point (although not common in area examined) (NG)
- Acacias are not used (MT, SW)
- *Alphitonia* spp. near the road might even be a threat to Herberts because they attract the species to the roadside (SW)
- Have been observed moving across roads between fragments and continuous forest (RW)
- Will use the top strand of a barbed wire fence to move through grassy powerline clearings (RW)
- Observed using a 2-lane road as a walkway for 20 metres (RW)
- Has been observed using the artificial canopy overpass on the Kauri Creek Road, Lamb Range road network (RR)
- Scats have been found in the underhang under the artificial canopy overpass (NW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Pseudochirulus cinereus***

COMMON NAME: **DAINTREE RINGTAIL POSSUM**

CONSERVATION STATUS: **RARE**

FEATURES: Ash-brown rainforest possum of northern Wet Tropics. Weight approximately 1 kg.

HABITAT:

Vegetation type: Cool, wet upland rainforest.

Distribution: Mt Windsor and Mt Carbine Tablelands, and Thorton Range.

Macrohabitat: Arboreal. Rarely descends to the ground.

Microhabitat: Feeds at night on leaves of a variety of tree species, occasionally fruits and flowers, spends day in a tree hollow, large clumps of epiphytic ferns or nest if no other alternative, returns to den before dawn.

Altitude: Above 450 metres.

MOVEMENTS:

Movement Patterns: Arboreal, very rarely descends to ground.

Method of Movement: Climbs cautiously and methodically.

BREEDING:

Habitat: Solitary species, young left in dens.

Patterns: A single young in pouch and then riding on mother's back.

Time: Mating between March and May, pouch young emerge throughout the year, peak in October.

IMPACTS OF ROADS:

Narrow roads constitute a barrier as the animals rarely descend to ground level. Roads encourage disturbance through spotlighting.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. solid branches touching across road.

Construct arboreal walkways between trees with suitable natural vine cover to protect from flying predators, where canopy closure can not be achieved. Monitor use by arboreal species.

Regulate spotlighting tours to ensure animals are not continually disturbed (i.e. more than 3-4 nights per week) and monitor effects on animals habitat use close to road.

Avoid widening of roads in upland rainforest areas. Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

DAINTREE RINGTAIL *Pseudochirulus cinereus*

No. who **spotlight** or have **spotlighted** the species: 9

No. who have seen the species **crossing roads**: 4
No. who have seen the species **crossing on the road surface:** 4

Locations crossing on the road surface:
Mt Lewis 3.

No. who have seen the species **crossing via a canopy connection**: 4

Locations crossed via a canopy connection:
Mt Lewis 2.

Width of clearing crossed on the surface: 0-5m 1; 5-10m 2.
Width of clearing crossed via a canopy connection: 0-5m 1; 5-10m 1.

Tree species at road edge used for crossing:

Alphitonia spp.	3
Omalanthus sp.	1
Laurels	1

Tree species also used:
Alphitonia spp. *Omalanthus* sp

Plant species with potential to be used for crossing: *Alphitonia* spp. *Omalanthus* sp.

No. who have seen *roadkills* of this species: 1
Locations where roadkills observed:
Mt Lewis near big clearing; Rex Range at highest point.

Comments:
- Only observed one animal walking on a road, assumed it was because the animal was sick (RR)
- Very similar to Herbert River Ringtail Possum in behavior (BM) (MT)
- Have seen in wattles but that is most unusual (MT)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Pseudochirops archeri***

COMMON NAME: **GREEN RINGTAIL POSSUM**

CONSERVATION STATUS: **RARE**

FEATURES: Green tinged rainforest possum. Weight approximately 1 kg.

HABITAT:

Vegetation type: Dense, upland rainforest, particularly with many tangled, thornless vines.

Distribution: Mt Windsor, Mt Carbine and Atherton Tablelands, MacAlister, Bellenden Ker, Cardwell, Seaview and Paluma Ranges.

Macrohabitat: Found at all layers of the rainforest, will descend to the ground to cross gaps.

Microhabitat: Feeds at night on leaves of a variety of tree species, including figs and stinging trees, spends day curled up on a branch, runs along branches and vines to escape during day or night.

Altitude: Above 250 metres.

MOVEMENTS:

Movement Patterns: Markedly arboreal, will descend to ground to cross small gaps.

Method of Movement: Walking on branches and climbing up vines, avoids leaping.

BREEDING:

Habitat: Solitary species, pairs only together during mating.

Patterns: A single young in pouch and then riding on mother's back.

Time: Between August and November

IMPACTS OF ROADS:

Narrow roads do not constitute a severe barrier as they will descend to ground level, but attempted crossings appear to be infrequent, indicating inhibition of movements. Roads encourage disturbance through spotlighting. Crossing individuals have been recorded as road kills, but this is not thought to be a major cause of mortality. Road noise, headlights and other emissions could be sources of disturbance.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. treetops touching across road. Construct arboreal walkways with suitable natural vine cover to protect from flying predators, where canopy closure can not be achieved. Monitor use by arboreal species.

Regulate spotlighting tours to ensure animals are not continually disturbed (i.e. more than 3-4 nights per week) and monitor effects on animals habitat use close to road.

Avoid widening of roads in upland rainforest areas.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

GREEN RINGTAIL *Pseudochirops archeri*

No. who **spotlight** or have **spotlighted** the species: 24

No. who have seen the species **crossing roads**: 19
No. who have seen the species **crossing on the road surface:** 12

Locations crossing on the road surface:
Mt Baldy x4, Mt Lewis x3, Kennedy Highway x1, Rifle Ck x1, Upper Barron school x1, Lake Eacham x1, The Crater x1, Palmerston x2, Teresa Ck x1, Mt Fisher x 1, Tolga scrub x1, Wongabel x1, Malanda x1, Williams Ck x1, Curtain Fig x1, Longlands Gap x1,

No. who have seen the species **crossing via a canopy connection**: 10

Locations crossed via a canopy connection:
Tully Falls Rd x3, Curtain Fig x1, Lamb Range Rd x1, The Crater x2, Mt Fisher x1, Mt Baldy x3, Rifle Ck, Upper Barron State school x1,

Width of clearing crossed on the surface: 5-10m 9; 10-15m 2; >20m 1.
Width of clearing crossed via a canopy connection: 0-5m 7; 5-10m 2.

Tree species at road edge used for crossing:

Alphitonia spp.	6
Mature rainforest	5
Dendrocnide sp.	2
Figs	2
Lianas	2

Tree species also used:
Alphitonia spp, Vine thickets, *Dendrocnide*.

Plant species with potential to be used for crossing: *Alphitonia* spp.

No. who have seen *roadkills* of this species: 11

Locations where roadkills observed:
Rifle Ck, Kuranda Rainforest Resort, Black Mt Road, near Malanda Ck, near Williams Ck, Tablelands (grassy area), near Millaa Millaa, Kuranda Range Road, Kuranda, Longlands Gap, Mt Fisher, Tolga scrub, Wongabel, Curtain Fig, Massey Ck, Kennedy Highway, Old Palmerston Hwy.

Comments:
- Tend to move away when flowering and fruiting in Spring (BM)
- Often spot them 0.5 – 1m off the ground when have just run to a sapling (RR)
- Seen crossing between trees over a gap (RR)
- Have not seen on ground (SW)
- Don't often come down to ground (MS)
- Can leap and so don't need a good connection (JW)
- Locations spotted: Mt Lewis, Millaa Millaa, Old Palmerston Hwy, Mt Fisher, Mt Baldy, Curtain Fig, Tully Falls, Danbulla, Mt Haig C, Paluma, Thomas Rd, Yungaburra, Curtain Fig, Koombooolooma.
- Have translocated one animal across powerline clearing which returned within 5 days to point of capture (RW)
- Seen commonly on ground (MT)
- Home range of at least one individual overlapped a narrow road (crossed at least 15 times in 6 months (RW)
- Has been observed using the artificial canopy overpass on the Kauri Creek Rd, Lamb Range network (NW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Trichosurus vulpecula johnstoni***
COMMON NAME: **COPPERY BRUSHTAIL POSSUM**
CONSERVATION STATUS: **COMMON**
FEATURES: Copper-coloured rainforest possum to about 4kg.

HABITAT:

Vegetation type: Cool, wet, upland rainforest and occasionally tall open wet sclerophyll forest at rainforest margins.

Distribution: Atherton Tableland, Cardwell, Bellenden Ker, Walter Hill and Seaview Ranges.

Macrohabitat: All layers of rainforest, will descend to the ground to cross rainforest gaps.

Microhabitat: Feeds at night on leaves and fruit, spends day in a tree hollow, or nest if no other alternative.

Altitude: Above 600 metres

MOVEMENTS:

Movement Patterns: Arboreal, but will descend to ground to cross rainforest gaps

Method of Movement: Climbing and walking

BREEDING:

Habitat:

Patterns: A single young in pouch and then riding on mother's back.

IMPACTS OF ROADS: Roads do not constitute a severe barrier as they will descend to ground level and attempt to cross. Roads allow spotlighting disturbance. Roadkills are common.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. solid branches touching. Construct arboreal walkways (with suitable natural vine cover to protect from flying predators) between trees where clearing widths are greater and monitor.
Control and monitor spotlighting tours to prevent frequent disturbance.
Trial faunal underpasses for use by the species.

ROAD CROSSINGS SUMMARY

COPPERY BRUSHTAIL *Trichosurus vulpecula johnstoni*

No. who **spotlight** or have **spotlighted** the species	regularly:	17
	intermittently:	3

No. who have seen the species **crossing roads**: 13
No. who have seen the species **crossing on the road surface:** 13

Locations crossing on the road surface:
Mt Baldy 2; Kauri Creek Rd, Lamb Range 1; Longland's Gap 4; The Crater 5; Tully Falls Rd 2; Mt Father Clancy 1; Tinaroo Creek Rd 1; Old Palmerston Highway 1; Palmerston Highway 1; Teresa Ck Rd 1; Yungaburra 2: Tolga Scrub 1; Peeramon 1; Curtain Fig 2; Upper Barron 1; Malanda Falls 1

No. who have seen the species **crossing via a canopy connection**: 5

Locations crossed via a canopy connection:
Mt Baldy 1; Longland's Gap 2; Maalan forestry track 1; The Crater 2;

Width of clearing crossed on the surface: 0-5m 3; 5-10m 16; 10-15 1
Width of clearing crossed via a canopy connection: 0-5m 3; 5-10m 1

Tree species at road edge used for crossing:

Solanum spp.	1
Mature rainforest	2
Elaeocarpus spp.	1
Helicia sp.	1
pasture	2
tall open forest	1

Tree species also used:
Alphitonia spp., regrowth, seen in *Acacia* once

Plant species with potential to be used for crossing:
Helicia spp.
Alphitonia spp.
Solanum spp.
Flindersia spp.
Elaeocarpus spp.

No. who have seen *roadkills* of this species: 12
Locations where roadkills observed:
Longland's Gap 3; Tolga Scrub 3; Mareeba-Kuranda Rd 1; Yungaburra 1; Herberton-Millaa Millaa Rd 1; Millaa-Malanda Rd 1; Teresa Ck Rd 1; Old Palmerston Highway 2; Barron R. bridge 1; Ravenshoe-Millaa Millaa Rd 1; all over Tablelands 6.

Comments:
- For a Coppery Brushtail to cross via a canopy connection, a good solid branch would be needed, but they can swing out if the gap is less than 0.5m (RW)
- Copperies will use whatever plants are available (RW)
- *Helicia, Solanum* spp. and *Alphitonia* are all used as canopy connections (RW)
- Observed crossing over the road surface and using a dead branch in the canopy (RR)
- They would use *Flindersia* spp., *Alphitonia* spp. and *Elaeocarpus* spp. to cross (NG)
- Copperies cross everywhere on the Tablelands over the road surface (MT, CC, SB)
- Coppery Brushtails will beat up Herbert River Ringtails, therefore more than a couple of canopy connections need to be available to give the Herberts an alternative route (NG)
- There are roadkills all over the Tablelands (many)
- Have not observed them on canopy connections. They may be a bit heavy and need stronger connections (JW)
- Have been observed in pasture feeding (CC, JW, RW)

- Tolga Scrub is thick with road-killed Coppery Brushtails and may be a good place to consider looking at artificial arboreal walkways (RR)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Cercartetus caudatus***

COMMON NAME: **LONG-TAILED PYGMY POSSUM**

CONSERVATION STATUS: **RARE**

FEATURES: Tiny, brown, mouse sized possum with black eye patches. Weight approximately 30g and length approximately 10cm.

HABITAT:

Vegetation type: Upland and lowland rainforest and fringing Casuarina and Eucalypt-Melaleuca forests.

Distribution: Cape Tribulation area, Mt Windsor, Mt Carbine and Atherton Tablelands, MacAlister, Lamb, Bellenden Ker, Walter Hill and Paluma Ranges, Mission Beach area.

Macrohabitat: Found at all layers of the rainforest, arboreal.

Microhabitat: Feeds at night on nectar, pollen and insects, spends day in a spherical nest of leaves or in fern clumps, tree hollows or palm fronds.

Altitude: From coastal plain to at least 700 metres.

MOVEMENTS:

Movement Patterns: Arboreal, using all layers of the forest, usually solitary, but may form feeding and nesting groups of two - four.

Method of Movement: Climbing using prehensile tail.

BREEDING:

Habitat: Nests of leaves or fern clumps, under palm, pandanus fronds and tree hollows.

Patterns: From 1-4 young.

Time: Two peaks, Jan to Feb and Aug to Nov.

IMPACTS OF ROADS:

Roads probably constitute a severe barrier as the animals are very small. However, roadkills have been occasionally recorded so the species will attempt to cross the road surface. Roadkills are not thought to be a major cause of mortality. Road noise, headlights and other emissions could be sources of disturbance. Roads encourage the intrusion into forests of feral predators such as cats, which are recorded Pygmy Possum killers.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. treetops touching across road. Construct arboreal walkways with suitable natural vine cover to protect from flying predators, where canopy closure can not be achieved.

Rehabilitation of road verges with rainforest species, besides encouraging canopy closure this will also discourage intrusion of feral predators such as cats.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

LONG-TAILED PYGMY POSSUM *Cercartetus caudatus*

No. who **spotlight** or have **spotlighted** the species: 11

No. who have seen the species **crossing roads**: 4
No. who have seen the species **crossing on the road surface:** 2

Locations crossing on the road surface:
Black Mt Road 1; Mt Windsor 1; Clohesey Rd 1; Mt Lewis 1; Davies Creek Road 1; Kuranda Range Road 1;

No. who have seen the species **crossing via a canopy connection**: 1

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: 5-10m 1; 10-15m 1;

Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: *Alphitonia* spp.
Mature forest

Tree species also used:
Alphitonia spp.
Mature forest

Plant species with potential to be used for crossing: -

No. who have seen *roadkills* of this species: 2
Locations where roadkills observed:
Mt Lewis 1; Kuranda Range Road, Streets Creek 1;

Comments:
- Locations spotted: Bellenden Ker 1; The Crater 3; Longlands Gap 3; Mt Lewis 2; Lamins Hill 1; Atherton Tablelands 1; Father Clancy 1; Noah Creek 1; Black Mountain Road 1; Mt Baldy 1;
- Never seen crossing nor on the ground (DS)
- Seen on the side of the road, on the ground at Mt Lewis and Mt Baldy (BM)
- Have not seen crossing roads (RR)
- Have not seen running on the ground, but have seen down near the ground on fallen logs (used as runways) (RR)
- Have seen on the ground but not crossing (SC)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Dactylopsila trivirgatus***

COMMON NAME: **STRIPED POSSUM**

CONSERVATION STATUS: **COMMON**

FEATURES: Small nocturnal, arboreal, black-and-white-striped possum with pungent sweet, musty orour. Weight approximately 300 g.

HABITAT:

Vegetation type: Upland and lowland rainforest and to a lesser extent the adjacent open forests and woodlands.

Distribution: Townsville to Cooktown and northern Cape York Peninsular rainforest areas.

Macrohabitat: All layers of the rainforest, arboreal.

Microhabitat: Feeds at night on wood-boring grubs and other insects found by probing rotting logs, limbs and tree trunks using an elongated 4th finger, also eats fruits, honey and small vertebrates, spends day in a leafy nest in a tree hollow or in fern clumps.

Altitude: At all altitudes.

MOVEMENTS:

Movement Patterns: Arboreal using all layers of the rainforest, usually solitary, but groups of three have been observed during the breeding season.

Method of Movement: Extremely agile, walking and running on horizontal branches and leaping or catapulting across to neighboring trees using overhanging vines.

BREEDING:

Habitat: Nests of leaves in tree hollows or fern clumps.

Patterns: Usually a single young but may be 2.

Time: February to August.

IMPACTS OF ROADS:

Roads may not constitute a barrier to movements as the animals are often seen crossing roads and found as roadkills. The species will descend to the forest floor to feed and possibly to cross roads. Roadkill may form a threatening process, particularly in areas where habitat has recently been cleared in the lowlands and animals are displaced. They will use canopy connections. Road noise, headlights and other emissions could be sources of disturbance. Roads assist in the penetration into rainforest of feral predators such as cats where road verges are wide.

MITIGATION OF ROAD IMPACTS:

Provide canopy closure over roads i.e. treetops touching across road. Construct arboreal walkways with suitable natural vine cover to protect from flying predators, where canopy closure can not be achieved. Monitor use.

Rehabilitation of road verges with rainforest species will aid in prevention of intrusions by feral predators as well as helping to provide canopy closure.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

STRIPED POSSUM *Dactylopsila trivirgatus*

No. who **spotlight** or have **spotlighted** the species: 8

No. who have seen the species **crossing roads**: 10
No. who have seen the species **crossing on the road surface:** 10

Locations crossing on the road surface:
Lake Eacham 1; Koombooloomba 1; Atherton 1; Crater 2; Kuranda Range Road 2; Edmund Kennedy National Park 1; Shiptons Flat 1; Palmerston Highway 1; Paluma 2; Seaview Range 1; Mt Lewis 1; Mt Baldy 1; Cape Tribulation 1; Rex Range 1; Longlands Gap 1; Mission Beach – Tully Road 3; Bramston Beach Road 2; East Innisfail 1; Old Palmerston highway outside Millaa Millaa 1; Yorkey's Knob Road 1;.

No. who have seen the species **crossing via a canopy connection**: 5

Locations crossed via a canopy connection:
Cathedral Fig 1; Mt Father Clancy 1; Mission Beach – Tully Road 1; Topaz 1; Seaview Range 1; Mt Windsor 1; Cathedral Fig 1; Koombooloomba 1.

Width of clearing crossed on the surface: 0-5m 8; 5-10m 6; 10-15m 8; 15-20m 2; >20m 1.
Width of clearing crossed via a canopy connection: 0-5m 3; 5-10m 4.

Tree species at road edge used for crossing:

Alphitonia spp.	4
Coastal mosaic	7
Acacia	1
Wattles	3
Mature rainforest	3
Melaleucas	2
Eucalypt	2

Tree species also used:
Mature rainforest, coastal mosaic.

Plant species with potential to be used for crossing: *Alphitonia spp.*

No. who have seen *roadkills* of this species: 10
Locations where roadkills observed: Palmerston Highway; Tully- Mission Beach Road; Longlands Gap; Edmund Kennedy National Park; Cape Tribulation road; Port Douglas; Cairns airport; Trinity Beach Road; Mt Molloy; Kuranda Range Road; Yorkeys Knob road; Southern Access Road Cairns; Rex Range.

Comments:
- Prefer to come to ground to cross roads – often sighted on road surface in lowland rainforest areas and coastal mosaics (MT)
- Road kills are often seen on roads after new developments and clearing in the coastal mosaic (MT)
- Striped possums are very good at leaping – can jump 10m vertically to cross a 4m road. They land on the ground and are very mobile on the ground (RR)
- Striped possums will jump across a gap 1-2m wide (JW)
- Have been seen wandering down a road (RR)
- Often see near ground on fallen logs (DS)
- Observed Striped possums using *Elaeocarpus* to cross roads (RW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Dendrolagus lumholtzi***

COMMON NAME: **LUMHOLTZ'S TREE-KANGAROO**

CONSERVATION STATUS: **RARE**

FEATURES: Small, dark-coloured, tree-climbing kangaroo to about 7 kg, predominantly nocturnal and arboreal.

HABITAT:

Vegetation type: Upland and lowland rainforest and to a lesser extent fringing open forests and pasture edges.

Distribution: The Carbine Tableland and the Atherton Tableland south to the Herbert River, and disappear-ing/-ed from the lowlands between Cairns and Ingham.

Macrohabitat: All layers of rainforest, arboreal.

Microhabitat: Feeds at night predominantly on leaves but also fruit, and will descend to ground to feed on adjacent crops and pasture, spends the day asleep crouched on a branch.

Altitude: At all altitudes, although disappear-ing/-ed from the lowlands.

MOVEMENTS:

Movement Patterns: Arboreal, using all layers of the forest, usually solitary, but may be seen in small groups.

Method of Movement: Efficient climber, walking forwards or backwards or running slowly along branches or hopping on ground or broad branches, descends trees backwards, leaps from tree to tree or tree to ground from up to 15m in height.

BREEDING:

Habitat: Nothing specific

Patterns: Usually a single young

Time: No definite breeding season

IMPACTS OF ROADS:

Roads would not constitute a severe barrier as the animals will descend to the forest floor and cross gaps. Road noise, headlights and other emissions could be sources of disturbance. Headlights may 'capture' the species in the middle of the road. The species is highly susceptible to road mortality, particularly in the Tablelands, which appears to be its main home area. Roads encourage spotlighting disturbance.

MITIGATION OF ROAD IMPACTS:

Trial traffic calming measures such as rumble strips, slow-speed designs with curves, chicanes and signage in known high roadkill density areas, particularly at ground level crossing localities.

Regulate spotlighting permits to prevent frequent disturbance. Investigate the effectiveness of faunal underpasses for the species. Examine 'floppy fencing' options for effectiveness in prevention of crossings in known hotspots.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

LUMHOLTZ'S TREE-KANGAROO *Dendrolagus lumholtzi*

No. who **spotlight** or have **spotlighted** the species regularly: 18
intermittently: 4

No. who have seen the species **crossing roads**: 15
No. who have seen the species **crossing on the road surface:** 14

Locations crossing on the road surface:
Mt Baldy 4; Millstream-Atherton Rd 1; Longland's Gap 3; Maalan Rd 1; The Crater 1; Tully Falls Rd 2; Mt Father Clancy 1; Kirrama Range Rd 1; Kennedy Highway 1; Upper Davies Creek 1; Thomas Rd 1; Bushy Ck 1; Yungaburra 1: Mt Fisher 3; Dirran-Malanda Rd 1; Curtain Fig 2; Upper Barron 1; Kennedy Highway near Ravenshoe 1

No. who have seen the species **crossing via a canopy connection**: 1

Locations crossed via a canopy connection:
Tully Falls Rd 1

Width of clearing crossed on the surface: 0-5m 4; 5-10m 11; 10-15 1; 15-20m 1; >20m 1
Width of clearing crossed via a canopy connection: 0-5m 1

Tree species at road edge used for crossing:
Tree species also used:
Polyscias spp., cluster figs

Plant species with potential to be used for crossing: -

No. who have seen roadkills of this species: 12
Locations where roadkills observed: Longland's Gap 3; Tarzali 2; Atherton-hilltop shop 1; Eubenangee 1; Kennedy Highway near Crater 3; Malanda Ck 1; Thomas Rd 1; Maalan track 1; Millstream Atherton Rd 1; Halloran's Hill 1; Upper Barron 1; Palmerston-Dirran Ck 3; Millaa Millaa pasture 1; Williams Ck 1; Winfield bridge 1.

Comments:
- Never seen using a canopy connection to cross a road (JK, RR, NG, DS, GN, MS)
- Would require a very sturdy canopy to cross by leaping (JK)
- Seen in isolated trees and pasture on the Tablelands (many)
- In closed forest will use vines between trees when researchers are trying to capture (GN)
- Have observed one group of 5 animals for a long period which lived near the side of a road in a rainforest patch but never attempted to cross to the other side (GN)
- At the Curtain Fig there is an average of one animal killed by vehicles per year and at Thomas Road one is killed every 1-2 years (GN)
- Have observed Lumholtz's Tree-kangaroo sleeping in a canopy connection over the road during the day (SW)
- They have been found 4-5 km from the nearest forest patch in pasture land (MS)
- They prefer *Alphitonia* spp. (MS)
- The Tree Kangaroo and Mammal Group have a list which records 29 tree-kangaroos killed on the Upper Barron Rd, 24 on the Dirran-Malanda Rd, 21 near the Curtain Fig and 6 at Winfield Bridge
- Have been observed hopping on large branches in the canopy from one tree to another. They also use exposed branches or vines (JK)
- Never observed using a canopy connection, believed to be too heavy (JW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Dendrolagus bennettianus***

COMMON NAME: **BENNETT'S TREE KANGAROO**

CONSERVATION STATUS: **RARE**

FEATURES: Small, dark brown, tree-climbing kangaroo with rusty coloured shoulders, neck and head. Predominantly nocturnal and arboreal. Weight approximately 13kg.

HABITAT:

Vegetation type: Upland and lowland rainforest and to a lesser extent open forests.

Distribution: Mt Windsor Tableland, and the upland and lowland rainforests north of the Daintree River and South of Cooktown.

Macrohabitat: All layers of the rainforest, arboreal.

Microhabitat: Feeds at night on predominantly on leaves but also fruit, spends day alseep crouched on a branch.

Altitude: All altitudes.

MOVEMENTS:

Movement Patterns: Arboreal, using all layers of the rainforest, will descend to the ground to cross large areas of open forest between rainforest blocks, can be active on overcast days.

Method of Movement: Efficient climber, walking forwards or backwards or running slowly along branches, hopping on the ground or broad branches, descends trees backwards, leaps from tree to tree to ground from up to 15m in height.

BREEDING:

Habitat: Nothing specific.

Patterns: Usually a single young accompanies mother for a prolonged period after leaving pouch.

Time: No definite breeding season.

IMPACTS OF ROADS:

Roads are not expected to constitute a severe barrier as the animals will descend to the forest floor and cross large open forest gaps. Road noise, headlights and other emissions could be sources of disturbance. The species does suffer mortality as road kills. Roads encourage disturbance through spotlighting. Due to its fragmented habitat, road mortality may be a threatening process during dispersal.

MITIGATION OF ROAD IMPACTS:

Trial traffic calming measures such as rumble strips, slow-speed designs with curves, chicanes and signage in known high roadkill density areas, particularly at ground level crossing localities.

Regulate spotlighting permits to prevent frequent disturbance. Investigate the effectiveness of faunal underpasses for the species. Examine ‘floppy fencing’ options for effectiveness in prevention of crossings in known hotspots.

Use of high bridge spans and retention of streamside vegetation with canopy closure would provide potential crossing points.

ROAD CROSSINGS SUMMARY

BENNETT'S TREE KANGAROO *Dendrolagus bennettianus*

No. who **spotlight** or have **spotlighted** the species: 8

No. who have seen the species **crossing roads**: -
No. who have seen the species **crossing on the road surface:** -

Locations crossing on the road surface:
-

No. who have seen the species **crossing via a canopy connection**: -

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: -
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: -
Tree species also used:
Figs, Poligs Flavocapy, Umbrella trees

Plant species with potential to be used for crossing: -

No. who have seen *roadkills* of this species: 3
Locations where roadkills observed:
Mt Windsor (road width 5-10m) 1; North of the Daintree 1; Gap Creek 1; Forest Creek Road 1;

Comments:
- Locations spotted: Shiptons Flat 4; Mt Windsor 2; Daintree 1;
- Have not seen crossing roads (RW)
- Have seen on the ground (DS)
- Seen along the side of a road once (GW)
- Fairly agile, able to swing between branches (MT)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES:	***Petaurus breviceps***
COMMON NAME:	**SUGAR GLIDER**
CONSERVATION STATUS:	**COMMON**
FEATURES:	Grey glider with dark stripe from between eyes to mid-back, pale underneath, dark tail, sometimes with white tip. Weight approximately 100 - 140 g.
HABITAT:	
Vegetation type:	Variety of habitats from rainforests through tall Eucalypt forest to open woodland.
Distribution:	Throughout northern and eastern Australia and New Guinea.
Macrohabitat:	Variety of forest and woodland habitats.
Microhabitat:	Strictly arboreal, feeds at night on sap of eucalypt trees, gum of acacia trees, nectar, pollen and insects, and spends the day alseep in tree hollows.
Altitude:	All altitudes.
MOVEMENTS:	
Movement Patterns:	Strictly nocturnal and arboreal, live in groups of several adults and juveniles, sharing a den in a hollow tree.
Method of Movement:	Highly mobile, able to glide up to 50m.
BREEDING:	
Habitat:	Hollow trees for dens.
Patterns:	One to two young remain in the pouch for about 2 months and then remain in a group nest for another month, when they begin to forage with their mother.
Time:	Probably continuous in northern Australia.
IMPACTS OF ROADS:	Narrow roads do not constitute a severe barrier as the animals inhabit open forest and are capable of easily gliding 30m. Wide clearings for highways would constitute a barrier as the species is strictly arboreal. Road noise, headlights and other emissions could be sources of disturbance. Roads aid the penetration of feral predators such as cats, dogs, and foxes, all of which are known to pray on the sugar glider.

MITIGATION OF ROAD IMPACTS:

Keep all road clearing widths as narrow as possible to allow gene flow between populations.

High bridges with the retention or rehabilitation of streamside vegetation could form potential corridors and crossing routes for this species and reduce the need to descend to ground level, providing opportunities for feral predators.

Protect tall trees adjacent to roadways to allow long distance glides above vehicle height.

Replace barbed-wire fencing along roads in known glider habitat.

Build high bridges with the retention or rehabilitation of streamside vegetation.

ROAD CROSSINGS SUMMARY

SUGAR GLIDER *Petaurus breviceps*

No. who **spotlight** or have **spotlighted** the species: 12

No. who have seen the species **crossing roads:** 3
No. who have seen the species **crossing the road surface:** 1 (gliding)

Locations crossing on the road surface:
Longlands gap, Tumoulin, Mt Spurgeon,

No. who have seen the species **crossing via a canopy connection**: 4

Locations crossed via a canopy connection:
Tully Falls Rd x3, Curtain Fig x1, Lamb Range Rd x1, The Crater x2, Mt Fisher x1, Mt Baldy x3, Rifle Creek, Upper Barron State school x1,

Width of clearing crossed on the surface: 0.5 -1; 10-15m 1.
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: Mature (upland) rainforest 2

Tree species also used:
-

Plant species with potential to be used for crossing: **-**

No. who have seen *roadkills* of this species: -
Locations where roadkills observed: -

Comments:
- Locations spotted: Mt Baldy; Sth Johnstone Forestry Camp; Boar Pocket Rd; Crystal Ck – Hull River area; Longlands gap; Tumoulin; Mt Spring.
- No trouble crossing except for 2 lane highways (JW)
- Have not seen crossing (RWh)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Petaurus norfolcensis***

COMMON NAME: **SQUIRREL GLIDER**

CONSERVATION STATUS: **COMMON (Near threatened)**

FEATURES: Grey glider with dark stripe from between eyes to mid-back, white underneath, bushy tail. Weight approx. 230 g.

HABITAT:

Vegetation type: Open eucalypt woodland.

Distribution: Woodland west of Wet Tropics, areas west, south and north of Wet Tropics Bioregion.

Macrohabitat: Open eucalypt woodland habitats.

Microhabitat: Feeds at night on sap of euclaypt trees, gum of acacia trees, nectar, pollen and insects, spends the day asleep in tree hollows.

Altitude: All altitudes, in the Wet Tropics region mainly between 400 and 1000m.

MOVEMENTS:

Movement Patterns: Strictly nocturnal and arboreal, lives in groups of several adults and juveniles, sharing a den in a hollow tree.

Method of Movement: Highly mobile, able to glide up to 50m.

BREEDING:

Habitat: Open woodland with hollow trees for dens.

Patterns: One to two young remain in the pouch for about 2 months and then remain in the group nest for another month, when they begin to forage with their mother.

Time: Probably continuous in northern Australia.

IMPACTS OF ROADS:

Narrow roads do not constitute a severe barrier as the animals inhabit open forest and are capable of easily gliding 30m. Wide clearings for highways would constitute a barrier as the species is strictly arboreal. Road noise, headlights and other emissions could be sources of disturbance. The species does suffer mortality as road kills but this is not considered a significant cause of death. Barbed-wire along roads are likely to be a cause of mortality due to animals becoming trapped when gliding. Roads aid the penetration of feral predators such as cats, dogs, and foxes, all of which are known to pray on the squirrel glider.

MITIGATION OF ROAD IMPACTS:

Keep all road clearing widths as narrow as possible to allow gene flow between populations.

High bridges with the retention or rehabilitation of streamside vegetation could form potential corridors and crossing routes for this species and reduce the need to descend to ground level, providing opportunities for feral predators.

Protect tall trees adjacent to roadways to allow long distance glides above vehicle height.

Replace barbed-wire fencing with other fencing strategies along roads in known glider habitat.

Build high bridges with the retention or rehabilitation of streamside vegetation.

ROAD CROSSINGS SUMMARY

SQUIRREL GLIDER *Petaurus norfolcensis*

No. who **spotlight** or have **spotlighted** the species: 11

No. who have seen the species **crossing roads**: 3
No. who have seen the species **crossing the road surface:** 3 (gliding)

Locations crossing on the road surface:
King's Plain 1; Black Mt road 1; Tumoulin 1.

No. who have seen the species **crossing via a canopy connection**: -

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: 0-5m 1; 5-10m 1; 10-15m 1;
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: Wattle re-growth 1.

Tree species also used: **-**

Plant species with potential to be used for crossing: -

No. who have seen *roadkills* of this species: -
Locations where roadkills observed:
-

Comments:
- Locations spotted: Mt Fox; west of Ravenshoe; Kuranda Range Road; Tumoulin; Mareeba - Atherton
- The glider kept walking along the road- there was flooding and water each side of the road (MG)
- No trouble crossing except for 2 lane highways (JW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Petaurus australis reginae***

COMMON NAME: **YELLOW-BELLIED GLIDER**

CONSERVATION STATUS: **VULNERABLE**

FEATURES: Large grey glider, white to orange on chest and underneath, large bare ears, long fluffy tail. Weight up to 700 g.

HABITAT:

- **Vegetation type:** Tall open forests at western edge of Wet Tropics rainforests with red stringybark and flooded gum.
- **Distribution:** Tall open forests at western edge of Wet Tropics rainforests from Windsor Tableland in the north to the Herbet River in the south, excluding the Lamb and McAlister Ranges.
- **Macrohabitat:** Tall open forest with red stringybark and flooded gum adjacent to rainforests.
- **Microhabitat:** Strictly arboreal, feeds at night on sap of red stringybark trees, nectar, pollen and insects, and spends the day alseep in hollows of large eucalypts.
- **Altitude:** Above 600m.

MOVEMENTS:

- **Movement Patterns:** Strictly nocturnal and arboreal, lives in vocal family groups of several individuals with a dominant male. Share a den in a tree hollow.
- **Method of Movement:** Active and highly mobile, running along top and underside branches. Able to glide 30m easily.

BREEDING:

- **Habitat:** Tall open forests.
- **Patterns**: A single young. Young is in the pouch for 3 months and left in the nest for a further 2 months.
- **Time**: Birth between Nov and May.

IMPACTS OF ROADS: Narrow roads do not constitute a severe barrier as the animals inhabit open forest and are capable of easily gliding 30m. Wide clearings for highways would constitute a barrier as the species is strictly arboreal. Road noise, headlights and other emissions could be sources of disturbance. The species suffer mortality as road kills and as populations are considered vulnerable road mortality could be significant. Roads encourage disturbance through spotlighting. Fences, particularly barbed wire can trap gliding animals causing death.

MITIGATION OF ROAD IMPACTS:

Reduce the width of road clearings in glider habitat to less than 30m for easier crossing.

Trial traffic calming measures and signage in areas with high density glider populations.

Regulate and monitor effect of spotlighting disturbance.

High bridges with the retention or rehabilitation of streamside vegetation could form potential corridors and crossing routes for this species and reduce the need to descend to ground level, providing opportunities for feral predators.

Protect tall trees adjacent to roadways to allow long distance glides above vehicle height.

Replace barbed-wire fencing with other fencing strategies along roads in known glider habitat.

ROAD CROSSINGS SUMMARY

YELLOW-BELLIED GLIDER *Petaurus australis reginae*

No. who **spotlight** or have **spotlighted** the species: 11

No. who have seen the species **crossing roads**: 5
No. who have seen the species **crossing the road surface:** 3 (gliding)

Locations crossing on the road surface:
Longlands Gap 1; Koomboolomba 1; Mt Spurgeon 1; Tumoulin 1; Wongabel 1; Mt Windsor 1.

No. who have seen the species **crossing via a canopy connection**: -

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: 0-5m 2; 5-10m 1; 10-15m 2;
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: Tall open forest
Wet Sclerophyll

Tree species also used:
-

Plant species with potential to be used for crossing: -

No. who have seen *roadkills* of this species: 1
Locations where roadkills observed:
Kennedy Highway near Ravenshoe.

Comments:
- Locations spotted: Tumoulin; Mt Windsor; Longlands Gap; Tumoulin; Little Millstream Ravenshoe; Mt Spurgeon; Ravenshoe area.
- No trouble crossing except for 2 lane highways (JW)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Petauroides volans***

COMMON NAME: **GREATER GLIDER**

CONSERVATION STATUS: **COMMON**

FEATURES: Very large dark-grey to cream glider, whitish underneath, with large fury ears and long furry tail. Weight up to approximately 1.7kg.

HABITAT:

Vegetation type: Tall open eucalypt forest and woodlands at the western edge of the Wet Tropics.

Distribution: Western eucalypt forests and woodlands from north of Cairns, south to west of Rockhampton.

Macrohabitat: Eucalypt forests and woodlands.

Microhabitat: Arboreal, feeds at night on new leaves of a few eucalypt species, and spends the day alseep in tree hollows.

Altitude: All altitudes above 400m in Wet Tropics.

MOVEMENTS:

Movement Patterns: Strictly nocturnal and arboreal, solitary and probably territorial, at night the animals emerge and glide along established routes to feeding areas.

Method of Movement: Agile climber, glides may cover 100m, usually less. Able to change direction in mid-glide, can descend to the ground and lope clumsily along.

BREEDING:

Habitat: Open eucalypt forest den.

Patterns: A single young, female breeds in second year. Pouch young for 3-4 months, carried on back and left in nest for another 3 months.

Time: Birth between March and July.

IMPACTS OF ROADS:

Narrow roads do not constitute a severe barrier as the animals inhabit open forest and are capable of easily gliding 30m. Wide clearings for highways could constitute a barrier as the species is strictly arboreal. Road noise, headlights and other emissions could be sources of disturbance. The species does suffer mortality as road kills however, this is unlikely to be significant. Roads encourage disturbance through spotlighting. Fences particularly barbed wire can trap gliding animals and cause death.

MITIGATION OF ROAD IMPACTS:

High bridges with the retention or rehabilitation of streamside vegetation could form potential corridors and crossing routes for this species and reduce the need to descend to ground level, providing opportunities for feral predators.

Protect tall trees adjacent to roadways to allow long distance glides above vehicle height.

Replace barbed-wire fencing with other fencing strategies along roads in known glider habitat.

Reduce the width of road clearings in glider habitat to less than 30m to allow for easy crossing.

Regulate and monitor the effect of spotlighting disturbance.

ROAD CROSSINGS SUMMARY

GREATER GLIDER *Petauroides volans*

No. who **spotlight** or have **spotlighted** the species: 11

No. who have seen the species **crossing roads**: 4
No. who have seen the species **crossing the road surface:** 4 (gliding)

Locations crossing on the road surface:
Mt Baldy; Mt Fox; Webster Rd; Taravale.

No. who have seen the species **crossing via a canopy connection**: -

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: 0-5m 1; 5-10m 1; 10-15m 1; >20m 1.
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: Dry Eucalypt woodland 2.

Tree species also used:
Dry Eucalypt woodland.

Plant species with potential to be used for crossing: Dry Eucalypt woodland.

No. who have seen *roadkills* of this species: 1
Locations where roadkills observed:
Near the Crater.

Comments:
- Locations spotted: Mt Fox; Windsor Tablelands; Longlands Gap; Tumoulin.
- Nursed young of a greater glider killed near Crater, young died after a week (LM)
- Greaters can glide the clearing which is 40-50m (AD)
- Not much trouble crossing (JW)
- Landed in the middle of the road (road width 0-5m) (SC)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Petaurus gracilis***

COMMON NAME: **MAHOGANY GLIDER**

CONSERVATION STATUS: **ENDANGERED**

FEATURES: Brown-grey glider with dark stripe from between eyes to mid-back, pale underneath, bushy tail. Weight up to 230 g.

HABITAT:

- **Vegetation type:** Open eucalypt and melaleuca woodland.
- **Distribution:** Lowland eucalypt and melaleuca woodland between Hull river near Tully and Crystal creek north of Townsville.
- **Macrohabitat:** Open eucalypt and melaleuca woodland with grass tree in understorey.
- **Microhabitat:** Strictly arboreal, feeds at night on sap of eucalypt trees, gum of acacia trees, nectar, pollen and insects, and spends the day asleep in tree hollows.
- **Altitude:** Below 80m.

MOVEMENTS:

- **Movement Patterns:** Strictly nocturnal and arboreal, lives in groups of several adults and juveniles, sharing a den in a hollow tree.
- **Method of Movement:** Highly mobile, able to glide up to 50m.

BREEDING:

- **Habitat:** Hollow trees for dens.
- **Patterns**: One to two young remain in the pouch for about 2 months and then remain in a group nest for another month, when they begin to forage with their mother.
- **Time**: Probably continuous.

IMPACTS OF ROADS: Narrow roads do not constitute a severe barrier as the animals inhabit open forest and are capable of easily gliding 30m. Wide clearings for highways constitute a barrier, particularly where agricultural clearing has left only narrow connections along creeks as potential corridors. Road noise, headlights and other emissions could be sources of disturbance. Road kills could be significant due to the endangered status of the species. Barbed wire fences are known to trap gliders, causing death and occur along roads and highways in Mahogany glider habitat.

MITIGATION OF ROAD IMPACTS:

Keep all road clearing widths as narrow as possible to allow gene flow between populations.

High bridges with the retention or rehabilitation of streamside vegetation could form potential corridors and crossing routes for this species and reduce the need to descend to ground level, providing opportunities for feral predators.

Protect tall trees adjacent to roadways to allow long distance glides above vehicle height.

Replace barbed-wire fencing with other fencing strategies along roads in known glider habitat.

Build high bridges with the retention or rehabilitation of streamside vegetation.

ROAD CROSSINGS SUMMARY

MAHOGANY GLIDER *Petaurus gracilis*

No. who **spotlight** or have **spotlighted** the species: 3

No. who have seen the species **crossing roads**: 2
No. who have seen the species **crossing on the road surface:** 1 (gliding)

Locations crossing on the road surface:
South of Cardwell; Porters Ck, Hinchinbrook Channel Area; South Murray Upper road.

No. who have seen the species **crossing via a canopy connection**: -

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: 10-15m 2; >20m 1.
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: Dry Eucalypt woodland 2; Melaleucas and eucalypts 1.

Tree species also used: Melaleucas and Eucalypts.

Plant species with potential to be used for crossing: Melaleucas and Eucalypts.

No. who have seen *roadkills* of this species: 2
Locations where roadkills observed:
Bruce Highway South of Cardwell 2; South Murray Upper road 2; Cardwell Gap 1; Bruce Highway Ingham 1.

Comments:
- Locations spotted: Cardwell region; Crystal Creek Tully.
- Successfully crossing (roads) by hopping or gliding (KS)

SPECIES HABITAT AND DISTRIBUTION SUMMARY

SPECIES: ***Acrobates pygmaeus***

COMMON NAME: **FEATHER-TAIL GLIDER**

CONSERVATION STATUS: **COMMON**

FEATURES: Small brown-grey glider, pale underneath, with flattened, feather like tail. Weight up to 10 - 14 g.

HABITAT:

Vegetation type: Open eucalypt forests and sclerophyll forests and woodlands.

Distribution: Open eucalypt forests and sclerophyll forests and woodlands on the eastern coast of Australia.

Macrohabitat: Open eucalypt forests and sclerophyll forests and woodlands.

Microhabitat: Arboreal, feeds at night on nectar, manna, blossoms and sugary sap of eucalypt trees.

Altitude: Below 80m.

MOVEMENTS:

Movement Patterns: Nocturnal and arboreal, lives in groups of several adults and juveniles, sharing nests built of dried overlapping eucalypt leaves in hollow tree limbs.

Method of Movement: Highly mobile and agile, able to glide or leap up to 20m.

BREEDING:

Habitat: Nests in hollow tree limbs.

Patterns: One to three young are carried in the pouch for about 2 months and then remain in a group nest for another month, when they begin to forage with their mother.

Time: Continuous in northern Australia.

IMPACTS OF ROADS:

Roads probably constitute a barrier as the animals are only capable of easily gliding 20m. Wide clearings for highways are expected to constitute a severe barrier, particularly where agricultural clearing has left only narrow connections along creeks as potential corridors. Road noise, headlights and other emissions could be sources of disturbance.

MITIGATION OF ROAD IMPACTS:

Keep all road clearing widths as narrow as possible to allow gene flow between populations.

High bridges with the retention or rehabilitation of streamside vegetation could form potential corridors and crossing routes for this species and reduce the need to descend to ground level, providing opportunities for feral predators.

Protect tall trees adjacent to roadways to allow long distance glides above vehicle height.

Replace barbed-wire fencing with other fencing strategies along roads in known glider habitat.

ROAD CROSSINGS SUMMARY

FEATHER-TAIL GLIDER *Acrobates pygmaeus*

No. who **spotlight** or have **spotlighted** the species: 10

No. who have seen the species **crossing roads**: 4
No. who have seen the species **crossing the road surface:** 4 (gliding)

Locations crossing on the road surface:
Webster Road Yungaburra 1; Mt Spurgeon 2; Taravale 1.

No. who have seen the species **crossing via a canopy connection**: -

Locations crossed via a canopy connection:
-

Width of clearing crossed on the surface: 5-10m 2; 10-15m 1.
Width of clearing crossed via a canopy connection: -

Tree species at road edge used for crossing: Dry Eucalypt woodland.

Tree species also used:
-

Plant species with potential to be used for crossing: Dry Eucalypt woodland.

No. who have seen *roadkills* of this species: -
Locations where roadkills observed:
-

Comments:

- Locations spotted: Crystal Ck – Tully; Atherton; Herberton; Longlands Gap; Lamb Range Road; Mt Spurgeon; Cameno creek.
- Never seen glide, may have trouble crossing (JW)
- Landed on the ground (SW)