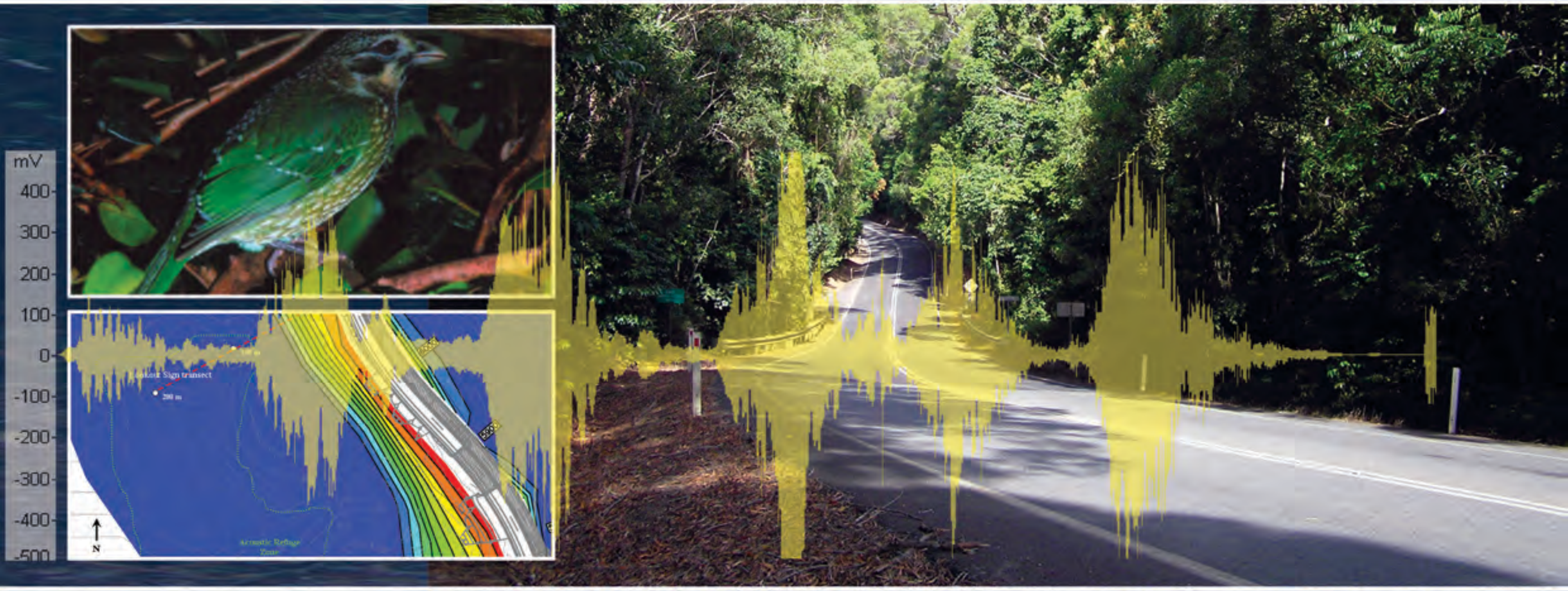
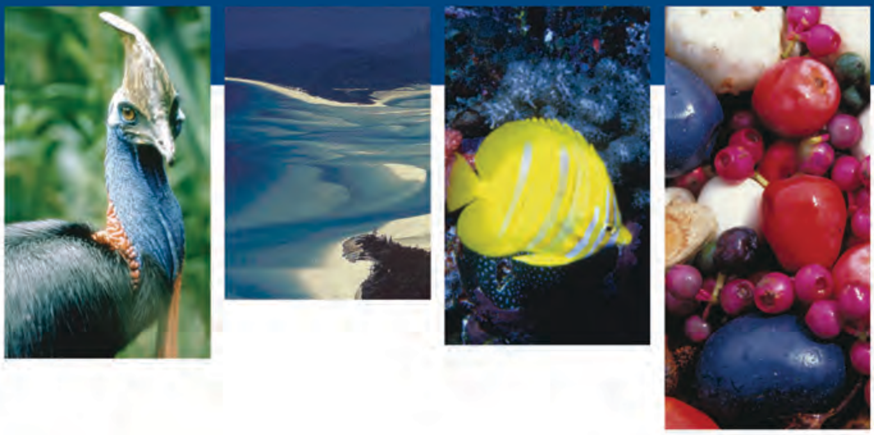
Commonwealth Environment Research Facilities

Marine and Tropical Sciences Research Facility



Noise Disturbance along Highways: Kuranda Range Road Upgrade Project

Gregory Dawe and Miriam Goosem



JCU
JAMES COOK UNIVERSITY

Australian Government
Department of the Environment, Water, Heritage and the Arts

Noise Disturbance along Highways: Kuranda Range Road Upgrade Project

Gregory Dawe and Miriam Goosem

School of Earth and Environmental Science, James Cook University

JCU
JAMES COOK UNIVERSITY

Rainforest CRC

Australian Government
Department of the Environment,
Water, Heritage and the Arts

Supported by the Australian Government's
Marine and Tropical Sciences Research Facility (MTSRF)
Rainforest CRC / MTSRF Transition Project

ISBN 9781921359132

This report should be cited as:
Dawe, G. and Goosem, M. (2008) *Noise Disturbance along Highways: Kuranda Range Road Upgrade Project.* Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns (157pp.).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's Marine and Tropical Sciences Research Facility.

The Australian Government's Marine and Tropical Sciences Research Facility (MTSRF) supports world-class, public good research. The MTSRF is a major initiative of the Australian Government, designed to ensure that Australia's environmental challenges are addressed in an innovative, collaborative and sustainable way. The MTSRF investment is managed by the Department of the Environment, Water, Heritage and the Arts (DEWHA), and is supplemented by substantial cash and in-kind investments from research providers and interested third parties. The Reef and Rainforest Research Centre Limited (RRRC) is contracted by DEWHA to provide program management and communications services for the MTSRF.

The Cooperative Research Centre for Tropical Rainforest Ecology and Management (CRC-TREM) was established in 1993 as a joint venture between its partners and the Australian Government. Having achieved national and international recognition during its first phase, the Centre was successfully refunded in 1999 as the Rainforest CRC, under a new and expanded partnership of twelve organisations. After two highly successful seven-year funding periods, the Rainforest CRC wound up operations on 30 June 2006. Several new developments since then, including the establishment of the MTSRF, has ensured that the research and intellectual property of the Rainforest CRC will continue into the future.

Reef & Rainforest
RESEARCH CENTRE

First released February 2007
Published by RRRC October 2008
Cover artwork, report layout and editing: Shannon Hogan

Contents

List of Figures

List of Tables

Acronyms Used In This Report

4WD	Four-wheel drive
CRC	Cooperative Research Centre
QDMR	Queensland Department of Main Roads
SLM	Sound level meter
SPL	Sound Pressure Level
SEL	Sound Exposure Level
UK	United Kingdom
USA	United States of America

Glossary

L_{eq}	The noise level equivalent to a continuous sound at that amplitude for the selected integration time.
L_n	Noise levels with ‘n’ indicating the percentage of time that noise levels are exceeded.
L_{den}	Noise levels weighted to account for different perceived loudness levels during the day, evening and night.
RMS	The root mean square conversion of data originally containing both positive and negative values. This parameter is typically used to obtain a positive value for average energy levels within a waveform, by squaring all values to transform all negative integers, averaging the original and newly converted positive values over a designated period, and then taking the square root of the result to return data to the original scale.

Acknowledgements

This project owes its success to contributions from many individuals from several organisations.

Funding was provided by the Rainforest CRC / Queensland Department of Main Roads Strategic Alliance, with logistical support from the School of Tropical Environment Studies and Geography, James Cook University.

Field assistance from Peter Byrnes, Tina Lawson and Catherine Pohlman was greatly appreciated, along with advice and support from Nigel Young and Frank Cuda. Thanks also to Mike Steele and Elaine Harding for valuable statistical advice, and to Les Searle for his surveying advice.

The Facilities Management team at James Cook University's Cairns campus arranged vehicle allocations. Eva King and the staff of the administration office of the Faculty of Science and Engineering, James Cook University, gave helpful advice and support with travel and field-trip arrangements, along with Steven Holloway and Steven Stanley who assisted with IT issues.

We also acknowledge the advice and assistance of the regional staff of the Queensland Department of Main Roads, particularly Boyd Angus for the provision of contour maps and topographic profiles. David Rivett of Environment North assisted with liaison between the project partners and supplied technical advice on the Kuranda Range Road Upgrade Project.

Thanks must also go to Richard Opie of Pentacom for undertaking repairs to recording equipment and for the provision of advice on acoustics, and to Krzysztof Koltys of Svantek Poland for his helpful advice and detailed explanation of functionality of the sound level meter.

Greg Dawe
Postgraduate Research Officer
School of Tropical Environment Studies and Geography
James Cook University

Dr Miriam Goosem
Senior Research Fellow
Cooperative Research Centre for Tropical Rainforest Ecology and Management
(Rainforest CRC)

Executive Summary

Section 1: Literature Review – The effect of traffic noise on wildlife

Research Objectives

This review of scientific literature was undertaken in order to identify known effects to wildlife caused by exposure to traffic noise. Such effects include:

- Physiological impacts such as ear trauma and raised hormone levels; and
- Behavioural responses such as elevated stress levels, acoustic adjustment and road avoidance.

Due to paucity of data on animal species, the review also includes known noise effects on human subjects

Significant Findings

- Most literature discussed animal avoidance responses to roads, and mostly in the temperate climes of the northern hemisphere.
- Information lost from calls and noise attenuation is determined by the loudness of sound, frequency range, the receiver's ability to detect the sound and the attenuation characteristics of the habitat – losses in forests are raised by five to ten decibels over areas with no obstruction. Animals adapt their calls to compensate for the type of habitat so that individuals can be recognised and distances estimated.
- Researchers link traffic noise with reduced bird diversity and species abundance adjacent to roads to distances of up to 1,750 metres from highways through forests and further through other habitats. Edge effects in the absence of noise may contribute to the reduced bird density. Frogs also exhibit reduced populations although it is unclear whether this is due to noise, pollution or mortality from traffic. Avoidance in coniferous forests has been measured and varies between forty and 1,750 metres depending on species and traffic levels, with even greater distances observed in less dense habitats such as grasslands.
- Traffic noise impedes movement by mammals through culverts under highways constructed in Canada for habitat connectivity and causes deer to flee in other areas. Noise also increases stress hormone levels in mammals. Some mammals also suffer raised stress hormone levels.
- Studies on acoustic responses to noise by fauna (mostly birds) have been predominantly laboratory-based, finding traffic noise to impede the recognition of mating calls in five North American frog and toad species, and to induce raised amplitude levels in songs or calls of tree swallow nestlings, zebra finches, lovebirds, African bush shrikes, nightingales, canaries and budgerigars.
- Field experiments have found some temperate birds overcome traffic noise blanketing by singing louder or by making adjustment to the pitch of their songs. This may impact their general fitness by requiring expenditure of greater amounts of energy. Birds singing songs with higher dominant frequencies appear, in some cases, to be less affected.
- Anthropogenic noise in the range of 65-85 dB(A) has caused flight and alert responses in birds and behavioural changes.
- Mating behaviour of North American frog species is altered by playback of traffic noise in the field. Similar responses might be expected in rainforest frogs.

- High traffic noise levels induce a range of severe, often chronic clinical responses in humans, with limited tests on selected fauna indicating similar adverse reactions.
- No studies have examined the effect of traffic noise on tropical rainforest fauna including those communicating by sound such as birds and frogs.

Management Implications

- Some species previously considered to comprise viable populations may now be at risk due to increasing traffic noise levels.
- Noise levels previously considered to be safe may negatively affect some fauna.
- Low-frequency sound and vibration from traffic sources may be impacting on some fauna.

Recommendations

- Studies should be undertaken on the effect of traffic noise on bird species living in tropical rainforests.
- Existing and future roads (including upgrades) should be designed to minimise the extent of traffic noise propagation into surrounding landscapes.
- Sections of highways generating high noise levels should avoid habitats occupied by rare or threatened fauna.

Further Research

- Wildlife populations in areas close to heavy traffic need to be assessed using indicators of highway avoidance, such as species richness and population density surveys combined with noise measurements within the habitat.
- Species which appear to alter vocalisations in order to exist in high traffic noise environments need to be assessed for stress to energy budgets, and ability for individuals to recognise calls from other individuals.
- The sphere of research into traffic noise effects should include more faunal groups including invertebrates and frogs.
- This research should include noise effects from the frequency spectrum edges including infrasound.

Section 2: Traffic noise propagation through montane rainforest

Research Objectives

The project was designed to collect daytime noise-level data along the Kuranda Range Road, north of Cairns, with the primary aim of accurately representing third-octave noise conditions through the rainforest adjacent to the road at heights of one and fifteen metres above the forest floor under varying microtopography.

A secondary objective was to delineate any acoustic refugia (areas of relative quiet shielded from traffic noise) along the current road and examine potential impacts on these from the proposed road upgrade.

Data covered a suite of acoustic descriptors including third-octave dissemination. Noise data was collected at heights of one metre (representing ground level) and fifteen metres above the forest floor (representing lower canopy level) for a period of twelve hours from each site.

Sample sites along eight transects perpendicular to the Kuranda Range Road were located at the highway edge, one hundred metres from the edge, and at two hundred metres into the rainforest. Data was used for comparison with noise modelling generated for the current and upgraded road.

Significant Findings

- Traffic noise at the edge of the forest was louder at ground level than in the canopy, whereas traffic noise levels in the forest interior were greater at canopy level than near the ground.
- Traffic noise levels decreased with distance into the forest; being louder at the edge than at one hundred metres, and louder at one hundred metres than at two hundred metres.
- Traffic noise was still a significant component of the acoustic environment at two hundred metres inside the forest away from the rainforest edge.
- There was no significant difference in edge noise levels at one metre above the ground between dawn, noon and evening during weekdays. However, edge canopy noise levels did vary significantly when tested across the three one-hour time periods. Traffic noise is relatively continuous during the day when examined over ten-minute intervals.
- Noise levels were strongly correlated to traffic flows at the edge of the rainforest at both height treatments, however further into the forest, biotic sounds and noise from other natural sources such as wind were more significant.
- Total noise levels at the edge of the forest during the daytime are relatively continuous at a loudness recognised to have serious implications for human health. Without further information concerning the impact of continuous noise on the variety of wildlife present on the Kuranda Range, a precautionary approach would suggest that such a level might also cause problems in at least some wildlife species.
- The dominant frequency of traffic noise on the Kuranda Range was 1 kHz however traffic noise caused changes to the forest sound frequency spectrum from 31.5 Hz to 2 kHz, which has the potential to blanket areas in which some bird and frog species communicate, particularly at the edge of the forest.
- Modelling prepared for the Kuranda Range Road Upgrade Impact Assessment Study by acoustic engineers failed to predict the high noise levels at the forest edge of the existing highway, although the same model was relatively accurate for most forest interior sample sites. At the edge, model underestimates of noise levels varied from 17 to 31 dB less than measured. This means that in some cases, the edge of the road was approximately four times as noisy as had been modelled.
- It is suggested that modelling for the road upgrade would be similarly inaccurate at the forest edge.
- Acoustic refugia that exist under the current alignment of the road were identified by extrapolating results from transects sampled, together with consideration of topographic data.
- Two quiet refuges in particular are likely to become far noisier if the upgrade proceeds, and several other refuges are also likely to be affected to some extent.
- New acoustic refuges may be created by the new alignment; however re-calibration of the noise models should be undertaken prior to delineation of these areas.
- Individual noisy vehicles do much to elevate noise conditions at both edge and interior sites. These peaks are missed from models using L10 descriptors, with L1 noise levels at the edge being typically about ten decibels higher (double the perceived loudness) than L10 levels. Peak levels along the edge are usually more than ten decibels above the L1 levels, with occasional A-weighted peaks above 110 decibels.

Management Implications

- Noise levels likely to arise from the proposed upgrade will significantly impact on the acoustic environment at several interior locations at present experiencing relative quiet.
- Fauna in some existing acoustic refugia will be subjected to significant increases in background noise levels.

Recommendations

- Modelling used to gauge noise levels adjacent to the existing Kuranda Range Road and other models predicting noise levels for the upgraded road should be re-calibrated to account for the significantly higher noise levels recorded along the highway edge compared to noise levels predicted by the ASK models prepared for the QDMR.
- Field noise data should be sampled below bridges to examine the degree of acoustic shading incorporated in the models in areas at lower elevations than the adjacent proposed highway. Currently, we have no data to assess this.
- Acoustic refugia currently occurring due to topographic shielding from traffic noise on the existing highway should be protected when the upgrade is built.
- Acoustic refugia created by construction of the new road alignment should be mapped and receive similar protection to those currently extant.
- Due to the high noise levels experienced at the current road edge, reductions in impulse and peak noise levels should be achieved through reducing emission levels from the noisiest road users. Muffling noisy exhausts, and curbing the deployment of compression braking, particularly in areas of high habitat and conservation value such as creek crossings and areas providing connectivity, should be implemented by the relevant authorities.
- Means of mitigating noise impacts including concrete crash barriers of varying heights should be tested for their ameliorative value for the majority of vehicles but also for any effect on heavy transport-generated noise. Alternative designs may need to be considered in sensitive areas such as bridges across creeks and connectivity corridors.
- Innovative means to trim commuter peaks by spreading employment hours or restricting heavy transport movement to hours outside commuter traffic peaks should be evaluated.

Further Research

- Evaluation of the effectiveness and suitability of the proposed noise barriers intended for the upgraded road should incorporate the noise levels recorded during this project.
- An assessment of noise outputs from the noisiest highway users aimed at reducing peak and impulse noise levels from these ‘rogue’ operators needs to be undertaken.
- Assessment of noise levels below bridges should be undertaken. As much of the upgraded highway will skirt valley acoustic refugia for fauna, and in consideration of the number of bridged sections intended for the upgrade, more research needs to be undertaken on the role of bridges on traffic noise propagation, which also examines propagation of infrasound noise and reverberation effects.

Section 3: Effect of traffic noise on avian vocalisation

Research Objectives

The objective of this section of the project was to analyse any frequency shifts in birdsong recorded at the edge of the Kuranda Range Road. This was achieved through comparison of dominant frequency of birdsongs recorded in the forest interior and at the edge of a road with minimal traffic with dominant frequencies of songs recorded at the edge of the Kuranda Range Road.

Significant Findings

- Songs of fifty-nine bird species were recorded along transects adjacent to the Kuranda Range Road and at control sites adjacent to Black Mountain Road. The dominant frequencies of songs from eighteen of these species recorded at locations adjacent to the highway and at two hundred metres into the interior were analysed for evidence of any acoustic modification over distance.
- Nine of the eighteen species showed significant differences in dominant song frequencies between individuals recorded at the edge of the forest closest to traffic noise and individuals recorded in the forest interior. Of these, five species were considered to have sufficient replication of the effect between individuals to be attributable to traffic noise and not to other potential confounding factors.
- At least three of the tested species appear to adjust their songs' dominant frequency in order to overcome traffic noise masking,
- It appears that, at least in some species, traffic noise can have deleterious impacts on rainforest bird species through adjustment of song frequency, which has the potential to alter energy budgets, increase predation risk and reduce success in reproduction.

Management Implications

- Traffic noise at current levels appears to cause modification of bird song with the possibility of altered energy budgets to achieve unnatural pitch adjustments, increased risk of predation and reduced success in mate attraction and therefore reduced fitness of individuals near the road.
- Pitch adjustments to songs are likely to have metabolic costs for species because of a possible requirement to use more energy to achieve a different pitch, which may result in less energy available for growth and reproduction. Pitch adjustments may also alter the ability of other birds of the same species to detect the song or alter the likelihood of predators detecting the individual. Such changes could, in turn, reduce the fitness of individuals.
- This is a road impact not generally considered in road construction or upgrade and requires consideration of mitigation strategies to prevent the propagation of traffic noise through areas close to a road so as to avoid reduced fitness of individuals of some species of birds.

Recommendations

- To reduce the need for pitch adjustments to birdsong, reduction of traffic noise propagated into the rainforest should be a priority in design of roads traversing areas of high conservation value such as the Wet Tropics World Heritage Area.
- Traffic noise along the edge of the Kuranda Range Road upgrade should be mitigated as far as possible using noise barriers.

Further Research

This research represents the first examination of traffic noise effects on tropical rainforest birds in Australia. Therefore many topics require further examination, including:

- Analysis of the remaining birdsong recorded during this project to allow further examination of the focal species as well as others;
- Future research that addresses the possible metabolic costs, potential increased risk of predation and possible reduced success in attraction of mates for birds of tropical rainforest;
- Future research that examines the effects of traffic noise on other elements of the calls of tropical rainforest birds such as call-spacing, mean minimum and mean maximum frequency, changes to loudness of song, modification of song repertoire and distance of signal detection and recognition by other individuals; and
- New studies that establish the relationship between habitation preference and dominant frequency of song, in order to assess whether species singing at frequencies close to traffic noise prefer to live away from the highway edge.

Section 4: Effect of distance from edge on avian populations and biodiversity

Research Objectives

The objectives of this section were to examine potential bird avoidance of habitat adjacent to the Kuranda Range Road in comparison with the forest interior and with a control road with minimal traffic.

Significant Findings

- There was evidence of a pronounced edge effect producing lower bird densities and reduced species richness immediately adjacent to the highway. Bird abundance increased with distance from the road edge and significantly more birds were observed at two hundred metres inside the forest than at the road edge.
- Abundance of bird species most dependent on rainforest increased significantly with distance into the forest with greatest abundances found in the forest interior (one hundred and two hundred metres from the edge). Species richness of rainforest-dependent birds was also greatest at these interior zones.
- No rainforest obligates were recorded at the edge zone.
- Opportunist species not normally associated with rainforest were found only at the edge zone.
- Increased bird abundance and species richness were observed at thirty metres from the highway at Streets Creek; most evident in the frugivore and omnivore feeding guilds. This suggests that the Streets Creek area is a special habitat that requires protection.
- Poor weather conditions during many surveys resulted in fewer bird observations.
- Although the observed edge effects cannot be attributed entirely to traffic noise, given the variety of other impacts on vegetation occurring in the vicinity of road edges, there is circumstantial evidence to suggest that road noise was a contributor to the edge effect. This evidence results from the presence of species that otherwise avoided the road edge in a zone thirty metres in from the road where an acoustic refuge occurred caused by the protection of a topographic ridge. Similarly, a group which appeared to avoid the road edge was also one in which members reacted to traffic noise by altering the frequency of their song.

Management Implications

- Both bird abundance and species richness are likely to be depleted in areas where the new highway footprint covers existing interior and zones providing an acoustic refuge due to edge effects from the new road.
- Noise levels associated with the upgraded highway and new alignment are likely to force rainforest dependent birds out of existing habitat, although the areas from which the road alignment has been moved may be quieter, allowing rainforest birds to colonise. However, such colonisation is dependent on the noise levels emanating from the greater levels of traffic (see Section 2).
- Regenerated areas available due to re-alignment are unlikely to adequately compensate for habitat lost by the upgrade, due mainly to the gap in re-establishment time. In time these areas may be colonised by rainforest interior bird species, subject to the success of the rehabilitation strategies implemented.
- Reducing the amount of traffic noise entering the forest adjacent to the highway is likely to reduce edge effects in bird abundance and species composition. Noise barriers could also contribute to a fence and funnel strategy that prevents animals entering the roadway, although this is unlikely to affect the majority of birds. Noise mitigation should especially concentrate on areas currently shown to have high bird diversity and abundance such as the area near the road adjacent to Streets Creek, affected interior zones and to areas with similar potential to support high bird populations.

Recommendations

- As it appears that traffic noise is likely to be at least a partial cause of bird avoidance of roadside edges, noise mitigation strategies for areas associated with highway re-alignment such as near Streets Creek need upgrading to account for expected loss of topographic shielding.
- Traffic noise along the edge of the Kuranda Range Road upgrade should be mitigated as far as possible using noise barriers.
- Data should be reinforced by follow-up avian surveys under more optimum weather conditions, undertaken prior to commencement of upgrade.
- A monitoring program to assess impact on avian diversity and abundance should cover both the construction and post-construction phases of the highway upgrade.

Further Research

- Other areas adjacent to the existing Kuranda Range Road with similar topographic characteristics to the Streets Creek transects should be examined for similar near-edge recruitment zones.
- Replication of data collection and further transect replication would strengthen the edge effect examination and possibly allow more detailed examination of guilds and common species.
- Inter-relationships between seasonality, guilds, climate and survey time require modelling in order to produce calibrations to accurately weight bird survey data.
- New surveys should examine bird occupancy and habitat quality under multi-lane highway bridges to assess the degree of useful habitat gain and occupancy potential for rainforest dependant species.

Terms of Reference

Rainforest CRC / QDMR Strategic Alliance Sub-project 2(b): Noise Disturbance along Highways (Kuranda Range Road Upgrade Project)

Aims

1. To undertake a literature review of faunal disturbance by traffic noise and relate this to fauna occurring in the Kuranda Range area.
2. To review standard engineering noise assessment and decibel weightings to consider whether these are applicable to noise impacts on fauna.
3. To examine potential bird avoidance of habitat adjacent to the Kuranda Range Road in comparison with a control road with minimal traffic.
4. To examine the dissemination of traffic noise in areas of varying microtopography and under different noise conditions.
5. To analyse any frequency shifts in birdsong recorded at the edge of the Kuranda Range Road, in the forest interior and at the edge of a road with minimal traffic.
6. To determine whether the Musky Rat-kangaroo avoids experimental traffic noise.
7. To examine the efficiency of noise abatement techniques suggested by Queensland Department of Main Roads aimed at reducing the dissemination of noise adjacent to bridges and underpasses.
8. To consider the implications of the report findings on fauna of conservation significance.

Background

Noise disturbance along highways may affect sensitive fauna. Groups affected could include both birds and amphibians that use aural communication and other groups disturbed by increased noise. For example, researchers in the Netherlands found that almost twenty percent of woodland areas were noise-affected for sensitive species such as the cuckoo (Reijnen *et al*. 2002) and that total bird population densities across all species were reduced once noise reached an average of 42dB (Forman *et al*. 2003). Noise disturbance is also known to cause problems for certain frog species. However, almost no research has examined noise impacts on fauna of tropical forest regions. One study in the rainforests of Central Africa found that one bird species had environmental variation in its song that might be attributable to road noise problems although other possible causes were not eliminated (Slabbekoorn and Smith 2002b).

Blanketing of communication by road noise has the potential to reduce breeding success, increase the risk of predation of birds calling louder and cause birds to expend more energy by calling louder or at an unusual frequency (Slabbekoorn and Peet 2003). In the Wet Tropics of Australia, road noise penetrates the rainforest understorey more than one hundred metres (Marks and Turton 2000). Recent studies along the Palmerston Highway and Kuranda Range section of the Kennedy Highway have extended the noise effect zone at understorey and mid-canopy level to more than two hundred metres where road noise shows a spectrum shift toward the lower frequency bands (Dawe 2005). Traffic noise is greater in the rainforest canopy than at ground level (Dawe 2005) and overlays the frequency bands at which some Wet Tropics birds sing. At least one bird species near the edge of the Kuranda Range Road shifted the frequency of its song in comparison with the nearby Black Mountain Road edge (Dawe 2005), even though its peak singing frequency is higher than peak traffic noise frequencies.

Objectives

This project will undertake a literature review with respect to those fauna known to be affected by traffic noise and relate this to species found in the Kuranda Range area and sections of the upgrade design that will need to consider noise abatement. The applicability of standard engineering noise modelling to fauna will also be reviewed. Transect assessments should allow any edge avoidance by birds to be examined. Continuation of birdsong recording will establish whether bird species other than the Grey Whistler (Dawe 2005) are affected by traffic noise to the extent of shifting the frequency of their song. The dissemination of noise into the forest will also be examined at areas of different microtopography and under differing noise conditions (e.g. comparison of large trucks using air brakes with smaller vehicles) and noise abatement techniques. As the methodology for both noise dissemination and birdsong collection has now been extensively tested, greater time can be devoted to data collection and analysis. The final component provides technical support to a postgraduate project that examines the impact of experimental road noise to Musky Rat-kangaroo individuals of the forest interior. Musky Rat-kangaroos appear to avoid highways, never having been observed dead on the Kuranda Range Road or nearby. One potential cause of avoidance is traffic noise and this was a focus of the project.

Results of analysis of this noise and birdsong data will enable:

- Calibration of the noise modelling currently used to assess existing and future noise conditions along the Kuranda Range Road;
- Assessment of the extent of impact traffic noise from the existing road is having on local avian communities; and
- Assessment of the degree to which some bird species are able to overcome acoustic blanketing from traffic noise.

Outcomes for QDMR and Rainforest CRC will include:

- An increased database on noise conditions proximate to the existing Kuranda Range Road based on actual field measurements, generating a range of noise descriptors including third-octave analysis;
- Identification of likely acoustic refugia close to the existing Kuranda Range Road; and
- Identification of bird species likely to be threatened by current noise conditions, and from the noise environment created by the proposed road upgrade.

Noise Disturbance along Highways

Section 1:
Literature Review – The effect of traffic noise on wildlife

1. Literature Review – The effect of traffic noise on wildlife

Gregory Dawe

Summary

The amount of information lost from a sound over distance is primarily determined by the loudness of the signal, frequency range, the receiver's capability to detect the sound and the attenuation characteristics of the medium through which it travels. With no obstruction, losses of six decibels occur each time the distance from the source is doubled, but through forests losses are typically raised by five to ten decibels. Birds adapt their calls to compensate for the type of habitat in which they are calling and to allow estimation of distances between individuals within that habitat. Tropical forest birds tend to avoid modulation of frequencies in long distance calls due to the high incidence of sound reverberations in dense forests.

Traffic noise impacts on behaviour of fauna, including five North American frog species which fail to recognise mating calls, with males altering their spacing when trying to attract mates. Similar effects are expected in rainforest frogs when calls are blanketed by traffic noise. Population declines in European and North American frogs near roads are correlated with traffic volume and may be due to traffic noise, but could also be associated with road mortality or pollution. Research in southern Australia is examining frog reaction to traffic noise playback with regards to call pitch adjustment and rate of calling.

Traffic noise is a significant deterrent to highway culverts providing connectivity for Canadian mammals and is likely to be the initial trigger that causes deer to flee from vehicle disturbance at a distance, thereby wasting energy. Physiological impacts of vehicles on mammals have been observed in the form of raised stress hormone levels, although this varies between species, gender and situation. Infrasound levels need also to be considered for certain species.

Anthropogenic noise can cause interference in areas of the sound spectrum used for communication by certain species, particularly amphibians. By using a particular frequency they avoid sound emanating from other species and also confuse predators seeking out individuals from the chorus. When noise disturbs the chorus, predators have more opportunity to locate an individual attempting to re-establish the chorus. Road traffic volume and noise from weapons testing can also disrupt activity patterns of raptors.

Elevated noise levels can cause a range of responses in birds, including raising the loudness of their song to overcome the noise blanketing. Tree swallow nestlings beg more loudly and longer and change their call pitch to compensate for nearby traffic noise. Calling more loudly diverts energy which would otherwise be used for normal activities, resulting in poorer growth and lowered fitness of individuals. Birds may also adjust the frequency (pitch) of their calls to compensate not only for anthropogenic noise but also for the presence of other sounds in their natural environment. They may also choose to call during quiet periods, to avoid interference from other birds and potentially also from traffic.

Reduced bird diversity, species richness and average density of species have been found near roads in many temperate areas of the world in habitats varying from forest through woodland to grasslands. Species-dependent effect distances in coniferous forests varied

from one hundred to 1,750 metres at traffic volumes of 40-60,000 vehicles/day and 40-790m at 10,000 vehicles per day. Greater distance effects are generally found for less dense habitats such as grasslands. Many researchers link this avoidance with traffic noise exposure. In some cases, birds singing at higher dominant frequencies appear to be less affected. Avoidance of roads by certain tropical forest bird guilds has also been demonstrated in the almost complete absence of traffic and is thought to be caused by edge avoidance and linear barrier effect (avoidance of crossing linear gaps in the canopy).

Anthropogenic noise can also trigger flight and alert responses in birds and altered behaviour after the noise disturbance, which can lead to reduced breeding success, at noise levels ranging from 65-85 dB(A). Complete habituation to such disturbance does not always occur, even in less noise-sensitive species.

Exposure to noise can trigger stress-type physiological reactions in humans, posing certain risks to health after long exposure across the medium-frequency bands. Increased blood pressure, heart disease, gastrointestinal disease, heart attack, cardiac arousal during sleep, shortened gestation periods and decreased birth weights, and hearing loss, have all been attributed to chronic exposure, while increased infrasound levels can increase respiratory tract infections, cardiovascular problems and neurological disturbances. Laboratory mice and rats also have demonstrated effects to low frequency noise.

Overall, despite the problems caused by noise to humans, there is little scientific literature about the effects of anthropogenic noise on wildlife. The limited available data concerns mainly northern hemisphere temperate bird species, with almost none on fauna of any group in tropical rainforests. It is expected that noise impacts may produce similar symptoms to those observed in humans, with some species and individuals being able to adapt, while in others adaptation is not an option and avoidance is the only possibility, with consequent reduction in diversity and abundance of faunal groups.

1.1 Introduction

1.1.1 Ecological effects of roads

Many of the ecological impacts of roads are well recognised but that of traffic noise is less well understood. Roads have an ecological impact upon fifteen to twenty percent of the mainland United States, with ten percent of those roads cutting through national forests (Forman and Alexander 1998). Although American car owners drive an average of only one hour per day, every square kilometre of land in the United States contains an average of 1.2km of road, while in the Netherlands that amount rises to 1.5km (Forman and Alexander 1998). The European Union's Green Paper on Future Noise Policy (1996) conservatively estimated the annual cost of transport noise to European society at over twelve billion Euros.

1.1.2 Signals and general acoustics

To understand the impacts of traffic noise requires some understanding of general acoustics and sound dissemination. The amount of information lost from a sound over distance is primarily determined by three parameters - the sound pressure level (loudness) and acoustic structure (frequencies) of the source signal; the receiver's capability to detect the sound; and the attenuation characteristics of the medium that the sound must travel through (Wiley and Richards 1978). Sound spreads in an almost spherical pattern from sources well clear of the ground, with attenuation losses for all frequencies of approximately six decibels each time the distance from the source is doubled (Naquib and Wiley 2002).

Attenuation losses in forests are typically raised between five and ten decibels above attenuation rates for sources clear of ground and foliage. At least one bird species (Carolina

Wren) calibrates its vocalisation according to seasonal foliage conditions (Naquib 1996a). It bases the degree to which it adjusts its song to compensate for the emergence of new leaves in spring upon previous learned experience of song degradation caused by attenuation through this environment. In studies of songs of the White-browed Warbler *Basileuterus leucoblepharus*, Mathevon and others (2003) found that vocalisations are accorded an 'active space'. Some songs, such as those for species identity, are "encoded into a parameter that resists sound degradation", while songs related to motivation and individual identity can be more sensitive to propagation-induced changes. There are also significant differences in species-distinguishing characteristics of songs of closely related dove species (Beckers *et al*. 2003). This is attributed to the difficulty of employing visual cues over large distances if caller and receiver are obscured from each other. Some species such as king and emperor penguins use combinations of both behavioural strategies (Aubin 2003) and acoustic adaptations such as close-matching codes embedded in a carrier signal of the parent's call (Aubin *et al* 2000; Aubin and Jouventin 1998) to aid parent/chick call identification in large colonies.

Studies by Wiley and Richards (1978) found that frequency-dependent attenuation is not consistently different between terrestrial habitats, e.g. vegetation-induced scattering of the higher signal frequencies in forests is to some extent balanced by microclimatological scattering of the same bands in open areas. These researchers were among the first to suggest that the vocalisations of some species may be designed with predictable degradation characteristics to allow estimation of the signaller's distance by the receiver (Wiley and Richards 1978). They also proposed that avoidance of frequency modulation within long-range signals of tropical-forest birds may be caused by greater likelihood of sound reverberations in dense forests; a feature that masks rapid repetitive frequency modulation and also amplitude modulation in the higher frequency bands (Wiley and Richards 1978).

1.2 Behavioural impacts on fauna

1.2.1 Frogs

Traffic noise has been demonstrated to have impacts on the breeding behaviour of frogs. For example, recordings of male mating calls were played back to female frogs of the same genus in laboratory experiments by Barrass and Cohn (1983). They found that introduction of traffic noise significantly impeded recognition of the call for five out of the six species tested. In these North American woodland frog and toad species, the distance between male frogs is normally influenced by aggressive vocalisations or long calls between individuals. Fieldwork by the same researchers (1984) found spacing between male frogs was significantly altered by exposure to traffic noise playback. It is likely that the acoustic cues normally employed by rainforest species in breeding choruses to gauge group density and thereby establish individual spacing, would be similarly weakened by the effect of traffic noise blanketing.

Research in Switzerland on European tree frogs *Hyla arborea*, found that the presence of vehicles in the vicinity of breeding ponds was responsible for low densities of the species (Pellet *et al.* 2004a), and that having roads in the vicinity reduced the probability of tree-frog presence (Pellet *et al.* 2004b). However the researchers were unable to discriminate between road mortality or less direct effects such as pollution or traffic noise as the causes of these population declines (Pellet *et al.* 2004a). Studies in the Netherlands by Vos and Chardon (1998) on the tendency of moor frogs *Rana arvalis* to occupy moorland ponds revealed a negative effect on population numbers attributable to traffic density. Frog population densities in this study were not based solely on chorus strengths, but also incorporated observational counts of tadpoles, egg-clusters, juveniles and adult frogs in ponds and their surrounds. This method assumed equal sex ratios of adults, with the final density estimate derived from the number of egg clumps in the area, and the number of calling male frogs, thereby enabling relative population densities between ponds to be calculated (Vos and Chardon 1998). Road-kill counts were not recorded in the latter study; therefore the contribution of direct effects of collision mortality on frog densities cannot be dismissed, along with the fragmenting effects of the roads.

In Canada, road-kill of frog and toad populations near three paved double-lane roads with traffic volumes of 500-3,500, 5,000-6,000, and 8,500-13,000 vehicles per day is significantly affected by day, time and traffic volume (Fahrig *et al.* 1995). Increasing traffic density resulted in a decreased density of frogs and toads as measured by the intensity of calls in the nightly chorus and the number of individuals identified, although again it was impossible to define whether the population decline was caused by avoidance of traffic noise, by failed breeding due to acoustic interference from traffic noise, or because of the loss of animals from road mortality. When these studies are considered overall, therefore, the degree to which traffic noise has affected frog densities remains unclear, although some factor associated with roads and traffic has been shown to reduce frog populations.

Current Australian research into frog vocalisations (Parris, cited in Catchpole 2004) is assessing whether frogs are compensating for traffic noise through pitch adjustment of calls, and whether larger frogs which call at lower frequencies are likely to be impacted to a greater extent than species of smaller frogs. That research is also examining frogs' reaction to traffic noise in relation to vocalisation activity levels, via playback recordings of loud traffic (Catchpole 2004). The results of this research should complement work done by Wollerman (1999) on neo-tropical tree-frogs *Hyla ebraccata* in Central America, which found that continuous background noise elevated acoustic interference to vocalisations and inhibited the detection of calls.

1.2.2 Mammals

Studies on the usefulness of highway culverts as connecting corridors for fauna (Clevenger *et al.* 2001) found traffic noise to be a significant deterrent in four out of five of the North American taxonomic groups tested. Carnivores (weasels and martins) were the least affected, while red-squirrels and snow-hares were the two species most influenced by the level of traffic noise. Studies undertaken on the use of faunal underpasses in tropical regions have thus far not incorporated traffic noise as a parameter.

Barrett (1976) studied the responses of 741 deer to a four-wheel drive vehicle driven along roads in the Eldorado National Forest (USA). An urgent escape response was observed for 56% of all deer encountered, with only 20% of deer exhibiting no indication of disturbance. Of this group, 38% displayed an urgent escape response when the vehicle was stopped after passing its closest point of approach. An urgent escape response was defined as the deer fleeing for at least fifty metres within thirty seconds of the vehicle encounter. Such a reaction was deemed likely to severely impact a deer's energy budget, particularly in late winter, and constituted a potential threatening stress. It was suggested that as almost one-third of the deer encountered were first observed running, that vehicle noise may be the triggering agent to the deer's reaction, particularly when terrain or foliage obscured the approaching vehicle (Barrett 1976).

Little research has been undertaken on mammalian vocalisation responses to the presence of traffic noise. However, one seminal study by Rabin and others (2003) found that ground squirrels exposed to traffic noise modified their calls by transferring the acoustic energy to higher harmonics free from traffic noise masking.

1.3 Physiological effects on fauna

Physiological impacts on fauna caused by vehicles nearby have been demonstrated for several species, although whether this is due to noise is unclear. For example, research in three North American national parks by Creel and others (2002), found wolves and elk suffer significant physiological stress responses to snowmobile traffic as indicated by raised faecal glucocorticoid levels. Whether these raised stress levels were due primarily to noise emissions from the vehicles was not established during this study, and concurrent studies on the effects on the same species from wheeled vehicle traffic indicated a much lower elevation of glucocorticoid levels. However extensive laboratory studies on both human and animal subjects indicate that extended periods of raised glucocorticoid levels reduce both reproductive rates and survival (Munck *et al.* 1984; Sapolsky 1992).

In some animal species traffic noise elicits a different response across gender. Adult male grizzly bears venture closer to vehicles and traffic noise than do females of the same species. This aversion to road traffic does not appear to represent a lesser tolerance of humans by the females, as they proved more willing to move into areas of human settlement than male grizzly bears (Gibeau *et al.* 2002). Research in Britain into otter mortality on roads by Philcox and others (1999) found a similar gender bias towards roads, with male otters significantly more likely than female otters to become collision mortality victims. No inference was made as to the role of road noise as a deterrent or contributor to the road-kill statistics in the above research. Gibbs and Steen (2005) point to a greater female road-kill composition for turtles (60-66% of the victims) than would be expected from latest gender ratios in living populations (approximately 60%). A contributing factor for this is likely to be the risk posed to female turtles during nesting migrations by the hazards of highway crossings (Gibbs and Steen 2005).

Not all mammals have been found to react adversely to the presence of motor vehicles, with Macarthur and others (1982) finding that heart rates of bighorn mountain sheep *Ovis canadensis canadensis* was elevated in only 8.8% of 215 sheep monitored. The approaching vehicle elicited a withdrawal response in only two of the sheep. This study was conducted within a protective wintering reserve for the sheep, using a gravel road regularly traversed by 25-30 vehicles per day. The researchers also tested responses to the presence of approaching humans, and humans with dogs, and generated far greater cardiac responses in the sheep. This is not surprising, as the sheep are hunted each year during summer (Macarthur *et al.* 1982), and an association between pedestrians and the threat posed by hunters would be expected, whereas a degree of de-sensitising to vehicular traffic is likely within the wildlife sanctuary.

Macroinvertebrate soil fauna has been found to be less abundant close to forest roads than at sites in the forest interior. This decline of abundance was found to extend for distances of up to one hundred metres from the forest edge, with a similar effect noted for leaf-litter depth (Haskell 2000). Whether the edge-effect on macroinvertebrate numbers was directly related to the presence of leaf-litter or to effects of traffic, such as noise, was unclear. A decline in species richness amongst the macroinvertebrates (significant for fourteen out of the fifteen taxonomic groups studied) was observed only within the first fifteen metres from the edge, and such reductions may contribute to diversity reductions in ground-dwelling vertebrates and birds that rely on macroinvertebrate food sources within those areas. The research did not link the alteration in macroinvertebrate populations to the effects of road noise, with the reduction in leaf-litter due to raised wind strengths and increased desiccation from edge-effects suggested as the most likely cause (Haskell 2000).

Studies of the effects on wildlife of infrasound from anthropogenic noise sources present another potential genre of impacts from traffic noise. O'Connell-Rodwell and others (2003) determined that sound transmissions need not be confined to an air or water medium to play an important role in animal communication, with African elephants employing seismically transmitted signals to distances up to at least 875 metres. Prenatal exposure of animals to noise has produced a range of teratogenic effects including high cortisol and corticotrophin levels in Rhesus monkeys, and increased serum corticosterone levels and behavioural abnormalities in rats (American Academy of Paediatrics 1997).

1.4 Consequential impacts

Anthropogenic noise has the ability to alter what Krause (2001) has termed the 'Biophony' or creature choir present in 'natural' habitats in which individual species vocalise in frequency bandwidths free from the acoustic clutter of other fauna. Krause suggests the level of bandwidth interference from competing species or anthropogenic noise within a habitat is inversely correlated to the health of that habitat, because the establishment of choruses by fauna such as frogs creates a degree of 'invisibility' for individuals within such a chorus, similar to the effect of schools for individual fish. Research on spade foot toads *Scaphiopus hammondi* has found an increase in opportunistic predation due to biophony disturbance from an aircraft, with the position of individual toads identified by owls and coyotes as they sought to re-establish the group chorus (Krause 2001). It therefore appears likely that other anthropogenic noise sources such as road traffic may also contribute to biophony disturbance and raised risk of predation.

Studies by Bautista and others (2004) along a road near Madrid, Spain (vehicles/day >5,000 on weekdays; >10,000 on weekends), found that road traffic has a cyclic effect on the activity patterns of some raptor species. For three of the larger species, European Black Vultures *Aegypius monachus*, Griffon Vultures *Gyps fulvus*, and Spanish Imperial Eagles *Aquilla adalberti*, more individuals were observed close to the road during weekdays than on weekends. The six other raptor species studied were always found in greater numbers closer to the road irrespective of day type (Bautista *et al.* 2004). The authors suggested that traffic levels of country roads may have a significant effect on the activity range of larger raptors, particularly the rare Spanish Imperial Eagle, one of the world's most endangered birds of prey. Schueck and others (2001) found no alteration to the population density of Northern Harriers *Circus cyaneus* due to military exercises, although a decline in numbers was observed during one period of intense activity involving the firing of main turret guns or machine guns on tanks, artillery rounds and small arms firing. Operations such as driving of tanks or convoy passage made no significant impact on raptor numbers (Schueck *et al.* 2001), however the effect upon other avian species by such activities was not covered in that study.

1.5 Traffic noise impacts on avifauna

1.5.1 Adjustment of song amplitude (loudness)

Laboratory exposure of nightingales *Luscinia megarhynchos* to a range of background noise levels by Brumm and Todt (2002) resulted in raised amplitude of song among the captive birds. Brumm (2004) later studied territorial songs of nightingales in noisy and quiet locations around Berlin for evidence of amplitude regulation (singing more loudly) as an adaptation to anthropogenic noise masking. This research provided the first evidence of any animal in its natural environment regulating its vocal amplitude due to noise, and suggests that some birds seek to maintain the distance of transmission of songs used for defence of territories or for attracting mates. This verifies a parallel in the avian community to the well-known Lombard effect in human conversation whereby speech loudness is adjusted by a reflexive response in noisy situations such as parties (Busnel and Mebes 1975; Katti and Warren 2004). Common nightingales position and orientate themselves to produce the most effective transmission of signals to the perceived location of the listener (Brumm 2003). Field studies by Leonard and Horn (2005) have recently discovered that tree swallow nestlings

(*Tachycineta bicolor*) in Nova Scotia (Canada) adjust amplitude of begging calls along with length and pitch of call to compensate for nearby traffic noise. However, laboratory tests on nestlings of the same species elicited only amplitude increases upon exposure to traffic noise playback. Such call adjustments are apparently necessary to elicit the desired response from the food-providing parents, but may divert energy away from growth, resulting in nestlings leaving the nest in poorer condition than individuals from quieter areas (Leonard and Horn 2005).

The raising of amplitude levels of vocalisations to compensate for noise-blanketing has been observed in laboratory experiments across a range of species including zebra finches (Cynx *et al.* 1998; Tchernichovski *et al.* 2001; Lohr *et al.* 2003), lovebirds (Busnel and Mebes 1975), African bush shrikes *Laniarius funebris* (Gahr *et al.* 1998), canaries (Lohr *et al.* 2003) and budgerigars *Melopsittacus undulates* (Dent *et al.* 1997; Lohr *et al.* 2003).

1.5.2 Adjustment of song frequency (pitch) characteristics

Field studies on the adjustment of frequencies within birdsong to compensate for anthropogenic noise pollution have covered such species as chaffinch *Fringilla coelebs* (Ilichev *et al.* 1995; Skiba 2000), the great tit *Parus major* (Slabbekoorn and Peet 2003), hooded warblers *Wilsonia citrina* (Godard 1991) and the black-capped chickadee *Poecile atricapillus* (Holschuh 2001). However, not all individual variations in frequency of birdsong can be directly linked to anthropogenic causes. A study of the song of chaffinches inhabiting three European towns by Skiba (2000) failed to find any significant alteration of the pitch of the ‘rain-call’ portion of the song, unlike results stimulating an earlier hypothesis to the contrary by Bergmann and others (1988, cited in Skiba 2000). It is therefore important to distinguish between environmental and ecological causes of alterations in the frequency used in birdsong segments of individuals of the same species. For example, Westcott and Kroon (2002) found significant variation in the dominant frequency of the song of the Golden Bowerbird *Prionodura newtonia* between five geographically isolated rainforest pockets in northeastern Australia. However, even song variations seemingly driven by ecological processes may have their roots in the acoustic characteristics of the home environment. Slabbekoorn (2004) compared the acoustic environments of contiguous rainforest and ecotone forest patches in Cameroon unaffected by anthropogenic noise. He found distinct and significant differences between the noise characteristics of the two forest types. Ambient noise from the contiguous rainforest displayed distinctive frequency bands, with the lower bands generally quieter, whereas the ecotone forest only displayed a distinctive high-frequency band at certain times during the day. Slabbekoorn (2004) attributed these habitat-dependent noise spectra to abiotic and biotic sounds, combined with the lesser effect of different attenuation properties in each habitat.

Certain bird species such as the Green Hyla that inhabit dense tropical forests, avoid excessive frequency modulation in vocalisations through the use of narrow-bandwidth notes (Slabbekoorn *et al.* 2002). Such song traits, whilst producing purer sounds and thereby triggering more reverberation than from broad-band notes (Wiley and Richards 1978), tend to form notes of longer duration that are capable of penetrating greater distances through the foliage. These types of notes provide a degree of invisibility for the bird by causing a ventriloquist-like effect, thereby hiding the signaller’s location from predators (Slabbekoorn *et al.* 2002).

Birds such as the Red-eyed Vireo *Vireo olivaceus* and the Least Flycatcher *Empidonax minimus* practice song spacing to avoid signal masking between the two species (Ficken *et al.* 1974). The song repertoire of both species share similar frequency bands, thereby potentially causing mutual song masking and interference. By adjusting the timing of their vocalisations, both species can convey information to other individuals of their own species during pauses in the calls of the other species (Ficken *et al.* 1974). It appears plausible that a similar technique could be applied by some bird species in order to overcome acoustic interference from vehicular traffic, provided sufficient quiet periods occur in the traffic stream.

1.5.3 Reduced densities in habitat adjacent to roads

Acoustic surveys in Germany by Rheindt (2003) found declines in bird diversity, species richness, and average bird abundance in forest one hundred metres from a two-lane Bavarian motorway (50,000 vehicles/day in 1992), compared to a control transect isolated from traffic noise by 750 metres of deciduous forest. This change in abundance was found to be independent of the mean body weight per species. Not all species (three out of fifteen species) were reduced in abundance near the motorway. Species with higher dominant song frequencies were found to be in greater abundance close to the motorway than those species with lower pitched song (Rheindt 2003). Earlier studies in the Netherlands by Reijnen and others (1995) found 60% of the 46 woodland bird species surveyed existed at reduced densities near roads. These researchers considered car visibility, pollution and collision induced mortality as possible contributors to density decline, but considered these factors ‘unimportant’ compared to the influence of traffic noise on species density. Mean traffic estimates for coniferous woodland roads was 45,319, and for deciduous woodland 33,334 vehicles per day (Reijnen *et al.* 1995). Noise effect distances in deciduous forests were found to be between 40 to 1,500 metres at traffic volumes of 10,000 vehicles per day, and 70 to 2,800 metres for traffic volumes of 60,000 vehicles per day. For coniferous woodland, effect distances ranged from 50 to 790 metres (10,000 vehicles per day) and 100 to 1,750 metres (60,000 vehicles per day). Rheindt (2003) agreed with this distance. Weiserbs and Jacob (2003) found a linear correlation between breeding-bird population densities in a Belgian forest and distance from sources of traffic noise. These researchers suggested that the disappearance of several sensitive species from the forest may be linked to traffic noise exposure (Weiserbs and Jacob 2003).

Other studies examined breeding bird densities in agricultural grasslands and the effects of traffic. Reijnen and others (1996) found traffic intensity strongly affected the densities of all twelve grassland bird species surveyed. Traffic volumes of 5,000 vehicles per day produced disturbance distances of between 20 and 1,700 metres for the various species. These distances expanded to between 65 and 3,530 metres depending on species for grasslands adjacent roads carrying 50,000 vehicles per day. At that traffic level all species had population density losses of 12-44% up to 500 metres from the highway, while five species: Lapwings *Vanellus vanellus*, Shovellers *Anas clypeata*, Skylarks *Alauda arvensis*, Blacktailed godwits and Oystercatchers displayed population reductions of between 14% and 44% up to 1,500 metres from the traffic noise source (Reijnen *et al.* 1996).

Not all studies have found a correlation between traffic noise exposure and avian territory selection, with claims that endangered Golden-cheeked Warblers in Texas do not prefer to inhabit areas with lower levels of traffic noise (Centre for Bioacoustics Research 1999). However, as populations of this species are already low, it is possible that other factors such as loss of preferred habitat or food sources may be driving this bird’s apparent indifference to noise-pollution with regards range selection. A more-extensive study on grassland birds near Boston (USA) by Forman and others (2002) did find a significant correlation between occupation and both the size of the patch of grassland remnant and the distance from roads. That study found that low traffic volumes of between 3,000 and 8,000 vehicles per day produced no significant effect on the distribution of grassland birds. However, for traffic volumes between 8,000 and 15,000, a significant reduction in regular breeding numbers was noted within the first four hundred metres from the road. At traffic levels between 15,000 and 30,000, both breeding bird densities and overall population densities were reduced out to distances of seven hundred metres from the two-lane highway. This effect was extended to 1,200 metres from a multilane highway with a traffic level of 30,000 vehicles per day (Forman *et al.* 2002).

When Kuitunen and others (2003) examined breeding success of Pied Flycatchers *Ficedula hypoleuca* with respect to traffic density, they found no correlation between population density and distance from roads, but a significant decrease in fledgling numbers per breeding attempt in nest-boxes closer to the road. The researchers suggested that the more direct impact of parent-bird traffic mortality may have played a greater role than traffic noise in this reduction in fledglings due to reduced nestling nutrition (Kuitunen *et al.* 2003). Collision mortality amongst avian populations at Mount Revelstoke and Glacier National Parks (Canada) was studied by Morris (1998), with suggestions that proactive noise production via the operation of car horns may help reduce road-kill numbers of small seed-eating birds such as Pine Siskins and Crossbills which are attracted to the roadside's ready supply of digestive grit. Unfortunately the large collision mortality rates of these species may be aided by the absorption of high amounts of de-icing salt as the birds source the grit necessary for the digestion of conifer seeds (Morris 1998).

1.5.4 Barrier effects of roads

Not all birds are willing to venture above road surfaces, with Develey and Stouffer (2001) finding that mixed-species flocks of birds in the Amazon rainforests rarely cross roads with open canopies, even if such roads have traffic volumes of less than two vehicles per day. The same researchers found that roads with similar traffic volumes but with closed canopies still presented a significant territorial barrier to three out of five mixed-species flocks, although some birds could be coaxed across by playback recordings of conspecifics. The researchers suggest that such avoidance is more likely due to the effect of the road as a historical boundary to the flock's ancestors when the canopy was open during the road's construction twenty years earlier, than to any impact from current traffic noise levels (Develey and Stouffer 2001).

During a two year period in lowland tropical rainforest, Laurance and others (2004) found the barrier effect of roads to vary across foraging guilds, although at five of the six sites tested, the 30-40m wide road (less than two vehicles/day) through intact forest significantly inhibited total bird movement (the exception being the site with the tallest regrowth). This study was the first to attribute movement reduction by birds across barriers to two distinct (albeit interrelated) causes – gap avoidance and edge avoidance – and suggested that traffic noise had little or no effect upon avoidance at the test sites. Solitary understorey rainforest species displayed the least willingness to cross, even where the unsealed road had a closed canopy, while frugivorous species displayed no reluctance to cross road gaps at any site (Laurance *et al.* 2004). Studies in Banff National Park (Canada) found forest birds more likely to cross roads than rivers, suggesting that the presence of natural geographic barriers throughout a particular species' evolutionary history generates a barrier effect greater than the less-perceived mortality risk from traffic (St. Claire 2003).

1.5.5 Disturbance responses to anthropogenic noise

Anthropogenic noise has also been found to trigger flight responses and other behavioural characteristics in some birds. Goudie and Jones (2004) found noise levels exceeding 80dBA generated by military jet flyovers elicited a positive dose response in the alert behaviour of harlequin ducks *Histrionicus histrionicus*. This species also displayed residual behavioural effects lasting up to two hours for increased antagonism, and for up to one and a half hours for decreased courtship activity (Goudie and Jones 2004). Playback of recordings simulating helicopter over-flights to Crested Terns *Sterna bergii* on coral cays of the Great Barrier Reef induced flight responses at sound pressure levels above 85dBA (Brown 1990). However, most seabird species on the cays displayed raised levels of alertness through demonstrated scanning behaviour as a minimum response at playback noise levels of only 65dBA, with response levels of the exposed birds significantly higher than those of a control colony (Brown 1990). Incubating and brooding Herring Gulls *Larus argentatus* at Canarsie Pol Island, Jamaica Bay (USA) were observed for behavioural effects of jet-aircraft noise. Over-flights of supersonic transports resulted in sixty times more fights between gulls than levels of fighting observed during periods clear of aircraft traffic (Buger 1981). This increased aggression within the colony is thought to account for the significant decrease in clutch-size during the incubation period compared to a control colony isolated from most aircraft noise. Noise from both supersonic and sub-sonic aircraft elicited a greater flight response from loafing gulls at Canarsie Pol Island than at the noise-free control colony (Buger 1981). Although the latter aircraft noise studies (particularly those involving supersonic aviation) were conducted in locations exposed to sound pressure levels greater than those expected on most freeways, the results did displace earlier theories suggesting that gulls are unaffected by aircraft noise (Busnel 1978; Dunnet 1977); thereby suggesting that even birds seemingly habituated to high levels of anthropogenic noise are never completely so.

1.6 Noise effects on humans and applicability to fauna

The human auditory system responds best to mid-frequency sounds (1000-10,000 Hz): “The human ear captures sound within a specific window of the acoustic spectrum, generally within the 20-20,000 Hz range. However, it is most responsive to sounds within the mid-frequencies: 1000-10,000 Hz” (Alves Ppereira and Castelo Branco 1999). Exposure to noise can trigger stress-type physiological reactions in humans (Ouis 2002); however not all the effects of environmental noise are psychological in nature.

There is a long-held acceptance within the scientific and medical community of certain risks posed to human health due to long-term exposure to raised amplitude levels of noise across the medium-frequency bands. Babisch (2000) notes that children regularly are medically assessed with increased blood-pressure levels attributed to noise-related causes, and also suggests risks of an increased incidence of ischaemic heart disease in patients who reside in areas with outdoor noise levels in excess of 65-70dBA. This work followed on from earlier studies of middle-aged men in Berlin regularly exposed to high levels of traffic noise which postulated an association between gastrointestinal disease and the level of environmental noise exposure (Babisch *et al.* 1994). That study had a limited subject range and sample size, but the results suggested traffic noise to be the main contributor to ischaemic heart disease for one in fifty cases within the German population. More recent research examining first time myocardial infarction (MI) patients from 112 electoral districts in Kansas City (USA) indicates a relationship between the level of traffic noise exposure and the incidence of MI among 55-64-year-old men (Grazuleviciene *et al.* 2004).

A study of twelve subjects living close to a high traffic density highway by Hofman and others (1995) found that noise-triggered ‘cardiac arousal’ persisted during sleep even after ten nights’ conditioning. Those subjects slept in rooms fitted with double glazed windows and, although this lowered the mean sound pressure level, it had no effect on reducing the number of sound-peaks, hence no reduction in either the absolute level or the magnitude of the cardiac responses to those peaks (Hofman *et al.* 1995).

Recent research has found lower levels of maternal placental lactogen in women after 36 weeks of gestation if the subject was living in an area exposed to airport noise (American Academy of Paediatrics 1997). Other effects range from shortened gestation periods to decreased birth weights, with infants subject to loud noise whilst in neonatal intensive care units displaying significant behavioural and physiological responses (American Academy of Paediatrics 1997). Along with the risk of high-frequency hearing loss in newborn babies, exposure to excessive noise during pregnancy may be linked to intrauterine growth retardation and prematurity, while exposure during confinement within a hospital ward could cause cochlear damage (American Academy of Paediatrics 1997).

Ising and Ising (2002) found that long-term exposure to road traffic noise in sleeping children presented a raised risk of chronic stress hormone regulation disturbances. These subjects were tested in rooms adjacent to a highway with truck traffic passes at L_{max} >80 dBA (outside sound pressure level) on average each two minutes during a 24-hour period (L_{max} <55 dBA inside subjects bedroom). The dominant frequency for this traffic noise was 100Hz, indicating the high component of heavy low-speed vehicles along that section of highway. This noise exposure resulted in grave disturbances to the circadian rhythm of cortisol, with free cortisol excretion by the children in the first half of the night displaying chronic increases (Ising and Ising 2002).

Noise exposure also induces a response in humans of a more subjective nature – annoyance. Efforts have been made to quantify the psychological aspects of this response, with one questionnaire study by Sato and others (1999) finding a significant correlation between the extent of annoyance and $L_{eq}(A)$ noise levels. That study also found that the extent of annoyance was also strongly related to the maximum noise level experienced by the subject, but that the level of annoyance was irrespective of the number of noise events (Sato *et al.* 1999). However, such noise-event results should not override concerns discussed earlier about other clinical responses such as raised states of 'cardiac arousal' during sleep as found by Hofman and others (1995). According to Ouis (2002), studies aimed at establishing relationships between the quantitative nature of the parameters associated with road traffic noise, and the more subjective qualities of annoyance to its effects, will lead to more efficient planning of road traffic activity, thereby contributing to raised levels of comfort for the affected populace.

Researchers have also raised awareness of some consequences of exposure to infrasound (low-frequency sound below 16Hz), or from long-term exposure to frequencies up to 500Hz causing vibro-acoustic disease, producing such symptoms as raised levels of respiratory tract infections (Aguas *et al.* 1999), cardiovascular problems and neurological disturbances, bronchitis and coughing, and inflammation of the oral cavity (De Sousa Pereira *et al*. 1999).

Such risks are not restricted to humans; with laboratory tests on mice showing that exposure to the same low-frequency noise at levels below 90 dBA over a three-month period will produce a significant decline in spleen lymphocytes, along with associated changes to the mice immune system (Aguas *et al.* 1999). De Sousa Pereira and others (1999) found that exposing adult rats to low frequency noise produced partially-sheared cilia, along with increases of necrotic cilia of the tracheal epithelium and altered recovery rates for such cells. Oliveira and others (2001) also noted significant changes in the tracheal epithelium of rats when exposed to low frequency noise through the *in utero* and postnatal stage of development. Rats exposed after eight weeks growth were found to suffer less damage to the tracheal ciliated cells than those subjects exposed during early development, with the researchers warning of likely risks posed to human mothers and young children from environments subjected to low-frequency / high-intensity noise.

1.7 Mitigation

The use of acoustic deterrents as a means of reducing road-kill has been observed to produce habituated indifference for at least one species of deer *Dama dama* (Ujvari *et al.* 2004). However short-term use of concentrated sound from a variety of portable sources (including starting pistols, stock-whips, firecrackers, metal drums and gongs, and un-muffled two-stroke motors) has been successfully used to relocate several species of flying-fox from sensitive forest patches (Tidemann 2003). These studies highlight the range of tolerances to anthropogenic sound across wildlife species, and allude to an expected variety of responses by fauna to traffic noise.

In the course of this review we found no consideration of the effectiveness of noise barriers, such as those used to reduce noise effects in urban areas, for the protection of wildlife species from traffic noise effects.

1.8 Conclusion

Despite the troublesome and sometimes dangerous nature of noise, little scientific literature exists to identify many of its effects on wildlife. The limited data that is available is concentrated mostly on species found only in the northern hemisphere, with few studies on fauna from tropical regions. Most research has targeted bird species, and much of this has taken place in temperate areas of Europe or North America. This imbalance favouring avian species over terrestrial forms is understandable due to the relative ease of conducting such research compared to researching other species, and in view of the important role vocalisations play in the life of a bird. Bird studies by humanity have a long history possibly attributed to their colourful presence and song, and the amount of available data accrued on these life-forms is to be expected.

Unfortunately little of this data is based on noise-related research in tropical rainforest species, and even less has been conducted on those birds inhabiting rainforests within the Wet Tropics of north-eastern Australia. Some data on other fauna inhabiting the Wet Tropics is emerging, but there remains a dearth relating to impacts of anthropogenic noise including traffic noise on most species within this region.

The literature presented in this review draws on some studies of the effects of noise on human subjects, and it is suggested that many or at least some of these effects may produce similar symptoms in fauna. Human beings have the resources to ameliorate the impact of many of the noise sources in order to reduce the risk to public and personal health. Unfortunately few animals possess these resources, and many are likely to suffer effects from an acoustic environment transformed by anthropogenic sounds. Although, as some studies have indicated, some fauna appears quite adaptive in overcoming the effects of acoustic blanketing – for others such adaptation does not present an option.

Little is known of the effects many of these acoustic adjustments have on the metabolic processes and energy budgets of wildlife, and few studies have examined the cognitive processes of the listener to such an adjustment. Any compensation to noise interference by the caller is wasted if the intended receiver is unable to comprehend the altered song or call. It is therefore essential that any anthropogenic perturbation to the acoustic environment fully considers the Precautionary Principle, by assuming that there will be wildlife impacts, and that if left unchecked, for some species such impacts may be considerable.

Noise Disturbance along Highways

Section 2:
Traffic noise propagation through montane rainforest

2. Traffic noise propagation through montane rainforest

Gregory Dawe and Miriam Goosem

Summary

This project collected and analysed daytime noise data from three zones in rainforest along the Kuranda Range section of the Kennedy Highway (the rainforest edge, one hundred metres within the forest, and two hundred metres within the forest) along eight transects perpendicular to the existing road between Avondale Creek and Streets Creek. This data, including third-octave dissemination, was sampled from two heights above the forest floor (one metre or ground level, and fifteen metres or lower canopy level) for a period of twelve hours at each site.

Total noise levels decreased significantly with distance into the forest at both ground and lower canopy levels, but were still elevated above ambient noise at sites two hundred metres inside the forest. The lower forest canopy was quieter at the edge than the zone one metre above the surface. At both interior distances the canopy noise exceeded that near the ground.

Edge hourly noise levels were strongly correlated with traffic volume at both one metre above the forest floor and at fifteen metres from the ground. Mean total A-weighted noise levels did not vary significantly during the day close to the ground at the forest edge; however there were significant variations at the lower canopy height. Variations also occurred at both heights in the two hundred metre zones, probably due to increased biotic or wind noise at varying times during the day, but not at the one hundred metre sample points.

Modelling prepared for the Kuranda Range Road Upgrade Impact Assessment Study by acoustic engineers failed to predict the high noise levels at the forest edge of the existing highway, although models were relatively accurate for most forest interior sample sites. At the edge, modelled noise levels varied from 17-31dB below those measured. In some cases, the edge of the road was approximately four times noisier than model predictions. We suggest that modelling for the road upgrade would be similarly inaccurate at the forest edge.

Acoustic refugia that exist under the current alignment of the road were identified by extrapolating results from transects sampled, together with consideration of topographic data. The likely impact of the new highway alignment on these refugia has been considered, with two quiet refuges in particular likely to become far noisier if the upgrade proceeds and several other refuges likely to be affected to some extent. Similarly, new acoustic refuges may be created but re-calibration of the noise models should be undertaken prior to delineation of these areas.

The dominant frequency of traffic noise on the Kuranda Range was 1 kHz. However, frequency bands between 31.5 Hz and 2.5 kHz had noise levels elevated above the close to ambient levels seen in quiet refuges on the range. Sections of the spectrum in which fauna such as some birds and frogs communicate may be blanketed by this traffic noise, particularly at the edge of the forest.

Daytime total noise levels at the edge of the forest are relatively continuous at a loudness recognised to have serious implications for human health. Without further information

concerning the impact of continuous noise on the variety of wildlife present on the Kuranda Range, a precautionary approach would suggest that such a level might also cause problems in at least some wildlife species.

Individual noisy vehicles do much to elevate noise conditions at both edge and interior sites. These peaks are missed from models using L_{10} descriptors, with L_1 noise levels at the edge being typically about ten decibels higher (double the perceived loudness) than L_{10} levels. Peak levels along the edge are usually more than ten decibels above the L_1 levels, with occasional A-weighted peaks above 110 decibels.

Recommendations for mitigation of noise impacts and requirements for further research are identified.

2.1 Introduction

2.1.1 Background

Road traffic has long been associated with a suite of mostly negative environmental impacts, ranging from the potential for toxic or radioactive chemical release through accidents, to aesthetic devaluation of landscape. An area of increasing concern, but one mostly researched with an anthropocentric focus, is the permeation of traffic noise into the surrounding matrix.

An extensive road network interacts with the Wet Tropics World Heritage Area of far northern Queensland. Some of these roads form major transport corridors linking the narrow coastal strip to the Atherton Tablelands and beyond. One of these linkages, the Kuranda Range Road is approaching maximum design usage and requires a major upgrade. As part of the environmental impact assessment prior to the proposed upgrade, noise modelling was conducted in order to assess the extent of likely impacts on noise sensitive sites as defined by the *Environmental Protection Act* 1994 due to the altered road conditions imposed by the upgrade. Some sampling of residential noise levels was undertaken, but no actual field data was collected from forested areas traversed by the existing road.

Previous Rainforest CRC research conducted in the Wet Tropics has demonstrated that road noise penetrates the rainforest understorey more than one hundred metres (Marks and Turton 2000). Recent studies along the Palmerston Highway and Kuranda Range section of the Kennedy Highway have extended the noise effect zone at understorey and mid-canopy level to more than two hundred metres, with road noise inducing a spectrum shift toward the lower frequency bands (Dawe 2005). Traffic noise was greater in the rainforest canopy than at ground level (Dawe 2005).

Modelling of existing (2003 data) and future L_{10} (18 hr) traffic noise levels adjacent to the Kuranda Range Road was undertaken for QDMR by ASK Consulting Engineers as part of an assessment of the environmental impact of the proposed upgrade to that section of the Kennedy Highway. Three noise zoning models with contour intervals of two decibels were produced to accurately cover a six hundred metre wide footprint along the highway between Smithfield and Kuranda. A series of maps depicted:

1. Estimated noise levels at ground level for current traffic volumes of 6,125 vehicles/day on the existing road (2003 calibration model);
2. Predicted noise levels at ground level and upper story residential heights for ten years from construction on the upgraded road alignment under the traffic (8,000 vehicles/day) and vegetation conditions expected at the commencement of operations; and

3. Predicted noise levels for 'ultimate' traffic loadings on the upgraded road alignment of 48,200 vehicles/day (a traffic level expected a long time in the future) and complete vegetation re-establishment (full revegetation is expected to take several years).

Data driving the noise models were obtained from acoustic surveys of several residences at either end of the upgrade section, as impacts on residents was the major focus of the traffic noise impact assessment as per legislative requirements. No actual recordings of noise levels were obtained at any rainforest site adjacent to the road during its traverse of the Kuranda Range. This led to concerns regarding the accuracy of the model in predicting noise levels in the rainforest environments of the escarpment, and the need for actual field sound-level measurements across a variety of topographic and vegetative types at set distances and heights from the roadside. The availability of such data would then enable an accurate assessment of the accuracy of the models with respect to natural values, rather than the human sites for which they were designed, and could allow re-calibration to account for local conditions if applicable. Assessment of potential impacts on fauna would also be easier with more accurate models of traffic noise propagation through rainforest. Areas of rainforest where traffic noise was reduced due to topographic shielding could also be identified.

2.1.2 Aims

The primary aim of the project was to generate enough quality noise data to accurately represent noise conditions in the rainforest adjacent to the Kuranda Range Road at both one metre above the forest floor, and at a height of fifteen metres above the forest floor. The dissemination of traffic noise was examined in areas of varying microtopography and under diurnal noise conditions.

Data collected could be examined to evaluate whether noise models prepared to assess impacts of the upgrade on humans could also be used to predict noise levels that might impact on native wildlife within the natural habitats adjacent to the Kuranda Range existing road and provide the potential to allow re-calibration of models if necessary.

A secondary objective suggested by QDMR as the project was undertaken was to examine whether any 'acoustic refugia' exist (i.e. areas of relative quiet shielded from traffic noise), and, if so, to examine likely impacts on these refugia from the new road alignment.

2.2 Methods

2.2.1 Site selection

Overview

Twelve-hour noise data were collected during daylight hours at heights of one metre (Huisman and Attenborough 1991; Reijnen *et al*. 1995; Marks and Turton 2000) and fifteen metres (Waser and Waser 1977) above the floor of rainforest to represent ground and lower canopy level strata on the escarpment of the Kuranda Range. Eight 200m long replicate transects were established perpendicular to the Kuranda Range section of the Kennedy Highway (Figure 2.1) at elevations ranging between 115-445 metres (Table 2.1). These transects were spaced along a nine-kilometre section of bituminised dual-carriageway subject to a maximum vehicle speed of eighty kilometres per hour at an average weekday loading of 7,268 vehicles, and a highest recorded daily volume of 8,535 vehicles (QDMR 2005).

Physical environment

Transects traversed a variety of rainforest regional ecosystems (Sattler and Williams 1999); mainly 7.11.1 *mesophyll vine forest growing on soils of metamorphic origin* or 7.12.1 *on granite soils*; and 7.11.7 *complex notophyll vine forest with emergent* Agathis robusta *established on moist metamorphic uplands and foothills* or 7.12.7 *on granite soils*. Some areas were dominated by *Acacia aulacocarpa* re-growth following past human disturbance (logging) as 7.11.10 *notophyll rainforest growing on wet to very wet metamorphic soils of foothills and upland ridges*, while 7.12.7 *grew on granite soils*. Most transects contained extensive areas of wait-a-while palm (*Calamus spp.*), and many also traversed disturbed gaps colonised by the woody weed lantana (*Lantana camara*) and stinging tree (*Dendrocnide moroides*).

Microtopography varied across the two hundred metre length of the transects (Appendix 2.1). Some proceeded mainly in an uphill or downhill direction, while others ascended ridges before subsequently descending or descended to a gully before then climbing a slope.

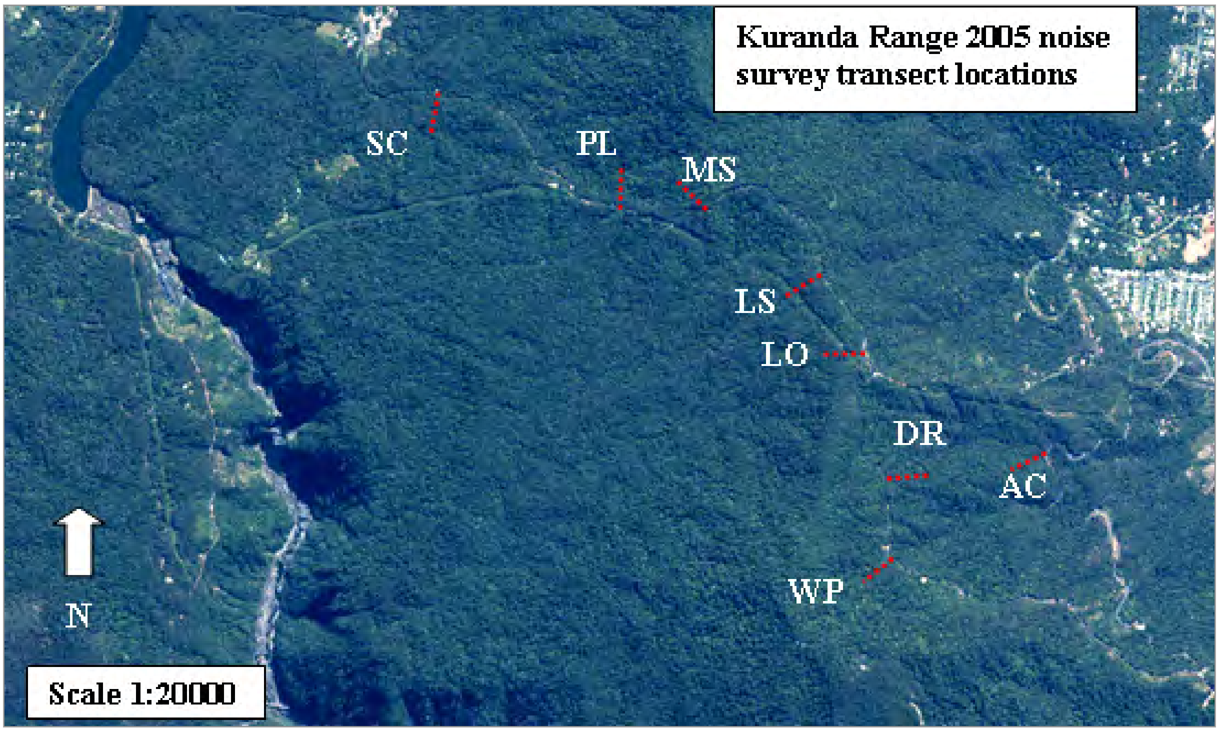


Figure 2.1: Aerial photograph of Kuranda Range showing the 2005 Rainforest CRC noise survey transect locations.

Climatic conditions

Noise data were collected along the eight transects between 15 June and 7 October 2005. That year saw an extended wet season across the region, with many days unavailable for data collection due to rain periods or windy conditions. The presence of moderate southeast trade wind activity throughout much of the winter period meant the unavoidable inclusion of occasional wind gusts in some data recording (Table 2.2). This effect was minimised by the discarding and replication of data from many days of sampling in order to obtain data less-affected by spurious background events. Local micrometeorological conditions were not recorded along transects. Any effect of local micrometeorological variations on excess attenuation was deemed to be slight, as concluded by Huisman and Attenborough (1991), who found such effects to be negligible for averaged (L_{eq}) sound propagation at distances of one hundred metres through pine woodland at frequencies of between 50 Hz and 6 kHz.

Table 2.1: Kuranda Range 2005 ambient noise-transect locations and orientation.

Transect ID	QDMR Kennedy Highway Chainage (metres)	Start Elevation	Magnetic Bearing	Start Latitude	Start Longitude
Avondale Creek (AC)	2260	115	236	-16°50'29.63758"	145°40'47.75360"
Water Point (WP)	5840	320	226	-16°50'45.04050"	145°40'24.24000"
Down Ridge (DR)	6470	350	61	-16°50'27.00961"	145°40'20.18263"
Lookout (LO)	6913	380	263	-16°50'15.11608"	145°40'19.84207"
Lookout Sign (LS)	7305	410	233	-16°50'3.68483"	145°40'13.97718"
Mareeba Sign (MS)	8070	445	311	-16°49'52.85753"	145°39'57.84271"
Powerline (PL)	8575	420	354	-16°49'53.23556"	145°39'43.47019"
Streets Creek (SC)	9590	350	182	-16°49'36.87566"	145°39'16.76366"

Table 2.2: Local climatic averages for 2005 Kuranda Range field study (Bureau of Meteorology 2006).

	Min temp (°C)	Max temp (°C)	Max wind speed (km/hr)	Av. 9am wind speed	Av. 3pm wind speed	Av. 9am Relative Humidity	Av. 3pm Relative Humidity
June	19.93	26.57	34.17	15.83	19.77	76.33	67.53
July	18.06	26.04	42.26	20.78	24.77	73.00	62.29
August	17.89	25.93	42.13	17.65	23.97	71.61	58.87
September	18.96	28.12	35.60	15.47	21.77	64.87	57.20
October	22.10	30.85	34.10	13.39	20.23	64.52	60.45
Av. Mean	**19.39**	**27.50**	**37.65**	**16.62**	**22.10**	**70.07**	**61.27**

2.2.2 Equipment

Instrumentation and ancillary equipment

A Svantek (Poland) Type-1 category sound level meter (SLM), Svan model 949, was coupled via a twenty-metre 50 ohm co-axial cable, to an omni-directional BSWA TECH Model SV-22 ½" pre-polarized condenser microphone and pre-amplifier, fitted with a 90 mm diameter foam windscreen. This was used to record ambient noise amplitude levels across each of the 45 third-octave bands between 0.8 Hz and 20 kHz, as well as A, C and Linear-weighted total noise-levels at a buffer time step of one second (aggregation time) and integration time of ten minutes. Equivalent noise levels (L_{eq}) based on the integration time were therefore available over each of the sampling days for between 70-78 ten-minute time segments depending on location, weather and accessibility factors. The statistical analyser of the instrument also provided a range of L_n loudness levels (L_1, through to L_{99}). A suite of other noise parameters including: peak maximum, minimum, Sound Pressure Level (SPL), Sound Exposure Level (SEL), Ltm3, Ltm5, and L_{den} were also displayed with each ten-minute linear integration file. The instrument was calibrated before and after each day's sampling using a 1kHz 94db test signal from a Rion NC-73 sound level calibrator conforming to EN 50081 (1992) and EN

50082 (1992) European emission and immunity standards. Data was accepted if both readings were within 0.2 decibels of the calibrator's test signal.

Noise level samples from fifteen metres above ground level, designated as lower canopy height, were achieved by the attachment of the microphone assembly to a fifteen-metre aluminium pole, comprising six sections ranging from 32mm to 16mm in diameter, accessed for extension and collapse via a 1.2m stepladder. The robustness of this pole was constrained to a weight and size suitable for carriage through the undergrowth and over the terrain encountered along the transects. The co-axial cable ran external to the tubing, being fed off a rotating drum attached to a ground-driven stake during the extension process.

Data from the Svan 949 meter was downloaded on to a personal computer each evening via the Svantek PC analysis program.

Measurement Parameters

Mean daytime third-octave noise levels at the three distances along each of the transects were averaged from the L_{eq} values of the ten-minute integration files obtained from the meter at the end of each day's data recording. These noise levels were all A-weighted Root Mean Square (RMS) values. The RMS value represents the 'effective' sound level, which for a pure sound of sinusoidal waveform is equivalent to $1/\sqrt{2}$ (@ 0.707) times the peak value of the wave. Total noise levels from the same files were available as A- weighted, C- weighted, or Z (un)-weighted, with the default values in this report being A-weighted. This filter selection was primarily based on the QDMR modeling L_{10} values which were A-weighted, and also on the SLM's third-octave dissemination which was only available for A-weighted values.

L_n noise levels were calculated by the Svan PC program from the mean levels of the approximately 44,000 1-second files on the SLM's daily buffer. Total noise levels were also available from three pre-selected buffer profiles; which for this survey were set for 'fast' detector sampling of RMS A-weighted levels, Peak A-weighted levels, and RMS Lin (Z) – weighted noise levels. Mean total noise levels using these buffers were based on the approximately five hundred values stored daily in each of these buffers. Mean daily total A-weighted noise levels obtained using this feature differ slightly from values calculated from the mean levels of each ten-minute file due to the different resolution and averaging periods. Therefore A-weighted levels from the three pre-selected buffer profiles (buffer profile #1) are only used in this report when comparing against Peak noise levels (buffer profile #2).

2.2.3 Analysis methods

Analysis programs

Field data were analysed using the software program Statistical Package for the Social Sciences (SPSS) for Windows, Version 12.0.1. (11/11/2003). Graphical displays were generated by SPSS and Microsoft Excel 2003 (11.6355.6408).

Statistical testing

Univariate Analysis of Variance (ANOVA) and t-tests were conducted on the effects of distance, height, time of day, and transects for the ambient noise data where data was found to be normally distributed. Kruskal-Wallis and Mann-Whitney U non-parametric tests were performed on data which failed to meet the assumptions of normality. The relationship between noise levels and distance and/or traffic volume were examined by Pearson's or Spearman's Correlation, depending on normality assessment (Cohen 1988).

Traffic data

Daily and hourly traffic data were obtained from the traffic counter situated at the base of the range by the Queensland Department of Main Roads through Mr Gordon Coppin. This was the only data available. Hourly traffic numbers for traffic travelling in both directions was correlated with the mean noise level for the previous hour calculated over all eight transects, with traffic levels descending the range assumed to balance those climbing the range over the ten-minute period it would take to reach the furthest transect. We believed this assumption resulted in a reasonable approximation to correlate with the noise recorded in the prior hourly period. The main inaccuracies from this assumption would occur for the furthest transects (e.g. Streets Creek) and for peak hour traffic flows when traffic is mainly travelling in one direction, but were not able to be corrected due to the likelihood of altered traffic speeds at different times of day introducing further problems .

2.3 Results and discussion

2.3.1 Summary of earlier studies of local rainforest interior ambient noise conditions

Ambient noise from rainforest areas with minimal exposure to traffic noise was sampled during 2004 as part of a Bachelor of Science Honours thesis (Dawe 2005) at Black Mountain Road, approximately five kilometres from its junction with the Kennedy Highway, and also along the K-Tree Track approximately five kilometres from its junction with the Palmerston Highway. Ambient levels in the absence of traffic prior to four-wheel drive test vehicle passes were also sampled at the end of eight two hundred metre transects perpendicular to the Palmerston Highway as part of the same study. Twelve hour diurnal noise levels in the 1 kHz dominant frequency band of highway traffic were found to average 23.09 ± 0.43 decibels at fifteen metres above the forest floor (canopy height) and 22.35 ± 0.58 decibels at one metre above the forest floor (ground level). Dominant ambient noise was concentrated in the upper portion of the frequency spectra, at about twice the level of the main traffic noise bands (Figure 2.2).

Mean total A-weighted noise levels at one metre above the ground prior to the 4WD tests (designated as local ambient) were 32.4 ± 3.73 dBA. Mean ambient total-noise levels at a height of fifteen metres above the forest floor were found to be 32.0 ± 1.42 dBA. These ambient noise conditions were of a considerably different spectral form to conditions at the peak of the 4WD test vehicle pass (Figure 2.3).

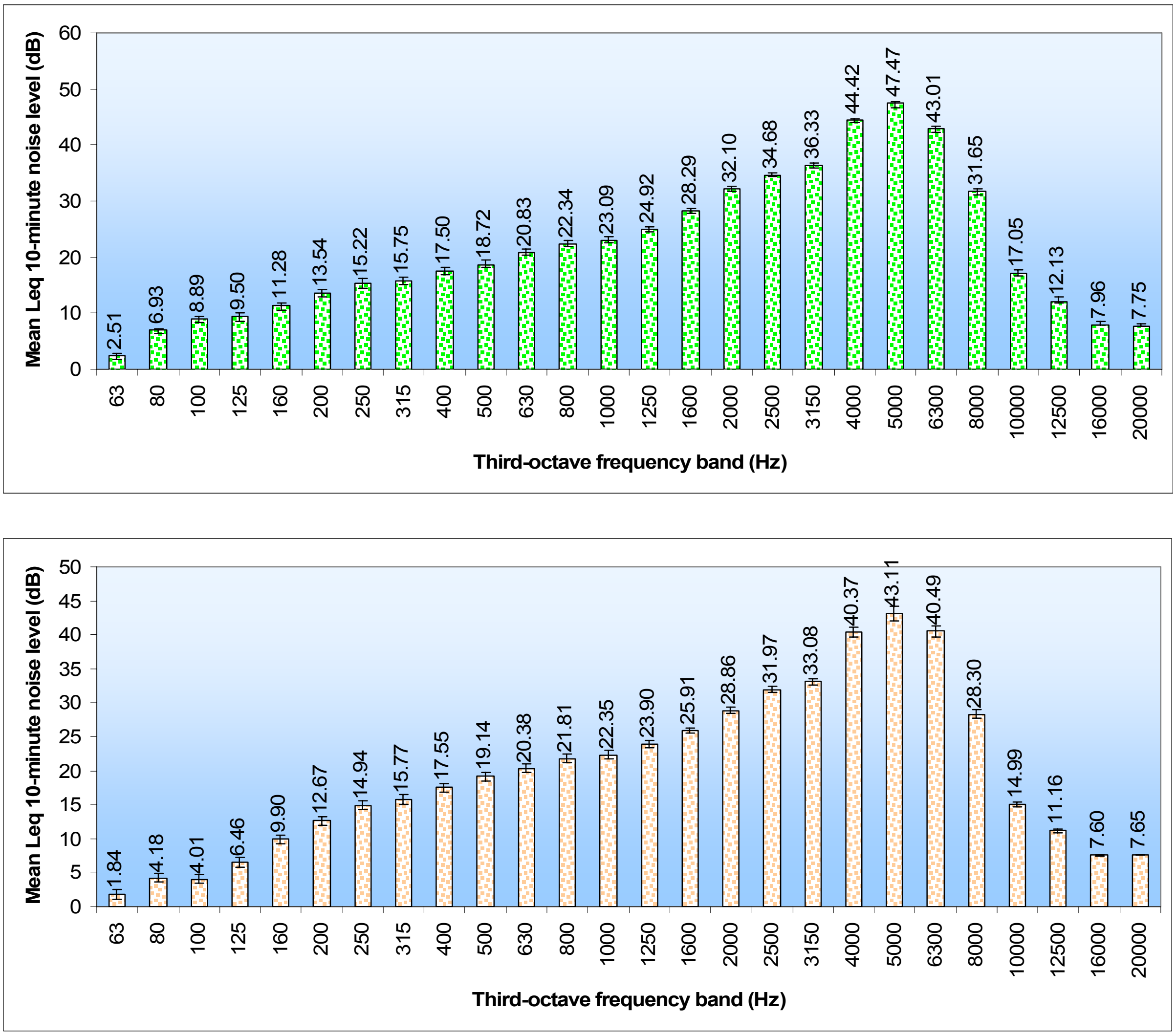


Figure 2.2: Mean twelve-hour diurnal noise levels across third-octave spectrum for Palmerston control site at canopy height (*top*) and ground level (*bottom*) (after Dawe 2005).

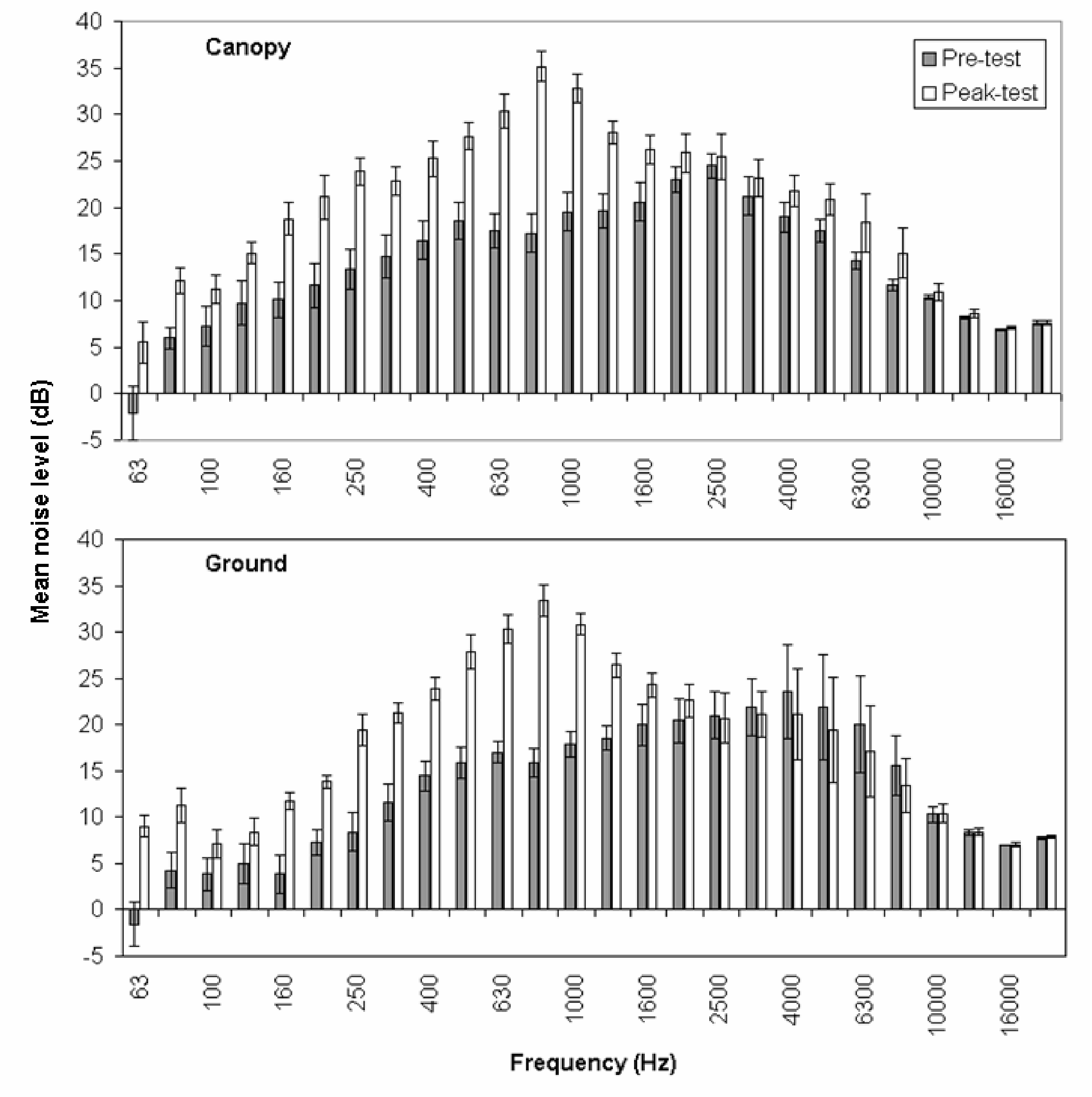


Figure 2.3: Noise spectrum in rainforest at two hundred metres from forest edge (Palmerston Highway) at two minutes prior to 4WD test vehicle pass and at peak of test vehicle pass at canopy height (*top*) and near ground (*bottom*) (after Dawe and Goosem, 2008). **Note:** Negative dB levels appear where sound pressure levels fall below 2x10-5 Pa. This by-convention is the minimum pressure considered detectable by young adult humans at 1 kHz (Attenborough 1991).

Mean diurnal total-noise levels at the Kuranda Range control site (Black Mountain Road) at one metre above the forest floor were 40.2 ± 0.49 dBA. At fifteen metres above the ground at the same location levels were found to be 44.9 ± 0.81 dBA. At the Palmerston Highway control site mean daytime total A-weighted noise levels at one metre above the forest floor were 48.1 ± 0.59 decibels. Ambient total-noise levels in the lower canopy were found to be 51.1 ± 0.50 decibels. These ambient total-noise levels at the two control sites were higher than expected for three main reasons:

1. Cicada activity was high during much of the sample period, with the 5 kHz third-octave band dominating the acoustic spectrum (Figure 2.2);
2. Traffic, although infrequent, did pass within distances of between ten and twenty metres of the microphone; and
3. Both sites were close to the edge of narrow unsealed roads, and thereby exposed to increased wind levels and other biotic and abiotic edge effects.

Therefore we consider that the noise samples taken locally before each 4WD test vehicle pass more accurately represent 'typical' interior noise conditions at times of minimal cicada activity. These are the levels that should be compared with interior ambient readings in the current study.

Local ambient noise levels in the dominant frequency band (800 Hz) of the particular test vehicle remained well below the amplitude of that vehicle's noise for a significant distance past two hundred metres (Figure 2.4), extrapolations demonstrating that ambient noise levels were not reached until about 350 metres into the forest.

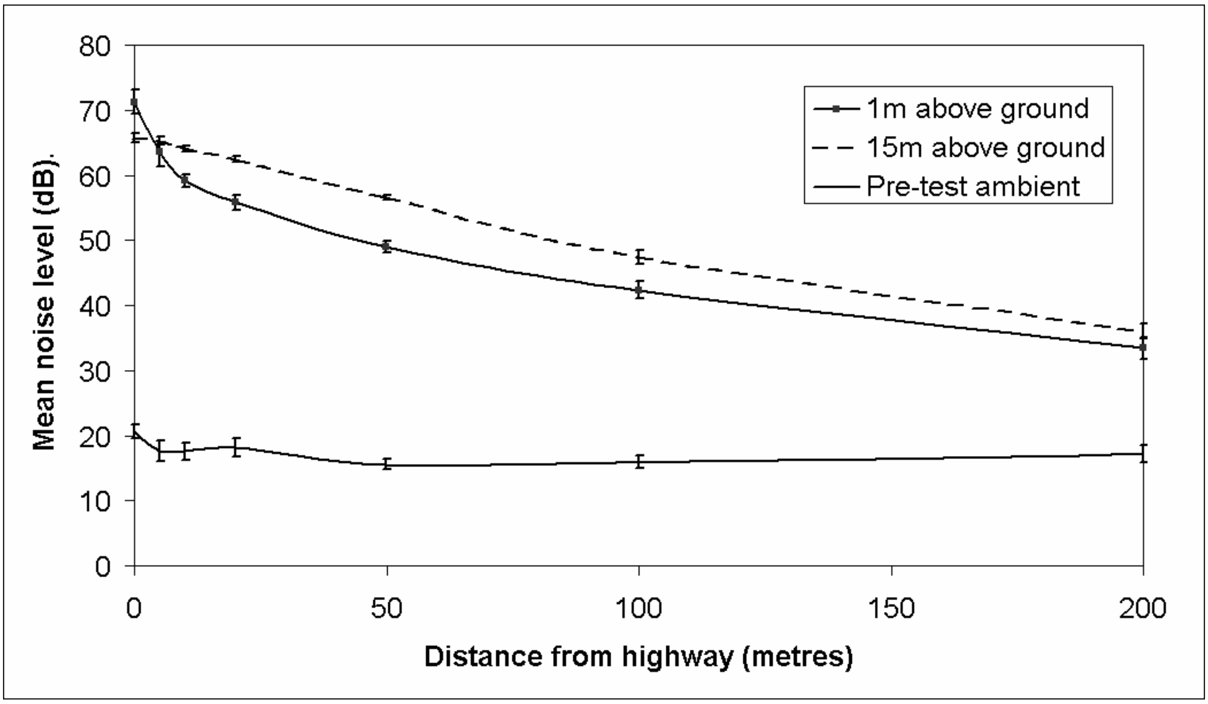


Figure 2.4: Noise levels in the 800 Hz third-octave spectrum in rainforest at the highway edge and at six distances into the forest (Palmerston Highway 2004).

2.3.2 Current noise environment

Height effect

At the forest edge, mean L_{eq} total-noise levels of all twelve-hour daytime samples were significantly greater at one metre above ground level (69.2 ± 0.57 dBA) than at fifteen metres above the ground (65.1 ± 0.36 dBA), (one-way analysis of variance of mean daytime total A-weighted noise levels at one metre above the ground and fifteen metres above the ground: F = 985.94; df = 1; $P < 0.0005$; power = 1.0).

This effect was reversed at the two interior distances (Figure 2.5). Mean daytime total-noise levels at one hundred metres from the forest edge were significantly different between the two height treatments (1 metre: 44.3 ± 1.4 dBA and 15 metres: 49.2 ± 1.1 dBA) (Mann-Whitney U non-parametric test: Z = -17.2; $P < 0.0005$). Total noise levels for the two sample heights were also significantly different at two hundred metres (41.7 ± 1.4 dBA vs 45.3 ± 1.2 dBA), (Mann-Whitney U-test: Z= -11.97; $P < 0.0005$).

At the edge, the different source to microphone distances would account for most of the greater noise levels near the ground (typically two to ten metres from source vehicles passing on the road for the near ground sampling points, and 16-24 metres for the canopy samples). Higher levels of canopy biotic activity (bird and cicada calls), greater attenuation close to the ground due to tree buttressing and trunk thickness, ground absorption, and more exposure to wind gusts at canopy level compared to ground level in the interior sites, are the most likely explanations for the lower ground noise levels compared to canopy levels at both one hundred metres and two hundred metres (Figure 2.5).

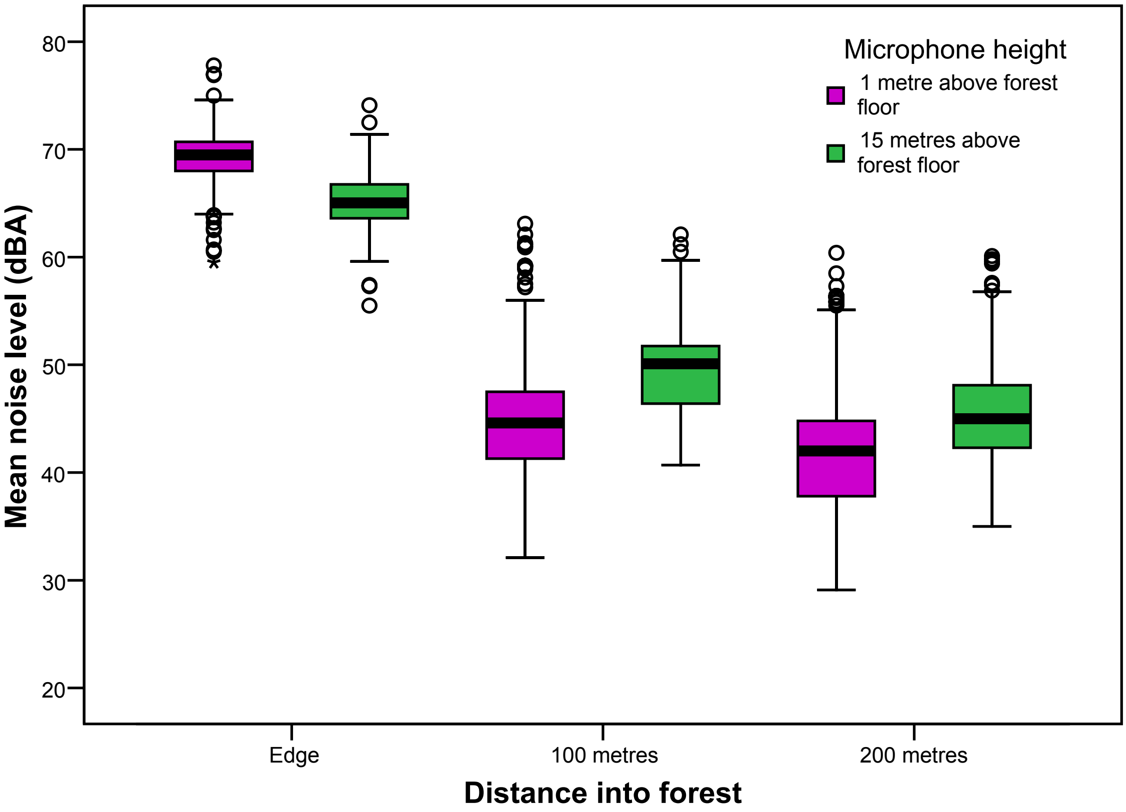


Figure 2.5: Mean total A-weighted daytime noise levels (twelve-hour) across eight Kuranda Range transects at the forest edge, and at one and two hundred metres into the forest.

The dominant road noise frequency on the Kuranda Range was found to be 1 kHz (Figure 2.6). Noise levels in the 1 kHz band were significantly different between height treatments at the edge (Independent samples t = 31.023, df = 1190.225, $P < 0.0005$), at one hundred metres (t = -18.310, df = 1122.809, $P < 0.0005$) and at two hundred metres (t = - 14.316, df = 1071.578, $P < 0.0005$).

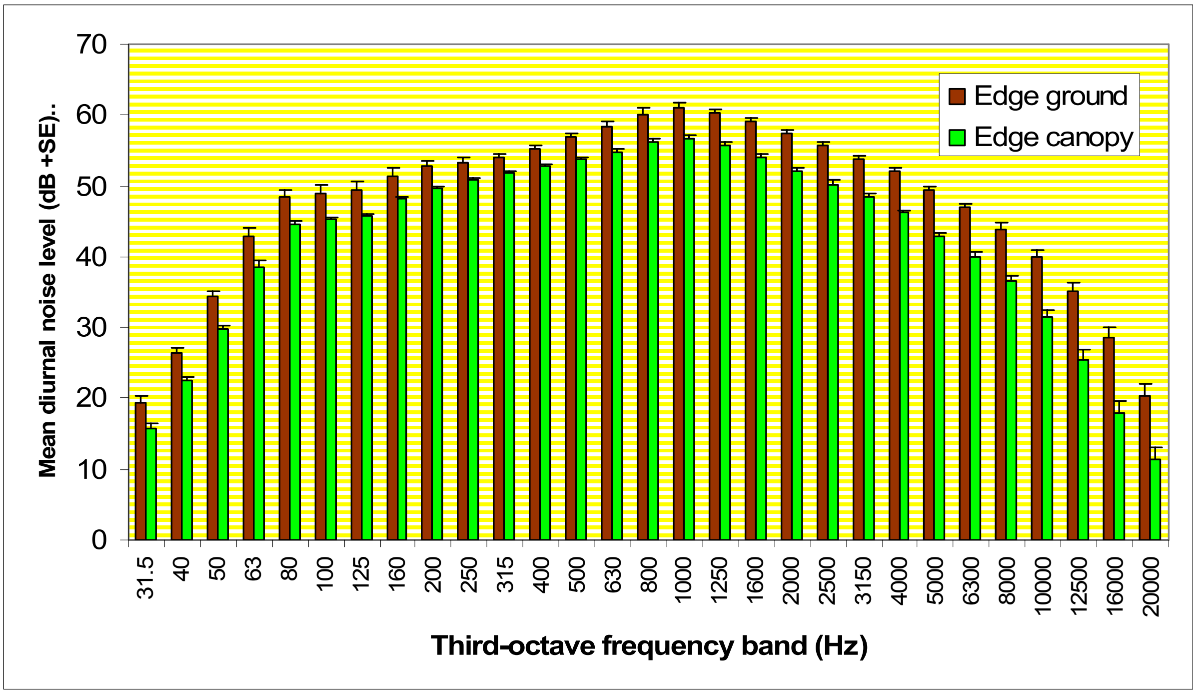


Figure 2.6: Mean diurnal spectra at two heights from eight 2005 highway edge noise sampling locations on Kuranda Range Road.

Effect of distance on current noise levels

Diurnal total-noise levels decreased with distance into the forest from the edge, at both ground and lower canopy levels (Figure 2.5).

Mean total-noise levels near the ground were significantly greater at the edge than one hundred metres from the edge (Mann-Whitney U-test: Z = -34.5; $P < 0.0005$), and greater at one hundred metres than two hundred metres (Z = -3.6; $P < 0.0005$). Similarly, mean daytime noise levels were also significantly greater in the lower canopy at the edge than at the one hundred metre sample points (Z= -34.47; $P < 0.0005$), and greater at the one hundred metre than the two hundred metre zones (Z= -21.4; $P < 0.0005$).

The significant effect of distance and height on noise levels was also demonstrated by one-way analysis of variance of selected third-octave bands, with differences in noise levels between heights and also between distances into the forest. Non-parametric testing (Kruskal-Wallis H-test) of diurnal noise in the 1 kHz dominant frequency band emphasised the decrease in noise levels over distance, showing significant differences in mean noise levels at the three distance treatments at both one metre above the ground (χ^2 = 1309, df = 2, $P < 0.0005$) and also in the lower canopy (χ^2 = 1371, df = 2, $P < 0.0005$).

Effect of time on current noise levels

Mean hourly total A-weighted noise levels at the forest edge were strongly positively correlated with the corresponding mean hourly traffic flows at most transect edges at both the noise sample heights (Pearson correlation coefficient: r = 0.132 to 0.881; mean r for ground noise = 0.602, canopy noise = 0.539; $0.0001 < P < 0.67$). These results demonstrate the expected increase in noise due to increasing traffic volume at the forest edge (Figure 2.7). Correlations were stronger at ground level than in the canopy, possibly relating to more variability in biotic noise from cicadas and morning/afternoon bird choruses in the canopy compared to ground level.

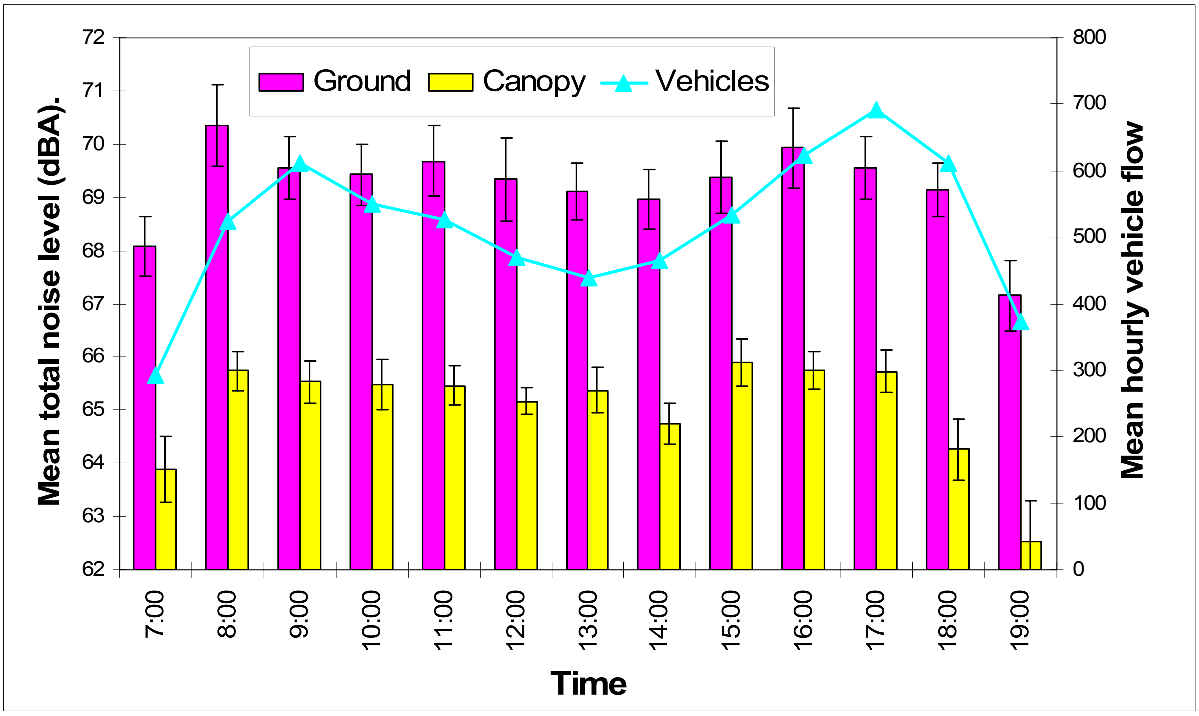


Figure 2.7: Correlation of vehicle flow patterns and average diurnal noise levels from two sample heights at the highway edges of all transects (mean total hourly A-weighted noise ± 1 SE).

Plots of total noise levels, and of selected third octave frequency band levels Leq (10-minute), at both ground and lower canopy height at two hundred metres into the forest, were visually assessed for likely correlation with traffic flows for the corresponding day. Only slight relationships were observed between any of the interior noise level plots and their corresponding traffic flows. Traffic flow data were only available in one-hourly increments. The time-consuming task of extraction and manipulation of noise data into hourly means to enable correlation analysis was not undertaken, as the result (based on the visual evaluation) was likely to be non-significant or of low significance. Biotic sounds involving cicadas and dawn and dusk bird choruses is the probable cause of the low correlation between interior noise and traffic flow, because, at this distance, the traffic noise bands are blanketed by these loud choruses (Figure 2.8).

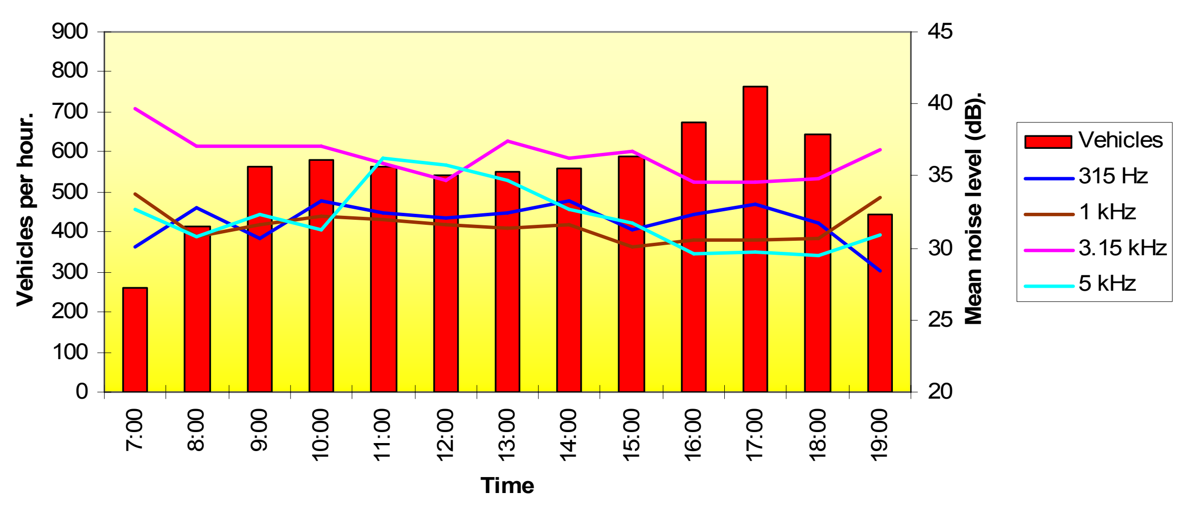


Figure 2.8: Mean hourly noise levels from selected third-octave bands and corresponding traffic flow at ground level on Water Point transect two hundred metres from highway.

Visual examination of plots of total A-weighted noise levels at the forest edge revealed little apparent variation throughout the daytime sampling sessions based on mean ten-minute L_{eq} values across all transects at each height treatment (Figures 2.9 and 2.10). At the forest edge, this effect was highlighted in the dominant frequency band of the local traffic noise (1 kHz) for the Kuranda Range Road, with median daytime variations of less than two decibels (dB) at ground level, and less than one decibel at fifteen metres above the ground (Figures 2.11a, 2.11b, 2.11c). Only at the two hundred metre interior sites did this frequency band display significant variation between early morning, midday and early evening near-ground noise levels, with the elevated early morning levels most likely attributed to increases in bird song during the 'dawn chorus' (Figure 2.11c). However, the lack of obvious traffic effect at the edge is partly a function of the scale of plotting compounded by the logarithmic decibel data (Figures 2.9 and 2.10). When mean hourly rather than ten-minute edge total A-weighted noise levels were displayed at an expanded scale on linear plots, these plots more closely resembled the corresponding hourly traffic-flow patterns (Figure 2.7).

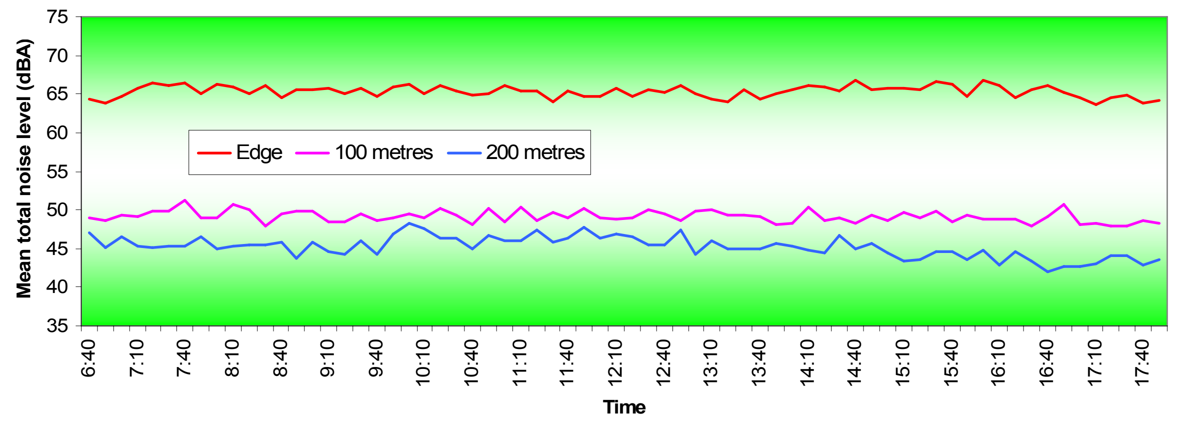


Figure 2.9: Mean daytime lower-canopy (15m) total A-weighted L_{eq} (ten-minute) noise levels in 2005 at three sample distances along eight transects perpendicular to Kuranda Range Road.

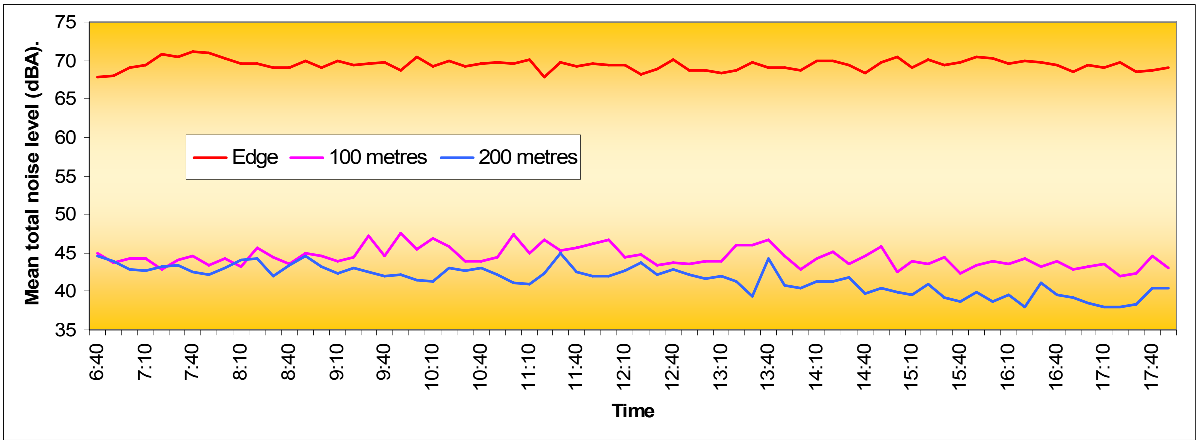


Figure 2.10. Mean daytime ground (one metre) total A-weighted Leq (ten-minute) noise levels in 2005 at three sample distances along eight transects perpendicular to Kuranda Range Road.

There was no significant difference in ground level total A-weighted noise at the edge of the highway between hours at dawn, noon and dusk (Kruskal Wallis χ^2 = 0.05; df = 2; *P* = 0.975). However, there was a significant difference in edge canopy noise levels for the same time periods (06:38-07:38 hrs; 11:58-12:58 hrs; and 16:58-17:58 hrs) (χ^2 = 8.77; df = 2; *P* = 0.012), with edge canopy noise lowered at dusk. Whether this difference was due to lower traffic noise levels at canopy height later in the day (which seems unlikely due to the increase in vehicular traffic at that time: Figure 2.5), or to increased exposure to wind, increased canopy biotic activity or other factors earlier in the day has not been established.

No significant difference between hours at dawn, noon and dusk was found for mean total A-weighted noise levels at one hundred metres close to the ground (one-way ANOVA: F = 0.781; df = 2; *P* = 0.46) or in the lower canopy (F = 1.25; df = 2; *P* = 0.29). However, noise levels at one metre above the forest floor at two hundred metres from the edge differed significantly across the three time periods (Kruskal Wallis χ^2 = 22.75; df. = 2; *P* < 0.0005), being lower at midday, probably due to reduced faunal chorus, as did levels in the lower canopy at the same distance (χ^2 = 9.06; df = 2; *P* = 0.11), the median of which was higher at midday with one possible factor driving this difference being wind levels that increase during the day and generate more impacts at canopy level.

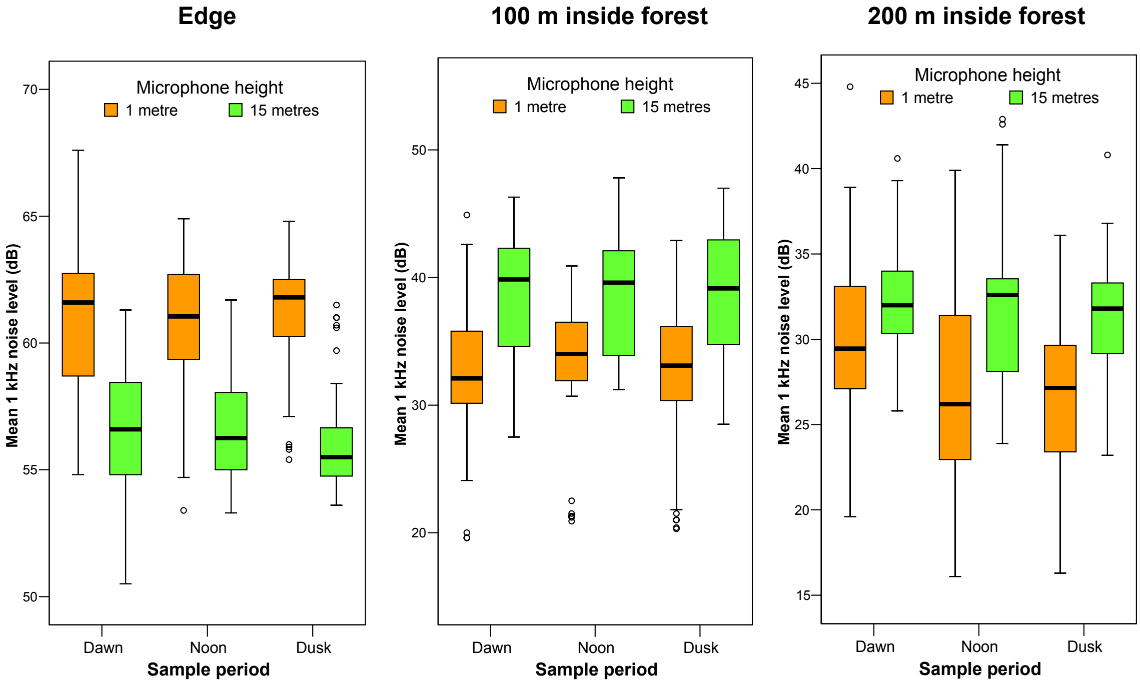


Figure 2.11: Mean dawn, noon and dusk (one hour each period) noise levels at the dominant frequency band of traffic (1 kHz) across all transects at edge (*left*), one hundred metres (*centre*) and two hundred metres (*right*). **Note:** Scales of noise levels vary with distance.

2.3.3 Comparison of modelled vs. measured noise levels

When compared with measured noise levels, figures obtained from the calibration model of existing noise levels provided to QDMR by ASK Consulting Engineers show that the traffic noise levels predicted for areas away from the edge of the road (one and two hundred metres) are in most cases relatively close to measured levels from this study (Figure 2.12, Table 2.3). However, this is not always the case. Areas beyond the edge where discrepancies occur include the one hundred metre zones along the transects near the Mareeba Sign where the measured value is six decibels greater than predicted and near Streets Creek where the measured levels are four to six decibels less than predicted. In the two hundred metre zone of the transect near the Powerline opposite Diplazium Gully, the levels are also about six decibels higher than predicted.

Overall, at distances of one and two hundred metres from the current road, noise predictions from the model appeared to be relatively accurate.

However, in comparison, edge noise levels measured in this study are consistently much greater than those predicted by the model (Figure 2.12, Table 2.3), with predicted levels ranging from an underestimate of 17, 18 and 22 dB less than measured levels at three transects to the very large underestimate of 27, 27 and 31 dB less in the three worst cases. Taking the log scale of decibel noise measurement into account, this equates to perceived noise levels more than four times greater than measured.

Table 2.3: Current sampled and predicted existing L10 noise levels at one metre above ground for Rainforest CRC sample sites at the edge, and one and two hundred metres from the edge, along eight transects perpendicular to existing Kuranda Range Road. **Note:** Current levels are based on data from one twelve-hour daytime sampling period at each of the 24 sites at a microphone height of one metre. Predicted existing levels are derived from levels indicated by noise contours of the calibration model for the existing road (ASK Consulting Engineers 2003).

Chainage (metres)		**Transect ID and existing / new chainage**							
		2260/ 1590	5840/ 4770	6470/ 5320	6890/ 5750	7305/ 6100	8070/ 6820	8575/ 7280	9590/ 8230
Noise levels		AC	WP	DR	LO	LS	MS	PL	SC
Edge	Current L_{10}	68.7	71.6	72.6	72.2	73.3	75.4	74.5	73.5
	Predicted existing L_{10}	50-52	52-54	46-48	46-48	42-46	46-48	52-54	50-52
100m	Current L_{10}	46	48.2	49.5	52.8	39.3	54.1	50.3	44
	Predicted existing L_{10}	46-48	50-52	52-54	52-54	n/a	46-48	50-52	48-50
200m	Current L_{10}	45.6	47.8	46.6	40.7	37	43.9	55.6	50.6
	Predicted existing L_{10}	44-46	46-48	48-50	42-44	n/a	42-44	48-50	48-50

After comparing the limited data available from the calibration runs, we consider it unlikely that much of the difference between actual recorded levels at the edge measured over a twelve-hour period and those presented in the current road model could be accounted for by the different temporal scales employed (twelve hours vs. eighteen hours) (Figure 2.12). Comparisons of mean twelve-hour (6:00 am to 6:00 pm) and eighteen-hour (6:00 am to midnight) recorded noise levels from model calibration runs (IAS Addendum Vol. 3, Supplementary Study #5, Appendix F) found $L_{10\ (12)}$ noise levels at the four locations to be less than 1.7% higher than $L_{10\ (18)}$ levels on the same day (Table 2.4).

Calibration runs for this model were focussed entirely on residential areas, as human habitats are those considered in current noise legislation. The problems with highway edge predictions shown by the measurements in this study are therefore at least partially due to the limited calibration and the lack of calibration runs required by legislation for wildlife habitat. This project will be one of the first occasions where the impact of traffic noise on wildlife as well as people is taken into account in considerations of highway design.

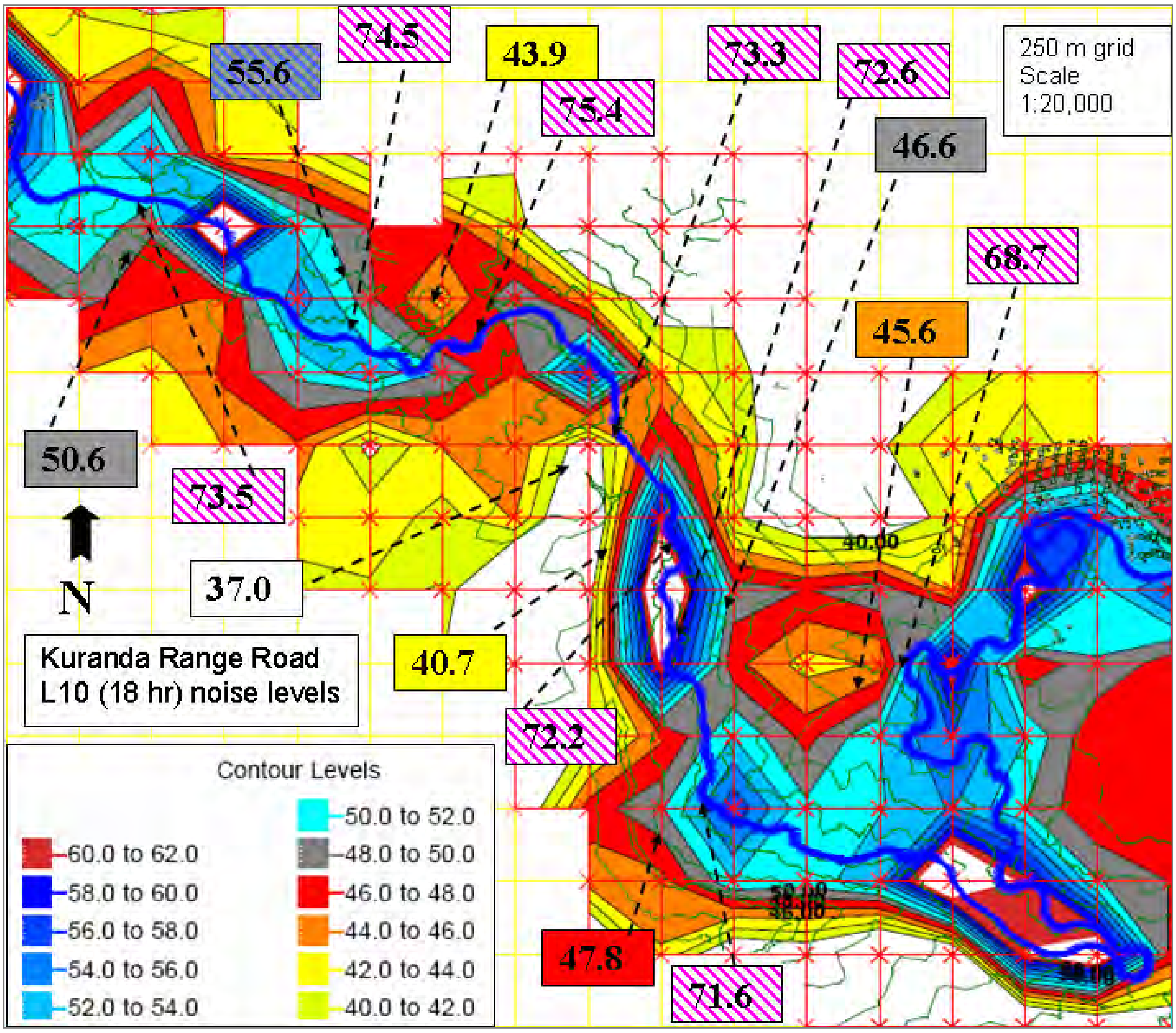


Figure 2.12: Measured L10 (twelve-hour) and predicted (ASK Consulting Engineers, 2004) existing L10 (eighteen-hour) edge and two hundred metre ground noise levels (2005) along the Kuranda Range Road. **Note:** Cross-hatched boxes indicate areas where modelled noise levels were more than two decibels outside actual field measurements. Boxes hatched pink indicate measured highway edge levels. Mono-color boxes indicate the zone where each noise sample was collected when the noise level fell within model predictions.

Table 2.4: Mean L10 twelve-hour and eighteen-hour noise levels from residential surveys adjacent to the Kuranda Range Road (IAS Addendum Vol. 3, Supplementary Study #5 Appendix F).

L10 Noise level (dBA)	QDMR Noise sample location			
	Lot 14 Chatham Terrace	2-4 Knight Road	1 Morton Street	Lot 8 Fig Tree Drive
Mean 12 hr	56.08333	55.83333	53.58333	46.16667
Mean 18 hr	54.69444	53.94444	52.63889	46.91667
dBA Difference	**1.38889**	**1.88889**	**0.94444**	**-0.75000**

2.3.4 Predictions from the 'Ultimate' and 'Ten Years Post-construction' noise models compared with present noise conditions

Edge noise levels – ground

Based on the predicted levels of the 'Ultimate modelling' with a traffic volume of 48,200 cars (ASK Consulting Engineers 2004), mean L_{10} noise levels close to the ground in seven of the areas sampled adjacent to the existing Kuranda Range Road would be expected to drop by between 4.6 and 21.5 dB once the upgrade is completed (Table 2.5). Noise levels around the existing road crossing of lower Avondale Creek were predicted to drop by up to 68.7 dB, due to attenuation over the greatly increased distance between traffic noise source and the Avondale Creek area (the new road lies approximately 240 metres to the east of the current bridge). However, there would be a concomitant increase in noise adjacent to the new bridge and this is reflected in the model (Figure 2.13). In the centre of the bridge directly above the creek itself, noise at ground level is expected to be reduced compared with edge levels adjacent to the bridge approaches due to the distance from the high bridge to ground level. Again this is reflected in the model, together with the noise blocking effects of deep cuttings on the western side of the bridge approaches and higher noise levels at the edge on the upper side of the bridge adjacent to fill slopes on the new road (Figure 2.13). However, the latter site's modelled noise increases of <2 dB would be indiscernible from existing edge levels, despite the model's apparent consideration of new traffic flows of 48,200; an increase in traffic volume of more than seven hundred percent. In an area where the upgraded road will mostly follow the current alignment and at a similar height, at one transect (Mareeba Sign, Figure 2.14), the predicted levels from the 'Ultimate Model' show noise at the edge as lower than those measured currently, even with the increased traffic levels used in the ultimate modelling.

Therefore, given the inaccuracy of modelling predictions of edge noise levels adjacent to the existing road (17-31 dB difference between predicted and measured levels, Figure 2.12, Table 2.3), we suggest that edge noise levels are also likely to be underestimated in the 'Ultimate' model predictions to at least a similar extent but more likely a greater extent depending on the impact of the increased traffic loads. However, it is acknowledged that switching to stone mastic asphalt (SMA) should account for an approximate two decibel improvement. Any advantage from this quieter road surface is likely to be offset by increased noise emissions due to bridge expansion joints.

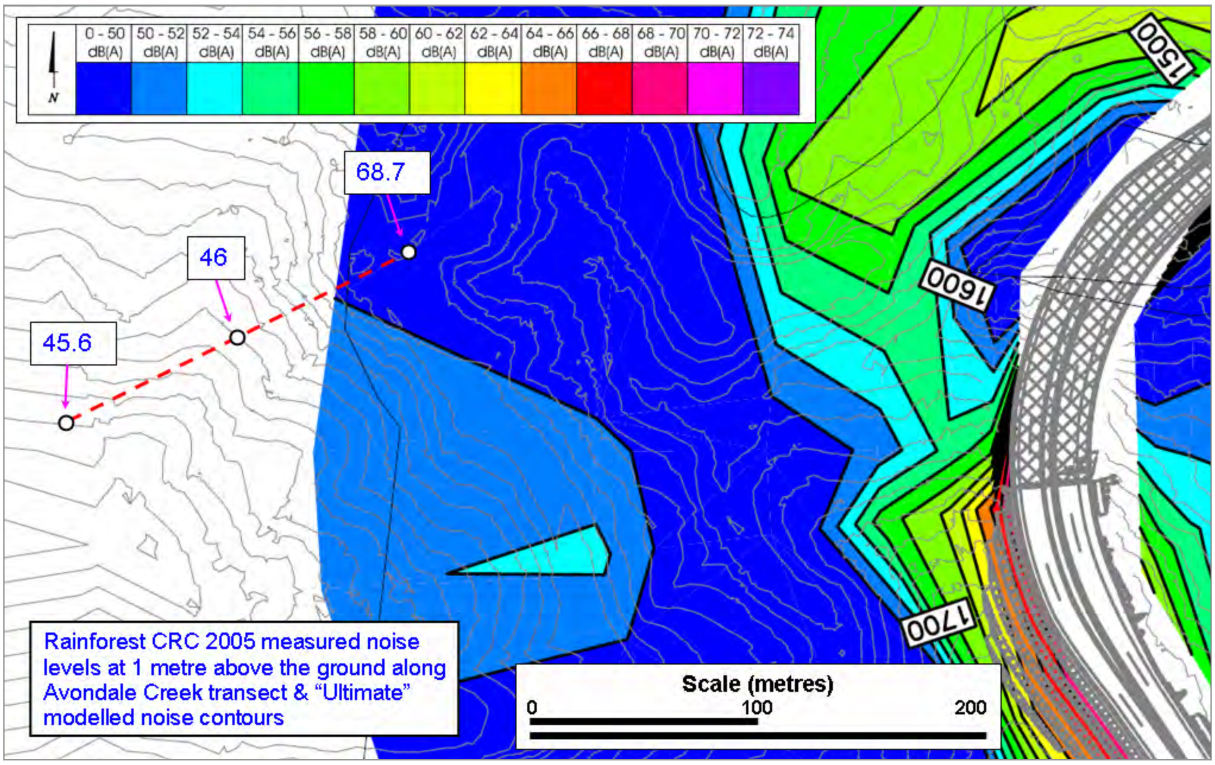


Figure 2.13: Measured current (2005) noise levels and ‘Ultimate’ modelled ground noise contours adjacent to Avondale Creek at new highway alignment (modified from ASK Consulting Engineers 2867FIGA-C11, 2003).

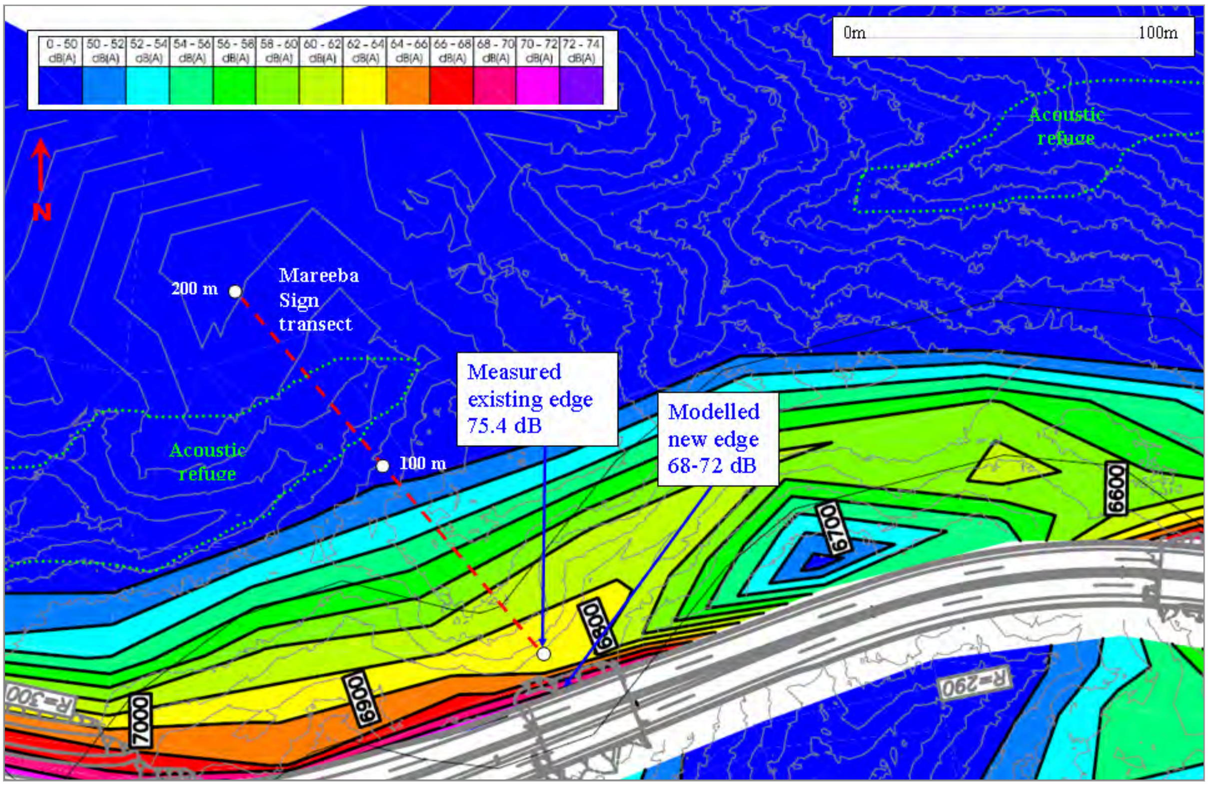


Figure 2.14: Measured noise levels at existing edge and ‘Ultimate’ predicted levels at edge of new highway alignment adjacent to Mareeba Sign transect (modified from ASK Consulting Engineers 2867FIGA-C6, 2003).

Edge noise levels – canopy

Predictions of changes to L_{10} noise levels in the canopy based on 'Ultimate' modeling were only available for the present edge zone of Streets Creek transect, with a predicted noise reduction against 2005 levels of between 7.7 and 9.7 dB. Predicted noise levels for the same site based on the '10-year from Construction Commencement' model indicate a noise reduction of between 15.7 and 17.7 dB (Table 2.6). The future highway lies approximately thirty metres south of the existing crossing of Streets Creek and a large proportion of the predicted noise-reduction could be accounted for by normal propagation losses over that distance.

All other calculations of predicted adjustments to canopy noise levels employed the '10-year' modelling (IAS Addendum Vol. 3 B5 to B11) and these were compared with the 2005 Rainforest CRC sampling. Predicted noise levels for the ten-year model at these sites also appear to be underestimated at the edge. For example, the predicted noise level at Streets Creek edge canopy was between six to ten decibels lower than measured at the edge of the road in the current study under conditions of less traffic than used in the ten-year model. This represents a thirty to fifty percent predicted reduction in perceived noise levels from those currently existing at this location despite a 23% increase in traffic. The ten-year model shows noise levels at the eastern entrance to the new Streets Creek bridge which are similar to those measured in the canopy on the edge of the current road at Streets Creek transect (Figure 2.15). We would expect with greater traffic volumes after ten years that the noise levels in the canopy at the edge of the new road should be greater than those currently measured, at least where the bridge is at similar elevation to the surrounding terrain such as bridge entrances. The bridge height would be expected to mitigate this to some extent towards the centre of the bridge.

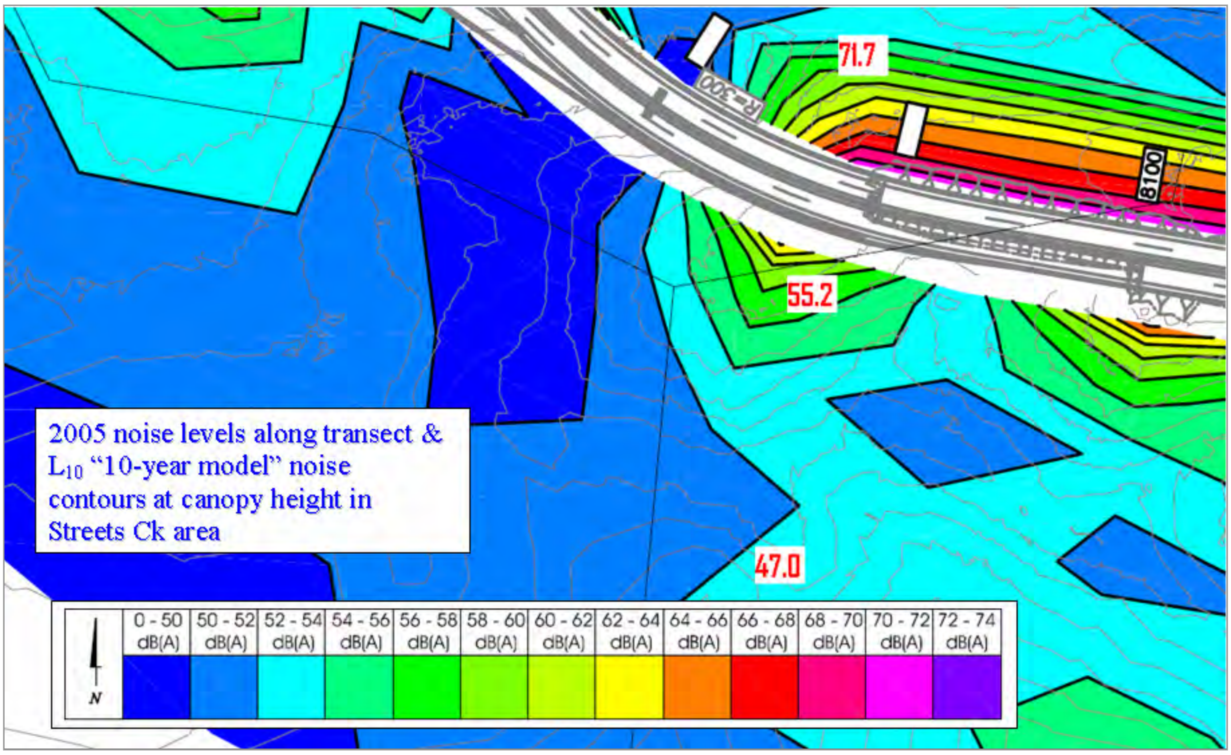


Figure 2.15: Measured noise levels at existing edge of Streets Creek transect and '10-year' predicted levels at edge of new highway alignment near Streets Creek (modified from ASK Consulting Engineers 2867FIGA-C6, 2003).

The '10-year' model suggests a noise reduction at the present Avondale Creek edge canopy of between 17.3 and 67.3 dB (due to the eastern relocation of the new road as mentioned earlier). Streets Creek had the next largest noise reduction with a predicted noise drop of between 15.7 and 17.7 dB (again mainly due to the southwards relocation of the new road by approximately 30 metres). Ten-year modeling of noise at Water Point edge generated predicted levels of between 5 to 7 dB lower than current values, while all other sites produced predicted values less than 5 dB above / below current noise levels (Table 2.6).

Interior noise levels – ground

Predicted noise levels at both interior sites at Avondale Creek lay outside the range of the 'Ultimate' model and no inference could be made as to expected alterations to existing noise levels at either one hundred metres or two hundred metres from the existing road (Table 2.5). Noise levels at the one hundred metre sample points of Water Point, Down Ridge and Streets Creek transects are all predicted to rise by between as little as 0.5 dB (Down Ridge) to as much as 12 dB (Streets Creek). This represents a doubling of the perceived loudness level of traffic noise at the latter one hundred metre zone. Noise levels at one hundred metres at Mareeba Sign may fall by between 4.1 dB and 54.1 dB, while the one hundred metre points along all other transects can expect to retain similar L_{10} noise levels to those recorded in the 2005 Rainforest CRC survey (Table 2.5). As the model of the current road was relatively accurate with regards predictions inside the forest, we expect these predictions for the Ultimate model to also be relatively accurate for forest interior sites, provided the increase in traffic flow and traffic speed was taken into account when the 'Ultimate' model was prepared (we are unsure as to whether this was the case).

The 'Ultimate' model predicts that future noise levels at two hundred metres along Water Point transect may be expected to rise by around two to four decibels, while levels at Streets Creek are predicted to remain unchanged. Reductions in noise levels of at least 5.6 dB are predicted for the two hundred metre site on Powerline transect. All other two hundred metre sites have current noise levels which lie within the limits of the model's predicted 0-50 dB zone.

Interior noise levels – canopy

Predicted noise levels at Avondale Creek interior canopy sites were unavailable; these locations being outside the scope of the ten-year model. Predicted noise levels at one hundred metre sites along all the remaining transects were closely aligned to current noise levels, with the largest change (between 4.2 dB and 6.2 dB) predicted for Mareeba Sign transect (Table 2.6).

The ten-year model predicts that at the two hundred metre sites, noise levels are expected to remain unchanged at Water Point transect; become elevated by between five and seven decibels at Streets Creek, be reduced by between 6.8 dB and 56.8 dB at Powerline transect, and by between 2.9 dB and 52.9 dB at Down Ridge transect. All other sites have current noise levels within or close to the ten-year model's predicted 0-50 dB zone (Table 2.6). Again we caution that the increase in traffic flow and speed must be included within the modelling.

Table 2.5: Current and predicted L10 noise levels at one metre above ground for Rainforest CRC sample sites at the edge, and one and two hundred metres from the edge, along eight transects perpendicular to existing Kuranda Range Road. **Note:** Current levels are based on data from one twelve-hour daytime sampling period at each of the 24 sites at a microphone height of one metre. Predicted levels (for current edge sampling position) are derived from L10 (eighteen-hour) levels indicated by noise contours of the 'Ultimate' model (IAS Addendum Vol. 3 C5 to C11).

Chainage (metres)		**Transect ID and existing / new chainage**							
		2260/ 1590	5840/ 4770	6470/ 5320	6890/ 5750	7305/ 6100	8070/ 6820	8575/ 7280	9590/ 8230
Noise levels		AC	WP	DR	LO	LS	MS	PL	SC
Edge	Current L_{10}	68.7	71.6	72.6	72.2	73.3	75.4	74.5	73.5
	Ultimate model	0-50	58-60	66-68	62-64	64-66	62-64	60-62	52-54
100 m	Current L_{10}	46	48.2	49.5	52.8	39.3	54.1	50.3	44
	Ultimate model	n/a	52-54	50-52	50-52	0-50	0-50	0-50	54-56
200 m	Current L_{10}	45.6	47.8	46.6	40.7	37	43.9	55.6	50.6
	Ultimate model	n/a	50-52	0-50	0-50	0-50	0-50	0-50	50-52

Table 2.6: Current and predicted L10 noise levels at fifteen metres above ground for Rainforest CRC sample sites at the edge, and one hundred and two hundred metres from the edge, along eight transects perpendicular to existing Kuranda Range Road. **Note:** Current levels based on data from one twelve-hour daytime sampling period at each of the 24 sites at a microphone height of fifteen metres. Predicted levels (for current edge sampling position) are derived from L10 (eighteen-hour) levels indicated by noise contours of the "10-years from Construction Commencement" model (IAS Addendum Vol. 3 B5 to B11).

Chainage (metres)		**Transect ID and existing / new chainage**							
		2260/ 1590	5840/ 4770	6470/ 5320	6890/ 5750	7305/ 6100	8070/ 6820	8575/ 7280	9590/ 8230
Noise levels		AC	WP	DR	LO	LS	MS	PL	SC
Edge	Current L_{10}	67.3	67	67.5	67.3	66.9	67.6	69.4	71.7
	10-year model	0-50	60-62	68-70	64-66	64-66	68-70	64-66	54-56
100 m	Current L_{10}	54.6	53.3	54.3	54.7	46.6	47.8	50.6	55.2
	10-year model	n/a	52-54	52-54	52-54	0-50	52-54	50-52	56-58
200 m	Current L_{10}	46.3	50.4	52.9	46.3	43.8	47.3	56.8	47
	10-year model	n/a	50-52	0-50	0-50	0-50	0-50	0-50	52-54

2.3.5 Acoustic refugia and noise 'hot spots'

Defining refugia – Identification parameters – 2005 noise conditions

Zones of relative quiet, sheltered by topographic and vegetative buffers, have been identified at several interior locations along the 2005 noise transects. Interior sites such as the one hundred and two hundred metre sample points along Lookout Sign transect, the two hundred metre areas of both Lookout transect and Mareeba Sign transect, and the one hundred metre point along Streets Creek transect, as well as having low annoyance (L_{10}) noise levels, also displayed mean daytime L_{eq} noise readings of less than 35 dB. Forty decibels is considered to be the noise level of a quiet living room, while public libraries typically have noise levels of about thirty decibels (Campbell and Isles 2001).

Unfortunately, acoustic assessment of an area based solely on L_{10} noise levels provides scant information about the true temporal and spectral composition of noise. Areas with similar daytime L_{10} noise levels such as the two hundred metre sample points along Avondale Creek and Down Ridge transects, with values of 45.6 and 46.6 dB respectively (Table 2.5), can have very different total noise distribution compositions (Figures 2.16 and 2.17). Wildlife at Avondale Creek would spend more time exposed to noise levels of 35 dB than to any other decibel level (Figure 2.16), whereas those two hundred metres along the Down Ridge transect, living in an area of much greater noise density, would rarely if ever experience such quiet during daylight hours (Figure 2.17). In such cases, a particular habitat's acoustic status may be better assessed using a combination of noise descriptors including L_{eq} levels, which for the above sites had mean daytime A-weighted levels of 40.1 and 44.1 decibels respectively. In the UK, where L_{10} has been commonly used as the preferred road traffic noise descriptor since the 1970s, moves are underway to convert to the L_{eq} descriptor adopted by the European Union and also employed by other UK transport authorities to assess railway and airport noise levels. Local planning authorities in the UK also endorse the use of L_{eq} when assessing all forms of environmental noise, including road traffic noise (Abbott and Harris 1999).

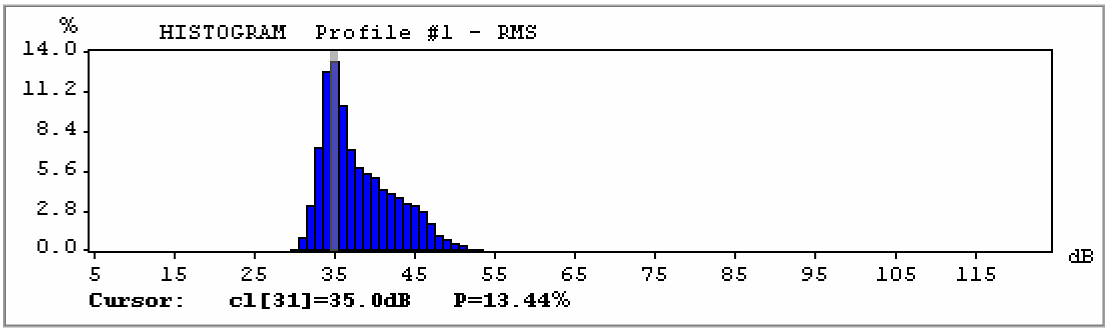


Figure 2.16: Avondale Creek transect two hundred metres ground daytime (twelve-hour) L_{eq} noise distribution, showing percentage of daylight hours at specific noise levels (Mode = 35.0 dB).

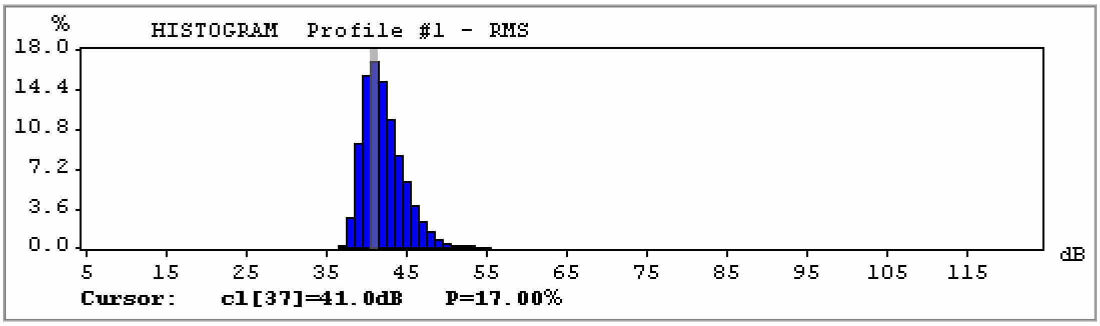


Figure 2.17: Down Ridge transect two hundred metres ground daytime (twelve-hour) L_{eq} noise distribution, showing percentage of daylight hours at specific noise levels, with a mode of 41 dBA (a perceived noise level about fifty percent higher than for Avondale Creek).

Some areas in the 2005 survey displayed (twelve-hour) L_{eq} noise distributions indicating zones well-insulated from traffic flowing as little as one hundred metres away. Typical acoustic refugia like the one hundred metre site along Lookout Sign transect, with noise densities centered around 30 dB (Figure 2.18), may attract noise-sensitive fauna sheltering from areas subject to greater perturbations of traffic noise. This site presents a far different acoustic environment from the one hundred metre point along Lookout transect only 415 metres further along the highway in the direction of Smithfield (Appendix A2.3.4). The latter transect produced a total A-weighted noise daytime distribution node at 39 dB; almost double the loudness associated with the zone at the same distance from the highway along Lookout Sign transect[1]. Although upper noise levels were almost identical at both sites (68 and 67 dB), wildlife at Lookout Sign transect would spend little time exposed to noise levels greater than 38 dB, while fauna at the neighbouring transect would only occasionally experience noise levels that low (Figure 2.18).

As well as having different noise densities to areas categorized as noisy, acoustic refugia present significantly different amplitude levels across the frequency bands of the one-third octave spectrum (Figure 2.19). This illustrates the alteration to the forest acoustic spectrum caused when traffic noise is present – frequency bands between 31.5 Hz and 2.5 kHz demonstrate much higher noise levels than the close to ambient levels shown by the acoustic refuge (Figure 2.19). In the refuge zones, frequency bands between 31.5 Hz and 2.5 kHz, which are blanketed by traffic noise in some other transects, become available for faunal communication (Figure 2.19). This increased spectral availability is similar to the acoustic window at 200 Hz found by Waser and Brown (1986) in East African rainforests (centred on the 160 Hz band in the Kuranda Range rainforests). These frequency bands displayed negative excess attenuation, thereby offering a pathway for faunal communication which is less impeded by propagation losses normally predicted by attenuation that obeys the inverse-square law.

The difference in acoustic environments at the two transects is most likely attributable to the far greater influence of topographic buffering at Lookout Sign transect. Although the one hundred metre point at Lookout Sign transect differed little in elevation to the adjacent highway when compared to the elevation difference at Lookout transect, the main acoustic determinant appears to be the placement of the one hundred metre point behind the Macalister Range at Lookout sign rather than near the ridge-top as was the case at Lookout transect (Figure 2.20). This was despite the much lower ridge height near the highway at the Lookout Sign transect.

---

[1] An increase of ten decibels is considered to represent a perceived doubling of noise levels by human subjects (Austroads 2005).

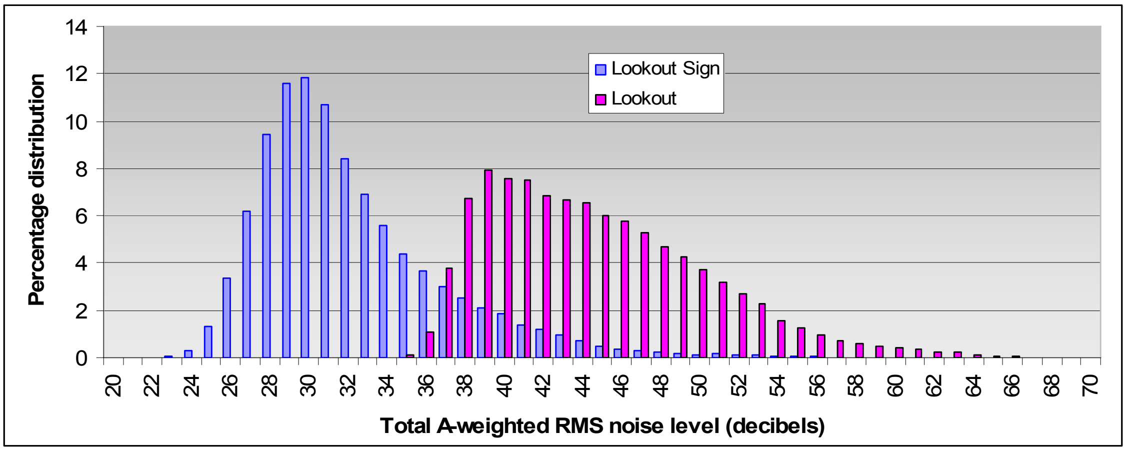


Figure 2.18: Lookout Sign and Lookout transect one hundred metres ground total A-weighted daytime (twelve-hour) noise histogram, showing daytime noise distribution levels, with a nine decibel nodal difference between the two locations.

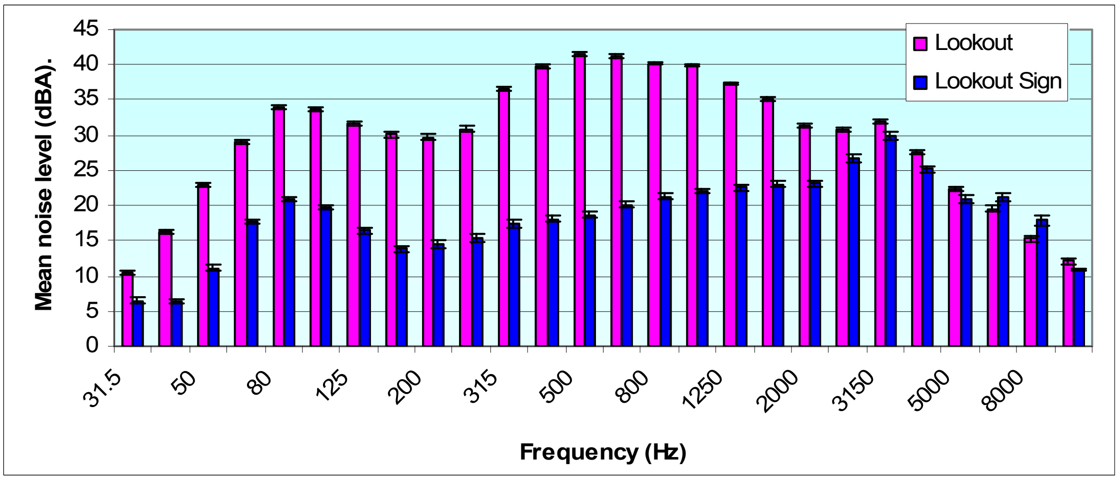


Figure 2.19: Lookout Sign and Lookout transect one hundred metres ground daytime (twelve-hour) L_{eq} noise distribution across third-octave-band spectra.

Annoyance levels and health risk – additional noise parameters

The quietest recorded edge zone, Avondale Creek, with its mean ground daytime L_{10} noise level over 6 dB lower than the loudest sampled edge areas, displayed L_{eq} noise densities stacked to give little respite from traffic noise even during local lulls in traffic, due to noise incursion from other sections of highway (Figure 2.21). These daytime L_{eq} noise distributions all employ RMS (effective noise level) values[2]; when Peak noise levels are examined, edge noise distribution levels are displaced to the right (higher) by around 12 dB, or more than double the perceived noise level (Figure 2.22). Despite some noise respite due to the bimodal nature of the noise distribution, even the quietest recorded edge areas with Peak nodes of 77 db (Figure 2.22), and with noise levels between this and 102 dB for more than thirty percent of daylight hours (Figure 2.23), represent acoustic environments which would induce a range of chronic health effects, if inhabited in the long-term by humans (see Section 1.6).

---

[2] For a pure sound displaying true sinusoidal form this would be equal to 0.707 times the peak amplitude (Fletcher 1992).

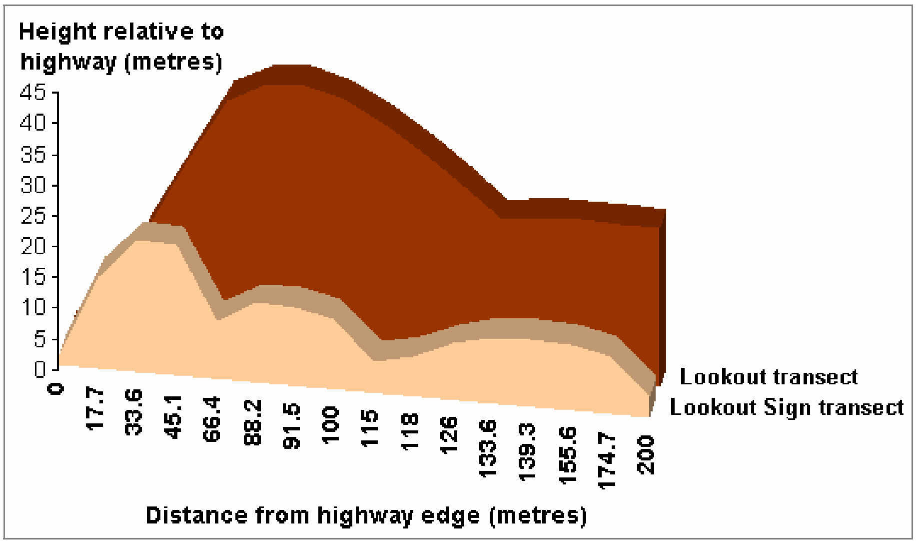


Figure 2.20: Topographic profiles for Lookout Sign and Lookout transects of 2005 noise survey.

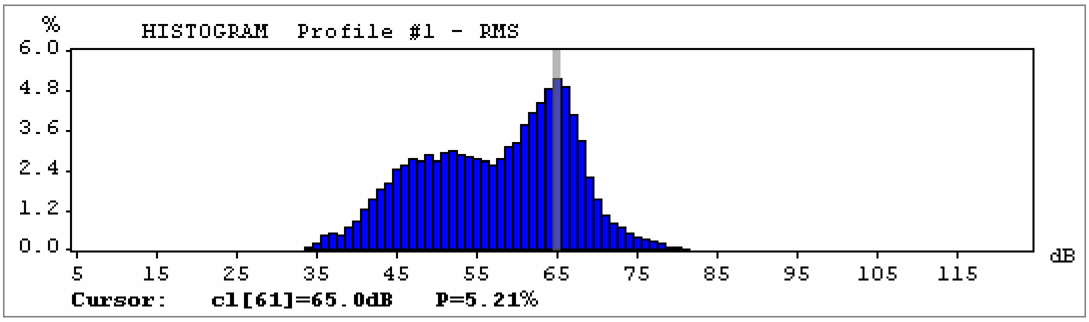


Figure 2.21: Avondale Creek transect edge ground-level daytime (twelve-hour) RMS L_{eq} noise distribution showing noise levels of 65 dB present for 5.21% of daylight hours.

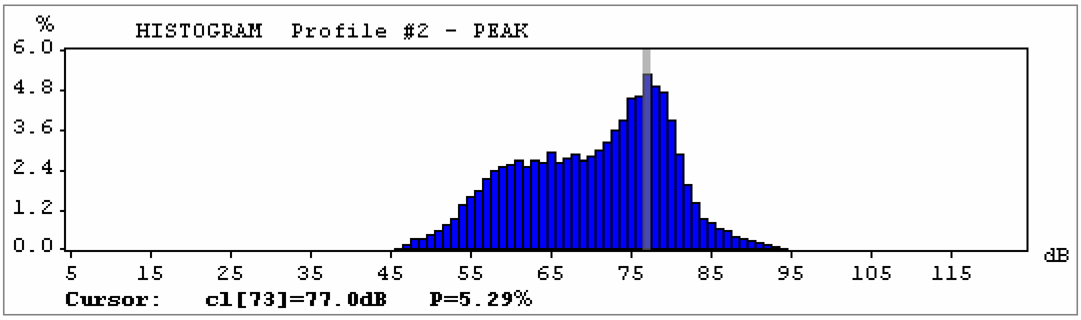


Figure 2.22: Avondale Creek transect edge ground-level daytime (twelve-hour) Peak L_{eq} noise distribution showing 77 dB to be the noise level present for the greatest percentage of daylight hours (5.29%).

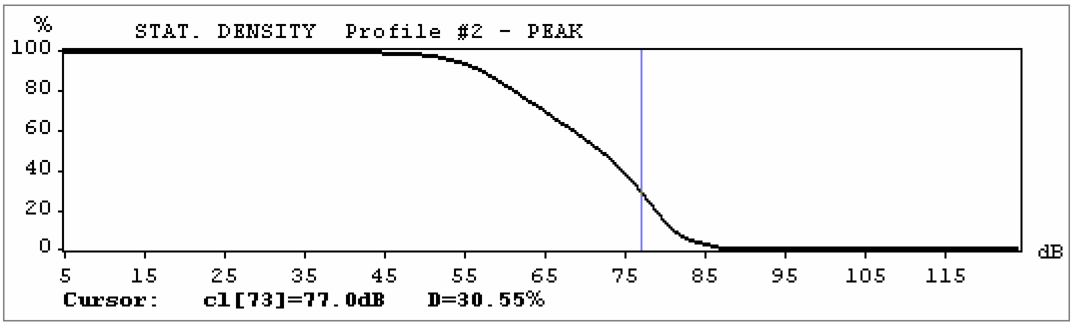


Figure 2.23: Avondale Creek transect edge ground-level daytime (twelve-hour) Peak L_{eq} noise density. The blue line shows noise levels of at least 77 dB to be present for 30.55% of daylight hours.

2.3.6 Likely refugia sites under existing highway conditions

Model accuracy and sampling data limitations

Certain areas along the existing Kuranda Range Road were excluded from transect representation for a range of reasons including safety, inaccessibility, forest type and/or quality, proximity to existing infrastructure and/or other noise sources, proximity to other sections of highway due to road sinuosity, and land tenure. Such areas include:

- The area to the north and east of the existing highway between chainage 6,500 and 8,000;
- Land northeast of highway section between 8,700 metre chainage and Rainforest Station;
- Areas east of the highway between Big Bend and Smithfield;
- Contained land between sections of highway approaching Big Bend between 2,400 metres and 6,300 metres;
- Land on the north side of the highway between Smithfield and 2,100 metres;
- Land to the south of the highway between 5,700 metres and Big Bend; and
- The area south of the highway between Diplazium Gully and Streets Creek.

Despite the absence of direct noise sampling in the above-mentioned areas during the 2005 Rainforest CRC survey, areas deemed likely to provide refuge to fauna from traffic noise impacts under present conditions have been identified based on topography, vegetation, available local noise data, acoustic theory and peer-reviewed studies, and QDMR modelling.

Traffic noise refuges – locations on existing transects

The following areas along existing transects, although not all directly noise-sampled, are suggested as being likely current refuges for fauna from traffic noise:

- Streets Creek transect between 160 metres and 190 metres;
- Powerline transect between 120 metres and 170 metres;
- Mareeba Sign transect between 120 metres and 160 metres;
- Lookout Sign transect between 80 metres and 200 metres (Appendix B1);
- Lookout transect between 170 metres and 200 metres; and
- Avondale Creek transect between 120 metres and 200 metres.

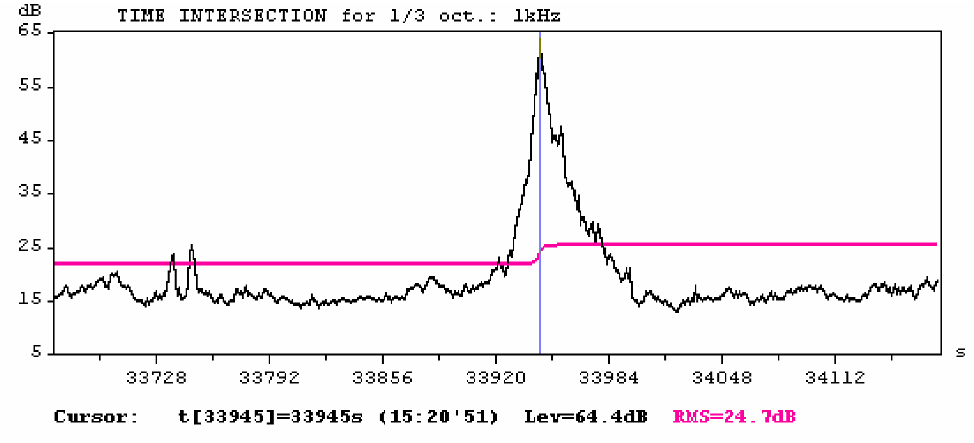
Threats to existing refugia on sampled transects

Streets Creek transect and Powerline transect acoustic refugia: The middle of the proposed highway crosses the sixty metre point along Streets Creek noise transect at chainage 8,230 metres (Appendix A2.3.9). While the existing local acoustic refuge lies mostly to the east of that transect, it nevertheless includes some of the area sampled during the bird surveys (Section 4), and extends to within ten metres of the proposed upgraded highway. Although noise data was not directly sampled from this refuge, bird surveys revealed a distinct increase in species diversity and population abundance in the area behind the ridge (see Section 4), buffered from the existing road by the local topography. Acoustic conditions at this refuge would be severely altered by the proposed southern translocation of the highway. This refuge area has since been noise sampled, analysis of which appears in a later report.

The upgrade would deliver little noise respite to areas around the edge of the existing road; apart from a possible western extension of the refuge along the upper reaches of Streets Creek after its crossing of Powerline transect (Appendix A2.3.7).

Lookout Sign transect acoustic refuge: The proposed bridge (BD 22) across Diplazium Gully brings the traffic noise source approximately ninety metres closer to the acoustic refuge area of Lookout Sign transect (to within four hundred metres of the end of the transect). Bridge 22 is aligned approximately twenty degrees to Lookout Sign transect, with bridge 23 having closer alignment (Appendix A2.3.4 and A2.3.6). A large proportion of current traffic noise reaching the Lookout Sign transect acoustic refuge originates from the existing road where it crosses the North-South Ridge (personal observation 2005). This noise, particularly from heavy vehicle sources such as the impulse noise generated during decompression braking, makes a significant impact to the existing acoustic environment at this site (Figures 2.24 and 2.25).

At present the amplitude and temporal extent of noise reaching the refuge from this direction is limited by three main factors: distance, vegetative buffering and topography. The proposed southeastern displacement and bridging of this section of the highway will severely weaken existing buffering from the first two factors in this otherwise quiet refuge. The single ‘rogue’ traffic noise event displayed in the following plots was the loudest 1 kHz noise spike on that day’s buffer (Maximum noise level of 64.4 dB, Figures 2.24a and 2.24b), generating a peak total A-weighted noise level of 79.5 dB (Max = 65.4 dBA). The two next loudest vehicle passes produced maximum noise levels of 53.6 dB and 52.8 dB in the 1 kHz band; also significantly higher than their respective ambients of 19.3 dB and 21.9 dB two minutes prior to each event. The impact of a similar event at canopy height would be considerably greater. Standard concrete barriers 80cm high would afford little ameliorative effect to noise originating from exhausts of many of the heavy transports using the present road, particularly the tandem bulk ore haulers with exhaust stacks discharging at three to four metres above the pavement. In the European Union only ten percent of heavy vehicles have this exhaust configuration (Jonasson and Storeheier 2001); while on the Kuranda Range this figure of ten percent appears to be exceeded (personal observation 2005). Whether the UK Department of Transport CoRTN model (the base model used in the Kuranda Range noise modelling) has accounted for this possible discrepancy has not been ascertained.



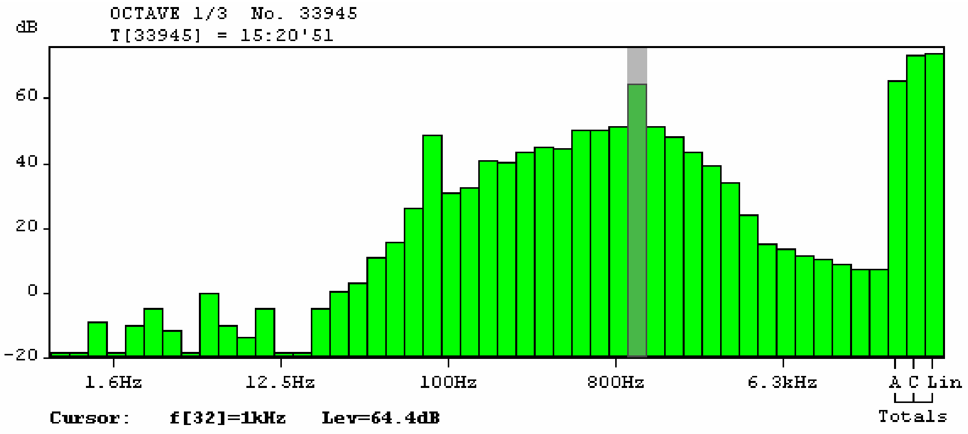
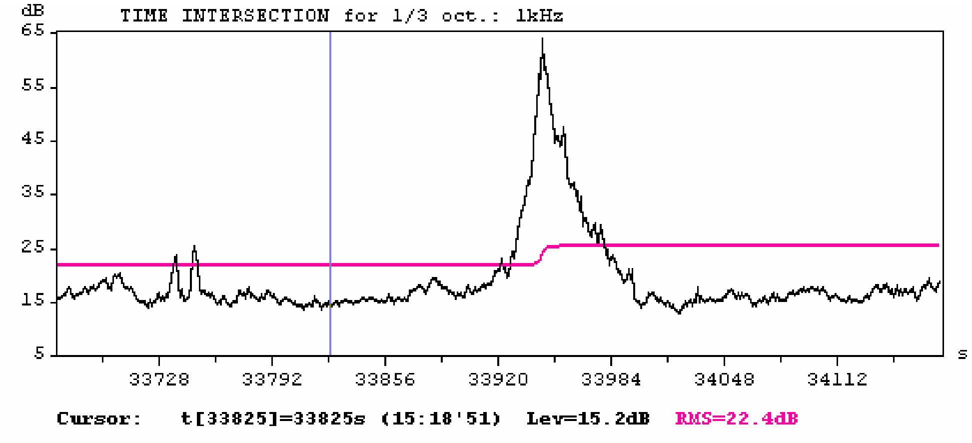


Figure 2.24a (*top*): Time-history plot of 1 kHz noise levels (max = 64.4 dB) at one metre above the ground, two hundred metres from the highway during heavy vehicle pass (Lookout Sign transect).

Figure 2.24b (*bottom*): Third-octave spectra of acoustic conditions at same time (cursor shows 1 kHz-centred third-octave band noise level).



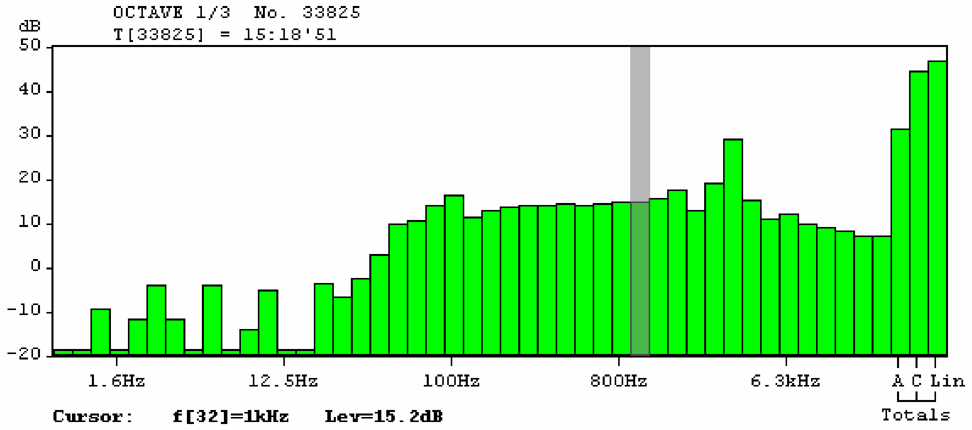


Figure 2.25a (*top*): Time-history plot of 1 kHz noise levels at one metre above the ground, two hundred metres from the highway two minutes prior to heavy vehicle pass (Lookout Sign).

Figure 2.25b (*bottom*): Third-octave spectra of acoustic conditions two minutes prior to truck pass (cursor shows 1 kHz-centred third-octave band L_{eq} noise 15.2 dBA).

Potential acoustic refugia from the existing road where noise measurements were not undertaken and likely impacts of the upgraded road on these

Potential existing acoustic refugia other than those traversed by the 2005 noise survey transects, have been identified at another twelve locations adjacent to the existing Kuranda Range Road (Appendix A2.3). Noise levels in these refugia are unlikely to be reduced as a result of the proposed upgrade, with noise levels at some expected to rise. Refugia at risk of greater noise intrusion include: the area to the south of the proposed highway near chainage 7,900 (Figure A2.3.9, page 117), the upper Streets Creek refuge area below the crossing of Powerline transect closest to the eastern approaches of bridge 24 (Figure A2.3.7, page 115), areas to the north of the western approaches to bridge 21 (Figure A.2.3.5, page 113), and two small refugia near the end of Down Ridge transect close to chainages 5,200 and 5,400 (Figure A2.3.3, page 111). Unfortunately, even in the case of the lower crossing of Avondale Creek, where the new highway is displaced approximately 240 metres to the east (Appendix A2.3.1; A2.3.2) and therefore it might be expected that noise levels should fall, little overall improvement in acoustic conditions is expected, as much of the traffic noise perturbation to those refugia has its origins in the Water Point-Lookout section of the highway (personal observations 2005).

2.4 Conclusions

The noise modelling employed to assess current noise conditions adjacent to the Kuranda Range Road was found to have significantly underestimated daytime L_{10} noise levels close to the roadside throughout its traverse of forested sections of the range. While predicted noise levels may have matched reasonably well with recorded noise data sampled from residential premises at the start and near the end of the route, the accuracy of such modelling in predicting future forest edge noise levels is questioned. In the current legislative environment, infrastructure agencies are required to consider the impacts of operational noise on humans, but not on wildlife, and therefore the noise models produced are not aimed at providing accurate estimates for non-residential areas. In areas of high conservation value such as World Heritage Areas and the habitats of endangered species, consideration should be given to a legislative requirement for more accurate models of noise impacts on wildlife habitat and to the testing of the models' applicability to non-residential areas. This research, funded by the QDMR, has undertaken what is believed to be the first Australian examination of such models in terms of impacts on wildlife habitat rather than human habitations.

In contrast, modelling of existing interior noise conditions was found to be much more accurate, with recorded noise data lying within one contour interval (two decibels) of predicted noise levels. However, as the model noise contours were not curvilinear, and in consideration of the map's scaling, caution should be exercised when interpreting sample point noise-data with modelled noise zones, particularly when contours are closely spaced.

Highway edge total A-weighted noise levels are louder at one metre above the ground than at a height of fifteen metres. This characteristic is reversed in the interior zones. Edge areas are about four times noisier at one metre above the ground than areas one hundred metres from the road. Noise levels in the lower canopy are about four times louder at the edge than at two hundred metres. Traffic noise attenuates most within the first one hundred metres from the highway, but still reduces significantly over the next hundred metres, both near the ground and in the lower canopy. However, traffic noise is still above ambient at two hundred metres inside the forest (Dawe 2005) and vehicular noise has been estimated to become undetectable at a distance of 350 metres on relatively flat terrain (Dawe and Goosem 2008), with dominant traffic frequency noise (800 Hz) still detectable in rainforest to distances of 650 metres.

Daytime edge total A-weighted noise-levels displayed no sustained peaks or lulls during the twelve-hour sampling sessions at the one-metre microphone height, although significant correlations of noise with hourly traffic flows were observed. Edge noise levels in the lower canopy did however display significant daytime fluctuations in mean noise levels.

Individual noisy vehicles do much to elevate noise conditions at both edge and interior sites. These peaks are missed from models using L_{10} descriptors, with L_1 noise levels at the edge being typically about ten decibels higher (double the perceived loudness) than L_{10} levels. Peak levels along the edge are usually more than ten decibels above the L_1 levels, with occasional A-weighted peaks above 110 dB.

Our identification of acoustic refugia employed a degree of subjectivity, with the fuzzy boundaries of such zones catering for different noise levels at the ground and in the canopy, as well as the variability caused by seasonal changes in foliage density, variable faunal noise tolerance, and local acoustic anomalies. However, transect noise and birdsong sampling (Section 3) and observed bird abundances (Section 4) did support the probable existence of these quiet refuges and the potential importance of their preservation in the maintenance of bird species diversity and bird abundance in the vicinity of the road, along with retention of acoustic connectivity between refugia. Nothing is known about the tolerance threshold of wildlife to low level noise; and seemingly insignificant increases in noise above the low noise levels existing in these refugia may produce impacts on fauna that are far from insignificant. In human subjects, levels of noise exceeding 65 dB (L_{eq}) (Table 2.7) pose a serious risk to health, while noise levels of 50 dB produce a moderate degree of annoyance. However, levels as low as 40 dB have been shown to be detrimental to well-being (WHO 2000).

Table 2.7: Typical noise levels from common sources (modified from Bernhard and Wayson 2005).

Source	Noise level (dBA)	Source	Noise level (dBA)
Threshold of pain	140	Normal speech at one metre	63
Loudest peak level sampled on Kuranda Range		Typical urban daytime	50
Jet flyover at 300 metres	110	Sampled L_{10} noise levels at 100 metres in forest, Kuranda Range	40-50
Rock band at five metres	105	Urban nighttime	38
Lawn mower at one metre	100	Sampled L_{10} noise levels at 200 metres in forest, Kuranda Range	37-50
Diesel truck at fifteen metres	90	Library	35
Food blender at one metre	85	Pre-test ambient sampled noise at Palmerston highway	32
Sampled L_1 noise levels at road edge on Kuranda Range		Bedroom at night	28
Sampled L_{10} noise levels at road edge on Kuranda Range	69-75	Rural nighttime	25
Vacuum cleaner at three metres	70	Detection threshold	0

2.5 Recommendations

All the models used to gauge noise levels adjacent to the existing Kuranda Range Road, and predict noise levels for the upgraded road should be re-calibrated to account for the significantly higher noise levels recorded along the highway edge compared to noise levels predicted by the models prepared for QDMR. Predictions by these models of similar future noise levels adjacent to the highway edge to those currently recorded appear to severely underestimate the effect of an expected seven-fold increase in traffic volume. Although some of that effect may be negated by the greater propagation distances between the source and the highway edge due to the increased road width, it appears unlikely to account for such a large rise in road usage. Alternatively, the 'Ultimate' noise predictions of similar noise levels to those currently experienced along the highway edge may be underestimating the effects of expected increases in average vehicle speeds from the present 50 km/hr to a predicted 80 km/hr (ASK Consulting Engineers 2004). If the traffic speed was to increase to 100 km/hr rather than 80 km/hr, noise at the highway edge would rise by between nine and twelve decibels; a perceived sound level twice as loud as that currently experienced (Austroads 2005). From curves displaying overall noise the expected 30 km/hr increase equates to a noise increase of 6 dBA (Figure 2.26); a sizable difference to that predicted in the model for edges such as at Mareeba Sign (68-72 dBA) when existing levels are already at 75.4 dBA (Figure 2.14).

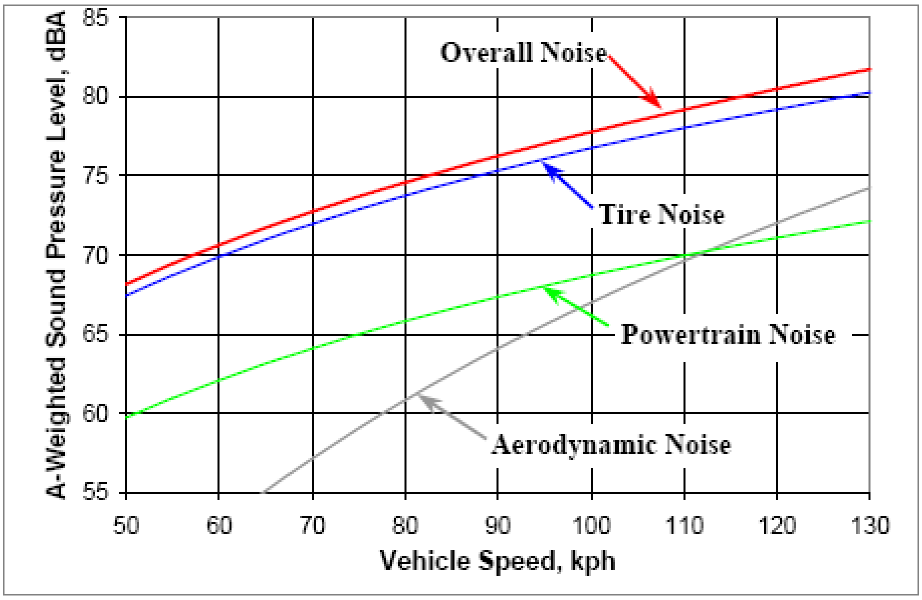


Figure 2.26: Contribution of sub-components of traffic noise (Source: Donavan, in press).

It is possible that noise levels below bridges and in areas at lower elevations than the adjacent proposed highway may have been underestimated. Therefore, field noise data should be sampled below bridges in rainforest areas at a variety of bridge heights to examine whether the degree of acoustic shading provided by bridges that has been incorporated in the models of the road upgrade is reasonable. Currently, we have no data to assess this.

Daytime noise levels measured at the edge of the road are relatively continuous at a level recognised to pose serious implications for human health. Without sufficient data to assess continuous traffic noise impacts on the variety of wildlife found on the Kuranda Range, a precautionary approach would assume that such noise levels would be sufficient to impact on at least some wildlife species. This assumption is supported for some of the bird species in Sections 3 and 4 of this report. Therefore means of mitigating the dissemination of traffic noise are suggested.

Considerable reductions in impulse and peak noise levels can be obtained by reducing emission levels from the noisiest road users. Therefore a program aimed at both muffling noisy exhausts, and curbing the deployment of compression braking, particularly in areas of high habitat and conservation value, including creek crossings and areas providing connectivity, needs to be implemented by the relevant authorities. A tightening of the noise emission standards will not only considerably reduce highway edge noise levels, but will also benefit interior zones. Significant noise reductions from these sources will help offset much of the deleterious noise impact associated with the proposed road upgrade as outlined in this report.

The intended concrete crash barriers may contribute to reduction in noise levels through reduced road and tyre noise from the majority of vehicles. Barriers should also help to reduce exhaust, engine, transmission and wind noise from passenger cars, motorbikes and some buses and trucks. However, the relatively low 800 mm profile of the proposed barriers is likely to contribute little to noise reduction from heavy transport, particularly if these users predominantly use the left-hand lane of the dual carriageway, as exhaust and compression brake noise is propagated above this height. Slight improvements over the 800 mm barriers may be produced by taller 1,200 mm barriers; however the three to four metre height of heavy transport exhausts would not be greatly ameliorated. Alternative designs should be considered in sensitive areas such as bridges.

Trimming commuter traffic peaks by strategies which spread employment hours would reduce the overall impact of both the current and upgraded road. Another option to reduce noise peaks could involve encouraging heavy transport movement in hours outside the commuter traffic peaks (e.g. 10:00-16:00 hrs).

More research into the ameliorative effects of noise buffers needs to be undertaken in order to effect real reductions in noise outputs from the upgraded highway. Little is known about noise propagation from bridges, particularly to areas at elevations below the road alignment. As much of the upgraded highway will skirt valley acoustic refugia for fauna, and in consideration of the number of bridged sections intended for the upgrade, more research needs to be undertaken on the role of bridges on traffic noise propagation, including transmission of infrasound and reverberation effects.

Consideration should be given to existing quiet refuges for fauna and the impact of noise from the upgraded road on these – alignment adjustment or careful noise barrier design may alleviate potential impacts caused by reduction of current topographic shielding from traffic noise.

Once models have been re-calibrated using the data collected in this project, acoustic refugia created by construction of the new road alignment should be mapped and receive similar protection to those currently extant.

Noise Disturbance along Highways

Section 3:
Effect of traffic noise on avian vocalisation

3. Effect of traffic noise on avian vocalisation

Gregory Dawe and Miriam Goosem

Summary

Songs of fifty-nine bird species were recorded along transects adjacent to the Kuranda Range Road, and at control sites adjacent to Black Mountain Road. Overall, 795 songs of call-notes were analysed from birds at the zone two hundred metres from the forest edge, and 1,821 songs or call-notes from song-files produced from recordings adjacent to the edge of the Kuranda Range Road. The dominant frequencies of songs from eighteen of these species recorded at locations adjacent to the highway and at two hundred metres into the interior were analysed for evidence of any acoustic modification over distance.

Birdsong from nine species had dominant frequencies at the edge of the forest that were significantly different from those recorded in songs from individuals two hundred metres inside the forest. Of these, five species were assessed to have sufficient replication of song alteration in terms of numbers of songs and a lack of confounding factors, for traffic noise to be considered the likely cause of the song frequency shift. Two of these were non-passerine species with low frequency calls and few individuals available for recording, and so were considered only potentially affected by traffic noise.

However, at least three of the tested species appear to adjust the dominant frequency of their song in order to overcome traffic noise masking. Such a change to the pitch of a song can potentially impact on the bird's energy budget by requiring more energy to achieve the unnatural pitch. Song alterations might also increase risk of predation or decrease ability to attract mates. Any of these changes could result in reduced fitness of the individual and possibly of the population near the road.

Results for other species may demonstrate song pitch adjustments as well, with several showing potential but requiring analysis of the large amount of data remaining from the recording sessions.

3.1 Introduction

Successful acoustic communication requires that sounds propagate through the environment between the sender and receiver. Therefore, vocalisations that transmit effectively in the habitat in which they are used are favoured by natural selection (Patricelli and Blickley 2006). An environmental factor which exerts selection pressure on acoustic signals such as birdsong is ambient noise (Ryan and Brenowitz 1985). To elicit a response from a receiver, signals must be detectable in background noise with communications that have a signal-to-noise ratio below the detection threshold of the receiver being masked. Noise varies among areas and many species have evolved signals that maximise the habitat-specific signal to noise ratio (Brumm and Slabbekoorn 2005). Four of the most important features of animal sounds are the frequency structure, loudness, timing of modulations, notes and syllables within vocalisations, and timing of delivery (e.g. repetition rates, diurnal patterns of calls). All of these are used to detect and discriminate relevant sounds from background noise.

For both humans and birds, noise resulting from the attenuation and degradation of signals mixed with ambient sounds impacts on both mutualistic and manipulative communication

(Wiley and Richards 1982). Traffic noise is becoming an increasingly important component of the acoustic environment, with many of its direct and indirect impacts on wildlife poorly understood (Forman and Alexander 1998; Forman *et al.* 2003). Although some research has been undertaken on road avoidance by birds in woodland (Reijnen and Foppen 1994; Reijnen *et al.* 1995), pine forest fragments (Brotons and Herrando 2001), and grassland (Reijnen *et al.* 1996; Reijnen *et al.* 1997), few studies have considered the impacts of traffic noise on *in situ* wildlife communication.

Whether birds respond to anthropogenic noise blanketing by adjusting vocalisations or by avoidance of habitat depends on the morphology, development of vocalisation and behaviour of the species and the context in which communication is undertaken (Patricelli and Blickley 2006). For example, many larger birds are physiologically restricted to lower frequencies of the sound spectrum due to body mass and size. In non-passeriform birds, such as pigeons and doves, which lack the vocal plasticity of oscine passerines, vocalisations are innate (Kroodsma 2004) and long-term frequency adjustments of vocalisations are unlikely, although changes in loudness and timing of vocalisations may still be possible. Even in species that can adjust the frequency of songs more quickly, it may not be possible to shift the entire vocalisation to higher frequencies due to restrictions imposed by head angle and beak gape and shape. The loudness of songs is one factor that may be increased and this appears to be a common response to anthropogenic noise by both birds and mammals but is limited by body size and energetic costs of producing louder sounds (Rabin and Greene 2002; Warren *et al.* 2006). Temporal structure such as increased repetition and duration may increase detectability when background noise is present, an adjustment known to occur in the face of high natural noise levels (Warren *et al.* 2006). In locations subject to infrequent traffic it is possible that birds may make temporal adjustment to their singing patterns, similar to the interspecies song spacing found by Ficken and others (1974) to be employed by Least Flycatchers and their Red-eyed Vireo neighbours to counter the effects of mutual song-masking. Birds might time their songs to take advantage of small gaps in noise (Lohr *et al.* 2003).

Notable exceptions to the lack of information regarding anthropogenic noise impacts on vocalisations include research regarding pitch adjustment by Great Tits (Slabbekoorn and Peet 2003) and amplitude adjustment by Nightingales (Brumm 2004) and Tree Swallows (Leonard and Horn 2005). Ilichev and others (1995), in an examination of several avian species across five Central Russian and Southern Ural regions, found significant deformity of the song of Chaffinches exposed to technological noise pollution. However Skiba (2000) found no evidence that Chaffinches, living in noisy urban environments using ‘rain-call’ dialects comprising higher frequencies, were more plentiful than conspecifics using lower-frequency dialects (although all six dialects utilised frequency bands ≥4 kHz – well above the dominant frequency of local traffic noise). In the United States, Song Sparrows have been found to respond to urban noise by adjusting their vocalisations, shifting more energy into the higher frequencies (4-9 kHz) of their songs in noisy areas (Wood and Yezerinac 2006). This avoids masking by the loudest component of urban noise at 1-2 kHz, much of which is contributed by traffic noise. A positive relationship was found between the minimum frequency of male song and the amplitude of anthropogenic noise (Wood and Yezerinac 2006). It is likely to be very difficult for birds to adjust vocalisations to noise by shifting the entire song to a higher frequency due to morphological restrictions on head angle, and beak shape and gape (Patricelli and Blickley 2006); in general, increased minimum and dominant frequencies are observed.

Not all song modification to overcome anthropogenic noise-blanketing may be advantageous. In a study of the dialects of Orange-tufted Sunbirds in an urban area of Israel (Ramat-Aviv), with its altered topography, atmospheric conditions and noise patterns, researchers found the song dialect with the highest dominant frequency to suffer severe frequency-dependent attenuation within seventy to one hundred metres from the caller

(Leader *et al.* 2005). Selective attenuation may in some instances be desirable. Mathevon and others (2003) found the coding of the song of the Brazilian White-browed Warbler to be adapted to propagation constraints. Species identity occupied an 'active space' less subject to acoustic degradation to allow long-distance recognition of individual ownership of territory, while codes on individual identity and motivation only of interest to nearby individuals were assigned to song parameters more susceptible to propagation-induced degradation. Optimum song transmission was dependent on both the time of singing and on perch height, with distance determination cues gathered by selective use of these propagation-induced factors (Mathevon *et al.* 2003).

Sound transmission varies greatly with forest type, with research on Green Hylia in Cameroon rainforests by Slabbekoorn and others (2002) suggesting that although dense foliage degraded vocalisations, avoidance of frequency modulation and the resultant enhanced reverberation produced longer and louder signals for the same energy expenditure. Slabbekoorn (2004) found ambient noise to occupy several distinct frequency bands in contiguous rainforest in Cameroon, while samples from an ecotone forest displayed only one high-frequency band at certain times of the day. These habitat-dependent noise spectra are most likely due to a combination of habitat-specific abiotic and biotic noise sources along with some habitat-dependent sound transmission (Slabbekoorn 2004). Long-distance primate vocalisations through the canopy of a Ugandan rainforest were found to suffer the least amount of excess attenuation at low frequencies (125 Hz) rather than in the midrange frequencies (Waser and Waser 1977). Unfortunately such signals tend to fare less well when impacted by traffic noise; with Rheindt (2003) finding that passerine species singing with lower dominant frequencies were more susceptible to acoustic masking by traffic noise, and consequently were less abundant adjacent to highways than those species singing with higher dominant frequencies.

No studies have measured the fitness consequences of vocal adjustments to individuals or populations, although some has speculated on the costs to conservation of bird populations (Patricelli and Blickley 2006). Vocalising more loudly in noisy environments may have energetic costs that decrease the net benefits of vocal adjustment and alter the bird's energy budget (Brumm 2004; Warren *et al.* 2006; Wood and Yezerina 2006). Shifting songs to higher frequencies may also impose energetic costs and may affect the efficiency of transmission and recognition by conspecifics, particularly mates, and therefore limit reproductive success. Similarly, adjusting song frequency may affect recognition of calls between parents and offspring or between flock members or enhance recognition of calls by predators, increasing predation risk (Patricelli and Blickley 2006).

No studies have investigated the effect of traffic noise on songs of tropical rainforest birds. This current project investigated the effect such noise is having on the vocalisations of birds living in rainforests adjacent the Kuranda Range Road by comparing dominant frequencies of songs between individuals of a species habiting close to the highway edge with others living in the forest interior.

3.2 Materials and methods

3.2.1 Location

Birdsong was recorded at the edge of the rainforest and at two hundred metres from the edge along eight transects perpendicular to the Kuranda Range Road (Figure 2.1 and Table 3.1). Reference songs to enable positive identification of song repertoires from target species, were also obtained from locations covered in the bird population surveys at Avondale Creek and Streets Creek, and at the Black Mountain control sites (Section 4). These species were positively identified by identification expert Mr Jonathan Munro as part of the 2005 Kuranda Range bird population / species richness surveys (Section 4).

Table 3.1: Birdsong transect location and orientation details, Kuranda Range 2005.

Transect ID	Elev (m)	Bearing (°M)	Transect ID	Elev (m)	Bearing (°M)
Avondale Creek (AC)	115	236	Lookout Sign (LS)	410	233
Water Point (WP)	320	226	Mareeba Sign (MS)	445	311
Down Ridge (DR)	350	61	Powerline (PL)	420	354
Lookout (LO)	380	263	Streets Creek (SC)	350	182

3.2.2 Avifauna species recorded during project

Digital recordings of fifty-nine species of birds were collected along the roadside and transects adjacent to the Kuranda Range Road, and along transects at the Black Mountain Road control sites (Appendix 3.1).

3.2.3 Methodology

This study was conducted in conjunction with a project measuring traffic noise levels at the highway edge and at interior sites adjacent to the Kuranda Range Road (Section 2). Song recordings were undertaken after the daily early morning setup of the sound level meter, and before the instrument's shutdown in the evening. Edge-zone birdsong recordings were gathered during pedestrian traverses of the roadside between Avondale Creek transect start and Streets Creek transect start. Interior song samples were collected from within an approximate twenty-metre radius of the transect end points. Target songsters were optimally located within two to twelve metres of the recording microphone.

Recordings were downloaded each evening to the laboratory computer, and the portable recorder's compact flash card then cleared prior to the next day's recording session. Song files were ideally limited to around four minutes each, to facilitate identification of the recording area and avian subject, thereby avoiding mis-cataloguing of song attributed to different individuals within a species.

3.2.4 Equipment

Uncompressed mono (.wav) recordings of birdsong were obtained using a Marantz PMD670 solid-state portable digital recorder and Sennheiser ME67 unidirectional microphone, at a sampling frequency of 48 kHz and recording bit rate of 768 kbps, using 16-bit linear Pulse Code Modulation (PCM).

3.2.5 Analysis

Preliminary song analysis including extraction of the dominant frequency of each song utilised Audacity software version 1.2.3 (Sourceforge.net 2004) sampling at a frequency of 48 kHz with a 32-bit float, to generate linear frequency spectrograms through a Hanning window at a Fast Fourier Transformation (FFT) resolution of 512. This resolution was adjusted for certain species where song harmonics and individual repertoires generated inconsistent dominant frequencies, or where the dominant frequency was obscured through reverberation or high ambients. Some species with vocalisations in the lower frequency bands required the use of log frequency plot-spectrum displays rather than linear frequency displays in order to disseminate clutter from traffic and wind noise.

Species identification employed locally recorded reference song files (Section 3.2.1), and commercially available compact discs and audio cassette tapes (Stewart 1996; Stewart 2002). Expert assistance (J. Munro) was also sought in identification of birdsong. Species' ranges and habitats assisted in cases where allospecific songs were of similar structure and pitch, with a number of reference texts including Williams' (2006) vertebrate atlas, and Pizzey and Knight's (1999) field guide aiding dissemination. Identification of individual conspecific birds at a particular site was based on a suite of song parameters including: amplitude, song spacing, frequency range, song length and pitch, and by visual confirmation where possible.

Statistical analysis of dominant frequencies of songs was undertaken using the software program Statistical Package for the Social Sciences (SPSS) for Windows, Version 12.0.1 (11/11/2003). Each species' suitability for statistical analysis was decided using four main selection criteria:

- Accurately identifiable and consistent dominant frequency of song from individual subjects;
- Sufficient quality and quantity of songs from the species at edge and interior sites;
- Narrow repertoire range or sufficient replication of songs or call-notes of one type within the species; and
- Size of the home-range area of subjects in order to avoid species with individuals moving between edge and interior zones (flyover species such as cockatoos were also excluded).

Independent samples t-tests compared dominant frequency of song of a species at edge sites with dominant frequency of the species' song at interior sites when data was normally distributed. Species presenting data which violated the assumptions for parametric testing were analysed using Mann-Whitney U non-parametric procedures.

3.3 Results

Following extraction of dominant frequency data from a sample of songs of each of the fifty-nine species recorded during the project, detailed statistical analysis was undertaken on the songs of eighteen species determined both by the selection criteria (Section 3.2.5) and examination of plotted data (Figure 3.1). Independent sample t-tests found significant differences in the dominant frequencies of conspecific song between edge-dwelling and interior birds of four species (Table 3.2). Mann-Whitney U-tests showed that songs from five species had significantly different dominant frequencies between the two sample distances (Table 3.3).

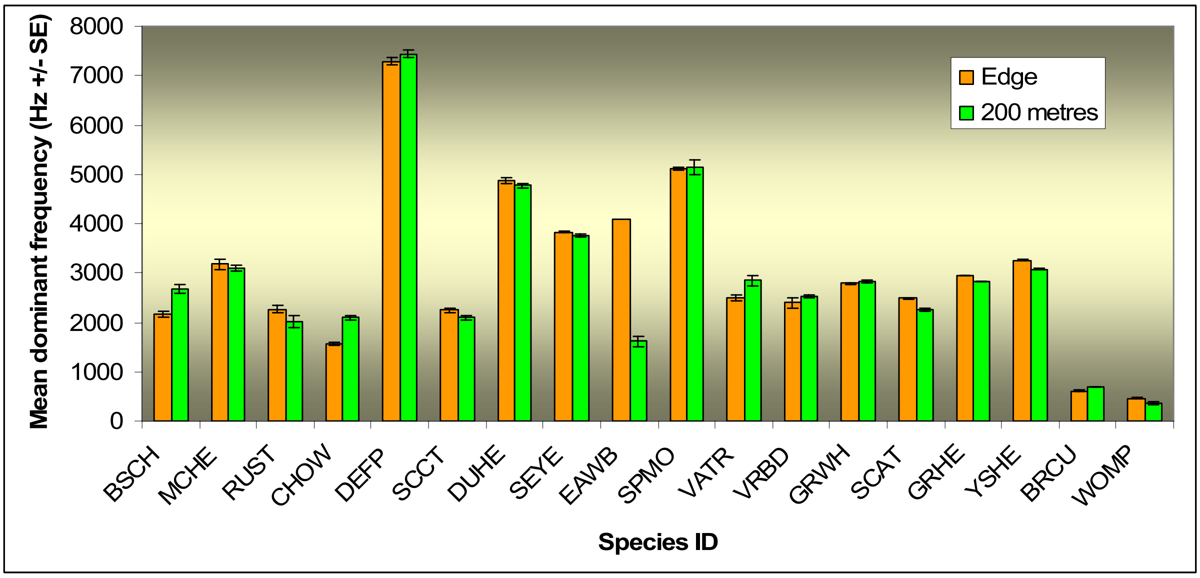


Figure 3.1: Dominant frequency of songs (± 1 SE) recorded from eighteen species during the Kuranda Range 2005 study period. Bird name abbreviations are expanded in Appendix 3.1.

Table 3.2: Independent sample t-test analysis of songs of ten species from the 2005 Kuranda Range recordings (significant results are highlighted in bold).

	Macleay's Honeyeater	**Rufous Shrike-thrush**	**Double-eyed Fig-parrot**	**Sulphur-crested Cockatoo**	**Silvereye**
t	0.551	1.655	-1.310	2.164	1.910
df	16	51	20	66	127
P	0.589	0.104	0.205	**0.034**	0.058
	Spectacled Monarch	**Grey Whistler**	**Spotted Catbird**	**Graceful Honeyeater**	**Yellow-spotted Honeyeater**
t	-0.292	-0.651	6.709	9.336	6.278
df	177	159	153	276	327
P	0.771	0.516	**0.000**	**0.000**	**0.000**

Table 3.3: Mann-Whitney U test analysis of songs of eight species from the 2005 Kuranda Range recordings (significant results are highlighted in bold).

	Barred Cuckoo-shrike	**Chowchilla**	**Dusky Honeyeater**	**Eastern Whipbird**
Z	-2.324	-5.734	-0.131	0.114
P	**0.020**	**0.000**	0.896	0.182
	Varied Triller	**Victoria's Riflebird**	**Brown Cuckoo-dove**	**Wompoo Pigeon**
Z	-2.000	-1.528	-4.301	-3.965
P	**0.046**	0.127	**0.000**	**0.000**

Of the nine species appearing to make statistically significant modifications to the mean dominant frequency of their song according to habitation distance from the highway, only three were considered to display this trait with sufficient replication, while another two species (the Brown Cuckoo-dove and Wompoo Pigeon) presented marginal replication (Table 3.4). Despite two species (Spotted Catbird and Yellow-spotted Honeyeater) displaying some overlap of their fifty-percentile range over distance, the median values for song dominant frequencies remained clearly separated (Figure 3.2).

Table 3.4: Modification to mean dominant frequency of song by bird species habiting highway edge zones and interior sites along the Kuranda Range Road.

Hz	Location	Species				
		Brown cuckoo-dove	Graceful honeyeater	Spotted catbird	Wompoo pigeon	Yellow-spotted honeyeater
Dominant frequency	Edge	616.29	2944.01	2486.58	461.64	3256.49
	200 m	694.67	2828.56	2263.31	364.56	3073.50
Difference		-78.38	115.45	223.27	97.08	182.99

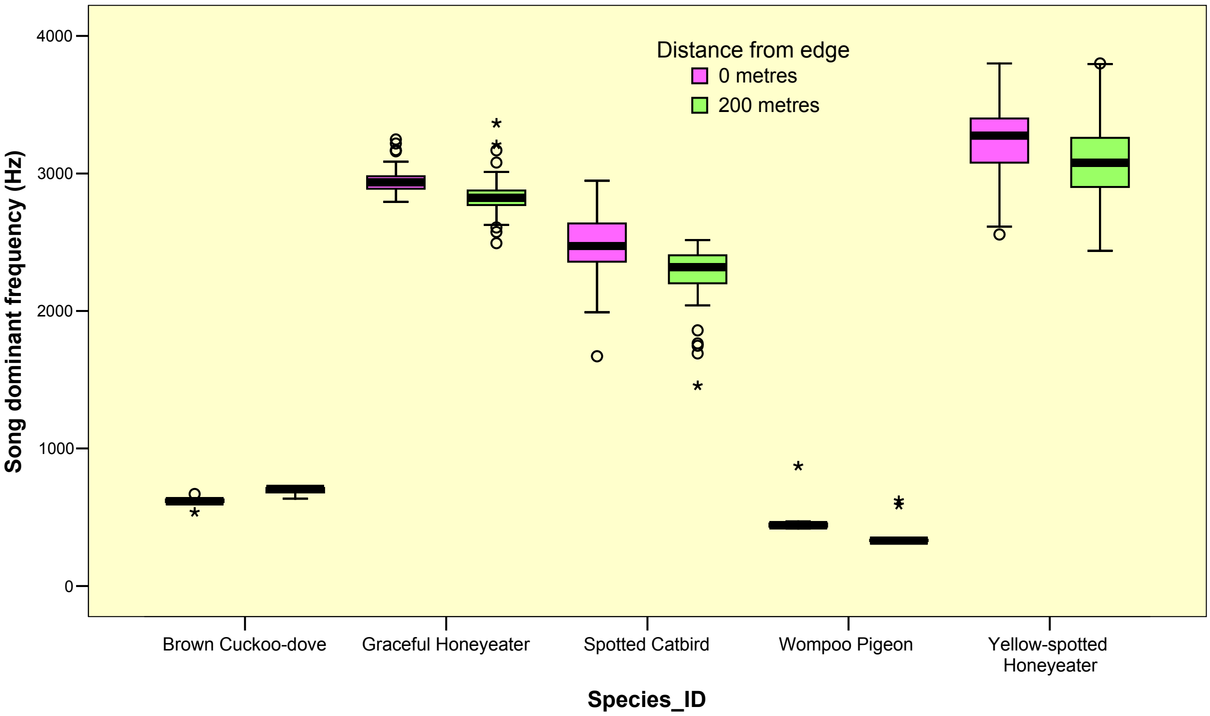


Figure 3.2: Boxplots displaying range and median of dominant frequency of songs from five species making significant acoustic adjustments adjacent to the Kuranda Range Road.

Analysis of the differences of the mean dominant frequencies of the call-notes of Graceful Honeyeaters *Meliphaga gracilis* (Figures 3.3 and 3.4) suggest that distance generated a very large effect ($\eta = 0.240$)[3] (Cohen 1988) with 24% of the variance in the dominant frequency explained by habitation distance from the road. Independent sample t-tests found the two habitation distances (edge and two hundred metres) to have a significant effect on the songs of that species (N_{edge} 131, $N_{interior}$ 147, $t_{276} = 9.336$, $P < .0005$).

Habitation distance also significantly affected the songs of Spotted Catbirds *Ailuroedus melanotis* ($\eta = 0.227$, N_{edge} 93, $N_{interior}$ 62, $t_{153} = 6.709$, $P < .0005$) (Figures 3.5 and 3.6) and Yellow-spotted Honeyeaters *Meliphaga notata* ($\eta = 0.107$, N_{edge} 136, $N_{interior}$ 193, $t_{327} = 6.278$, $P < .0005$) (Figures 3.7 and 3.8).

Although results from the Mann-Whitney U tests for the Brown Cuckoo-dove *Macropygia amboinensis* ($Z = -4.301$, $P < .0005$) and Wompoo Pigeon *Ptilinopus magnificus* ($Z = 3.965$, $P = .003$) were statistically significant, results for these two species should be treated with caution (Refer Section 3.4).

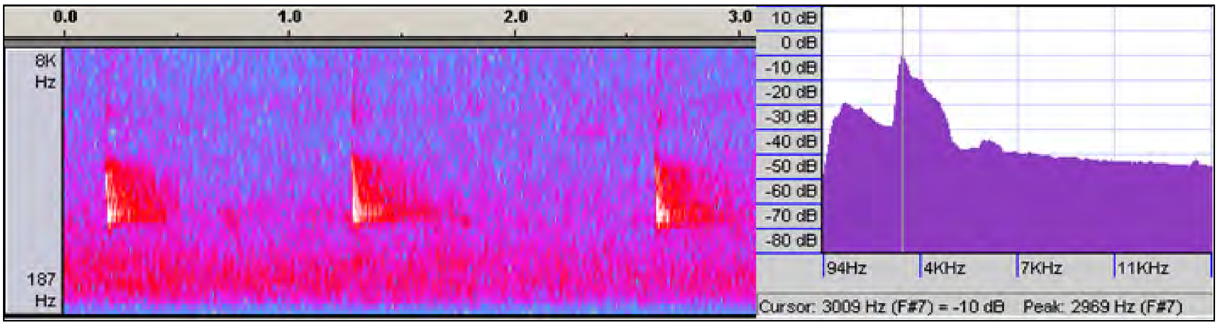


Figure 3.3: Spectrogram (*left*) and amplitude / frequency distribution plot through a hanning window (*right*) of three typical Graceful Honeyeater call notes sampled adjacent to the Kuranda Range Road 2005. **Note:** Cursor shows the mean dominant frequency at 2969 Hz. Fast Fourier Transformation size: 512 data points; Frequency resolution: 22 Hz; Time resolution: <1 ms; Sampling rate: 48 kHz.

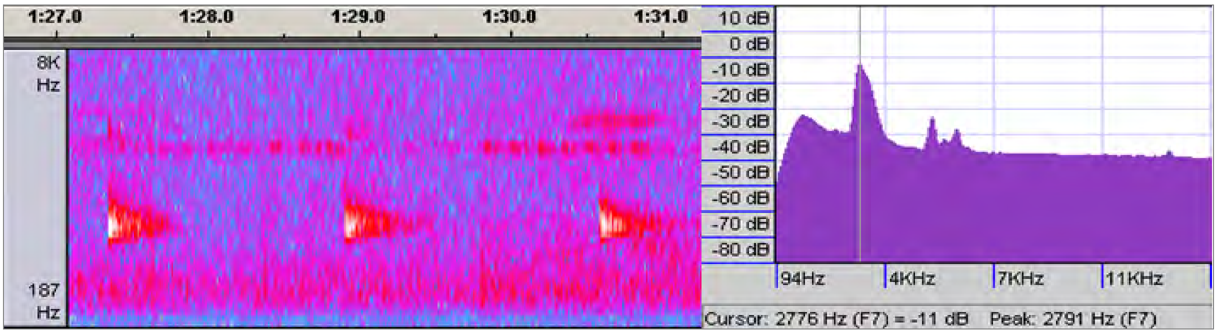


Figure 3.4: Spectrogram (*left*) and amplitude / frequency distribution plot (*right*) of three typical Graceful Honeyeater call notes at two hundred metres from the forest edge, Kuranda Range Road 2005. Mean dominant frequency is 2791 Hz.

---

[3] Eta squared (η) = $t^2 / t^2 + (N1 + N2 - 2)$ (Pallant 2005).

One other species the Silvereye *Zosterops lateralis* produced results from the independent sample t-tests lying just outside the level of significance with alpha set at 0.05 ($t_{127} = 1.910$, $P = 0.058$). However, raising the alpha level to 0.1 in the analysis of this species (with the increased risk of susceptibility to a Type 1 error) with the present data would be unwise, due to the eta squared statistic of 0.028 indicating only a small effect on song dominant frequency attributable to habitation distance from the highway (Cohen 1988).

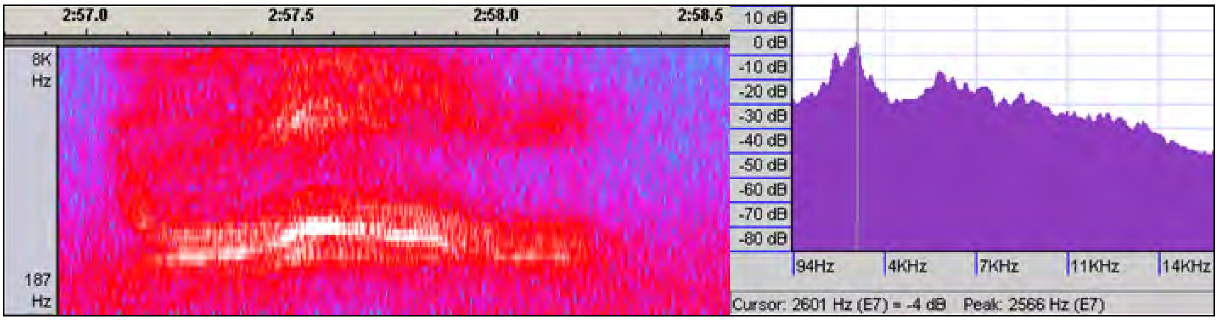


Figure 3.5: Spectrogram (*left*) and amplitude / frequency distribution plot (*right*) of a typical Spotted Catbird song at the forest edge, Kuranda Range Road 2005. Mean dominant frequency is 2566 Hz.

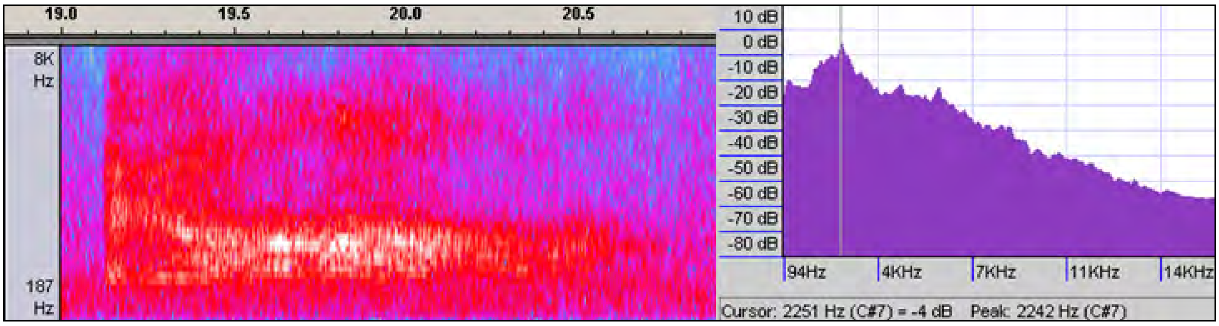


Figure 3.6: Spectrogram (*left*) and amplitude / frequency distribution plot (*right*) of a typical Spotted Catbird song at two hundred metres from the forest edge, Kuranda Range Road 2005. Mean dominant frequency is 2242 Hz.

Data from the thirteen species which failed to produce a significant result in the statistical analysis, or present results where some doubt existed, nevertheless generated some quite spectacular ranges in dominant frequency between edge and interior birds (Figure 3.9). While future analysis of the many remaining untouched song files may validate some of these results, at present the plots should be considered as pointers only in suggesting possible inverse relationships between noise levels and dominant frequency of song for some species. Such a relationship appears to exist in the statistically significant results for the Brown Cuckoo-dove as opposed to the other co-habiting pigeon which follows the 'normal' trend. Legible spectrograms proved difficult to produce for these two species (particularly the forest-edge dwellers) due to the 'active space' (Lohr *et al.* 2003) of their perch coos being embedded in frequency bands dominated by traffic noise. Therein lies a possible reason for the tendency of the edge-dwelling Brown Cuckoo-dove to lower its dominant frequency (from 695 Hz to 616 Hz), while the Wompoo Pigeon pitches its calls upwards from 365 Hz to 462 Hz (Table 3.2) as each searches for an acoustic window offering some respite from the traffic noise.

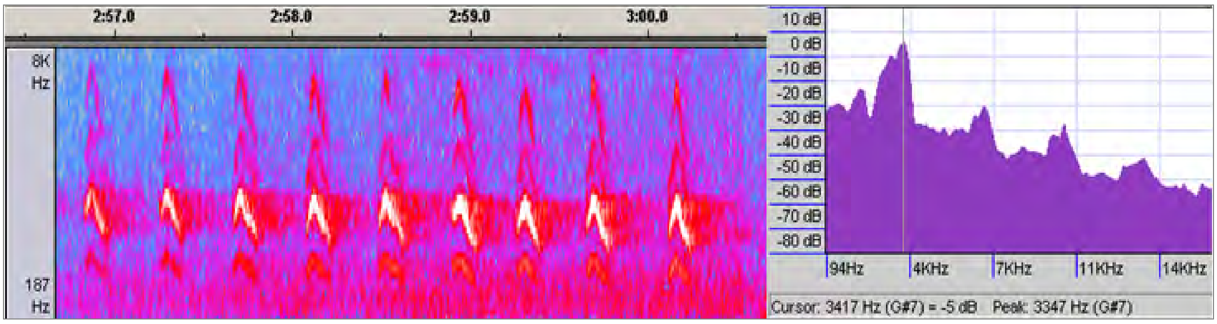


Figure 3.7: Spectrogram (*left*) and amplitude / frequency distribution plot (*right*) of a typical Yellow-spotted Honeyeater song at the forest edge, Kuranda Range Road 2005. Mean dominant frequency is 3347 Hz.

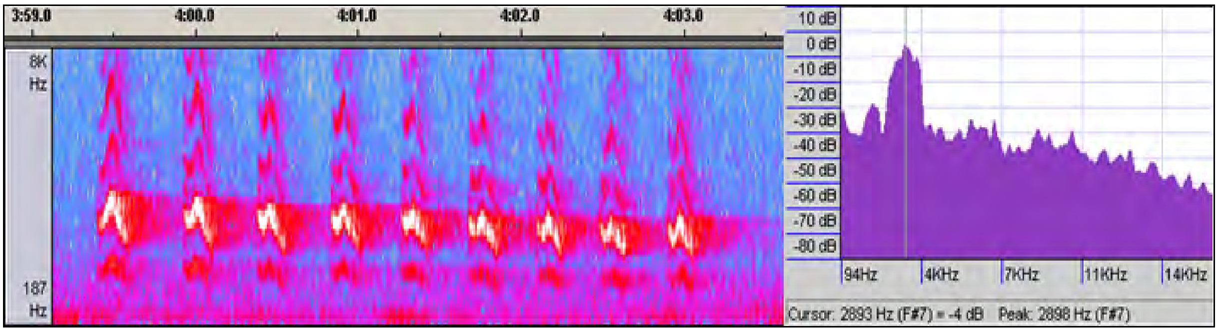


Figure 3.8: Spectrogram (*left*) and amplitude / frequency distribution plot (*right*) of a typical Yellow-spotted Honeyeater song at two hundred metres from the forest edge, Kuranda Range Road 2005. Mean dominant frequency is 2898 Hz.

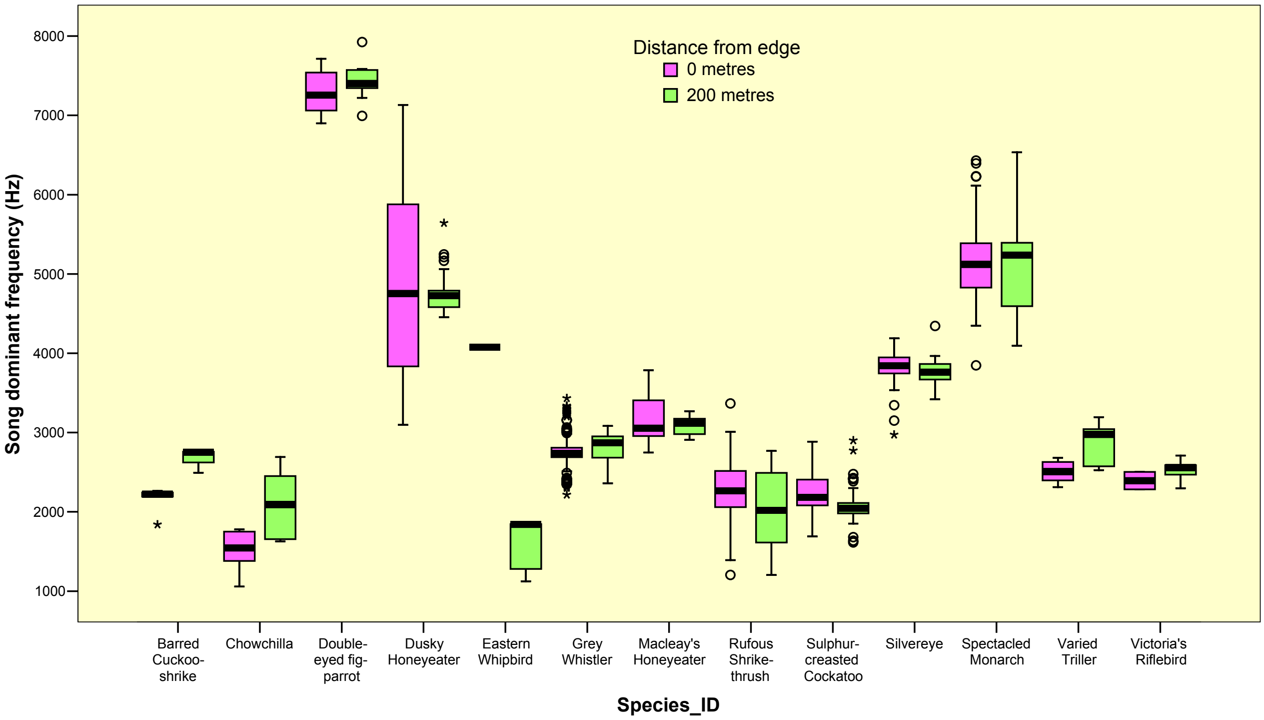


Figure 3.9: Boxplots of dominant frequencies of songs recorded from thirteen species with data constaints preventing accurate appraisal of degree of song modification.

3.4 Discussion

3.4.1 Extent of data analysed

Overall, 795 songs or call-notes were analysed from birds at the zone two hundred metres from the forest edge, and 1,821 songs or call-notes from song files produced from recordings adjacent to the edge of the Kuranda Range Road. Greater time was expended on roadside recordings and analysis as it was deemed likely that the edge zone would yield fewer songs suitable for analysis as a result of recording sessions being blanketed by traffic noise. Results of the concurrent avian population and species richness surveys also suggested that the edge zone would yield fewer songs of rainforest specialist species (Section 4). It was therefore important to create a database of candidates likely to occur in sufficient numbers at both zones; controlled to some extent by the dearth of interior-zone species habiting the roadside zones.

This analysis sampled only a little more than fifteen percent of the total song files produced during the project's recording sessions, and while more songs from each species at the two distance treatments would have been desirable, the number of song samples for the three passerine species that showed significant frequency adjustment to traffic noise were acceptable for the statistical analysis. The quantity of total songs analysed was comparable to that of other field studies of birdsong such as that of Ficken *et al.* (1974), who analysed 2,283 Red-eyed Vireo and Least Flycatcher songs, and that of Grant *et al.* (2000) , who examined 155 Sharp-beaked Ground-finches from six of the Galapagos Islands (1,882 songs). Of the 1,059 song files recorded during the 2005 Kuranda Range Road project, time constraints allowed only 162 (containing 2,616 suitable songs or call-notes) to be analysed. Further song analysis (assuming a continuing mean song rate of sixteen songs per file) would likely provide more than 14,300 further dominant frequency data.

Song file filtering, analysis and associated data logging proved extremely time intensive when using the (freeware) computer software available for the current project. As improved song recognition software and algorithms are developed, this process would be considerably streamlined, allowing a much more economical expenditure of time in possible future analysis of the remaining song-files. Song identification from song-files was also often particularly time-consuming due to lack of an experienced ornithologist in the laboratory and consequent searching through the limited number of available reference-song compact discs in order to connect a less-common call-note or song with a particular species. Attempts were made to identify all songs and call-notes / alarm calls / contact calls from each of the song-files in order to avoid revisiting each file to search for songs from particular target species. Tropical forests present a challenging environment for visual identification of avian species, with vocal identification preferred, although compromised by the limited availability of reference vocalisations compared to temperate species (Anjos 2003). Very few visual field identifications were made of songsters during the 2005 recording sessions, with many of those linking relatively common species to easily recognisable songs. In times of intense vocalisations such as during the 'dawn chorus', visual identification was almost impossible.

3.4.2 Species with limited available data

Even after possible future analysis of all available song files it is likely that songs from some species may still be too few to provide accurate comparative analysis of the mean dominant frequency of their songs across the two distance treatments. There are several reasons for this predicted possible shortfall in data for some species:

1. Some species, such as the Scarlet Honeyeater and Lovely Fairy-wren, are infrequent visitors to the study area, using rainforest as suboptimal habitat, while others such as the Leaden Flycatcher are only rarely recorded in rainforest (Williams 2006). However, as

the focus of this study is the impacts on species that prefer rainforest habitat, the lack of data for this group is not considered to be a major issue.

2. The extended local wet season and milder than 'normal' winter may have reduced the availability of food for some species, or may have altered visitation regimes for some migratory species, leading to fewer potential songsters to record at some sites.
3. Song recording was undertaken across a six to seven month period centered on July. Certain bird species may be either absent from the area during part of the study, or may be infrequent vocalisers due to the seasonality of triggers such as food availability, optimum weather conditions, or proximity / availability of potential rivals or mates.

These factors may have hindered adequate duplication of songs for some species due to the temporal lag / lead of up to six months for recording sessions between some of the sites. An earlier research project found one species, the Grey Whistler *Pachycephala simplex* to make a significant adjustment to the dominant frequency of its song from 2572 Hz at a site relatively isolated from traffic noise to 2974 Hz at the roadside (Dawe 2005). Although this current study found the roadside dominant frequency to be within one standard error of the earlier result, the interior data displayed a reversal of the trend apparent in the first study (2572 Hz in 2004, 2825 Hz in 2005) (Figure 3.9). This anomaly may have arisen from the difference in songster numbers from the interior in the two studies (five in 2004, one in 2005) or from the age or vocal experience of the only 2005 candidate. Juvenile songbirds experience a crystallisation phase of song development covering a transition from vocal plasticity of song elements and composition through to the production of typical adult song forms (Todt and Geberzahn 2003). The 2005 roadside recording sessions captured more songsters (N = 5) than the 2004 project (N = 2), and more songs (N_{2005} = 161) than the earlier study (N_{2004} = 69). Without extraction and analysis of dominant frequency data from the remaining song files, no conclusion should be drawn as to any frequency adjustment by this particular species at these locations.

Results indicating statistically significant modification to dominant frequencies by the Barred Cuckoo-shrike (nine songs) and the Varied Triller (thirteen songs) were felt to be possibly suspect due to a lack of an adequate number of songs. Further data analysis may confirm the statistical significance of these data.

3.4.3 Species with song modifications potentially related to factors other than traffic noise

Lack of data replication was not the case for Chowchillas, where adequate edge and interior songs (58 and 49 songs respectively) from three birds at each distance treatment, indicated an apparently significant increase in song dominant frequency over distance from the noise source – a reversal of the normal trend (Table 3.2, Figure 3.9). However, when distributions of dominant frequencies of songs from that species are compared over distance the node for the edge distribution (28 songs) occurs at a higher dominant frequency than the interior distribution node (17 songs) (Figure 3.10). It appears that vocalisations of Chowchillas display a wide variability between and within individuals independent of location, with separation of the mix of song types essential before commencing accurate analysis. Cataloguing of song-versions has not been performed for this species; consequently analysis of the present combined song data has only limited application to this study.

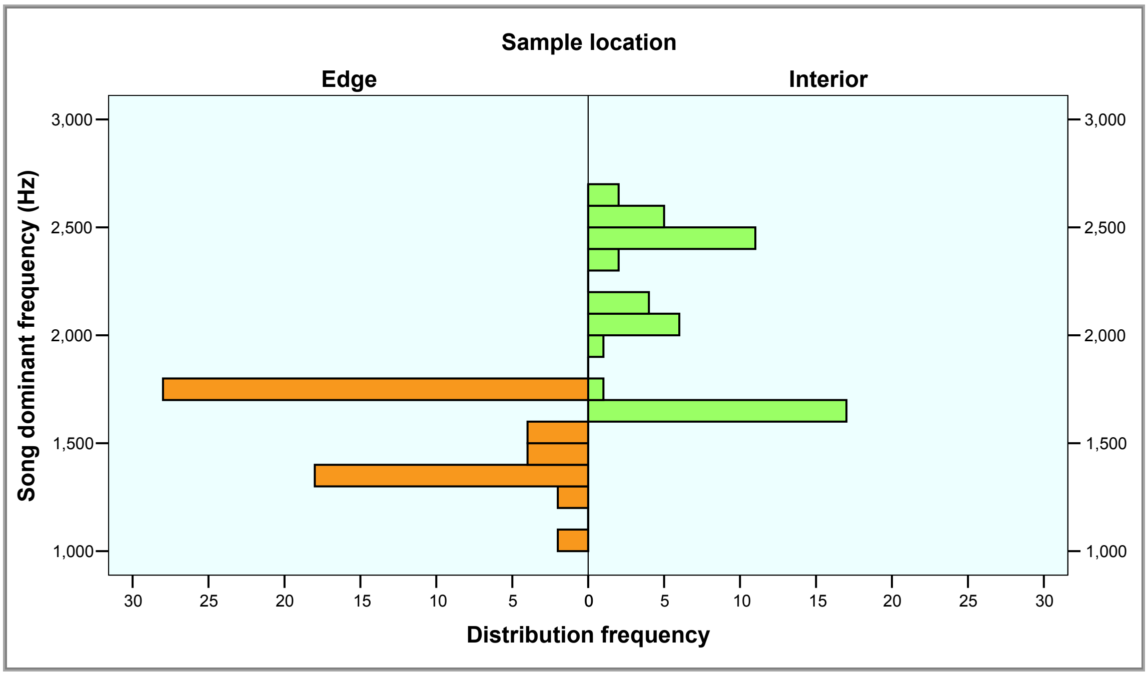


Figure 3.10: Distribution of the dominant frequencies of song of Chowchillas inhabiting edge and interior zones of the Kuranda Range Road corridor.

3.4.4 Species with significant results

Data for the four species producing significant results in the parametric analysis was derived from songs of multiple individuals per species at each of the distance treatments. Song samples per species were also greater for those three passerine species that produced significant results, ranging between 62 and 193 songs for each species per distance treatment. This was considered satisfactory for a multi-species study, with song numbers from each of these target species comparing well with other studies of single species such as field research of Gammon *et al*. (2005) on song divergence in Black-capped Chickadees (210 songs of adult birds recorded overall). Despite a significant result for songs from the Sulphur-crested Cockatoo, the apparent difference in dominant frequency may well be attributed to factors associated with the position and activity of individual birds. A greater number of interior birds were flying when recorded, thereby increasing the microphone to subject distance; with possible loss of power in the higher frequency bands (Section 2). Flying also is likely to produce a different song projection and possibly less energy allocation to that of song from perched subjects. In view of the above factors, the high energy levels of song from this species, its conservation status, and its transient nature, its apparent song modification is noted, but is of little management concern to this current study.

Although we analysed the songs with respect to distance from the road edge, we believe that the significant alterations seen in calls of the Graceful Honeyeater, Yellow-spotted Honeyeater and Spotted Catbird are related to traffic noise rather than just change in habitat with distance from the road. Although we can expect some edge effects in microclimate and vegetation, there is no obvious difference in habitat between the road edge and two hundred metres inside the forest of the magnitude that might cause the birds to alter their call frequency other than the blanketing effect of traffic noise being greater at the edge than at two hundred metres. In Section 2 we saw that the mean L_{10} noise levels at the edge of the road ranged between 69 and 75 dB at the eight transects, whereas at two hundred metres the levels ranged between 37 and 56 dB, a difference of between 19 and 36 dB at the various transects. This is a large alteration in the noise environment, when the logarithmic decibel scale is taken into account, equating to perceived noise levels at the edge of more than three to four times the noise level at two hundred metres. As the change in frequency of birdsong relates to the propagation of sound through the forest, it appears extremely likely that these changes are related to the large alteration in the acoustic environment.

3.4.5 Larger species and those with low frequency calls

Songs were only analysed from one individual bird at each of the edge and interior sites for each of the two pigeon/dove species that generated significant results in the Mann-Whitney analysis (Brown Cuckoo-dove and Wompoo Pigeon), so more analysis is recommended.

While pigeons, doves and other species producing low frequency notes recorded in the interior of the Kuranda Range rainforest were able to take advantage of the ‘acoustic window’ centered on the 160 Hz band if they so chose (See *Edge noise levels – ground*, page 32, and Figure 3.12), birds at the edge may have sought to call at the frequencies of a higher window around the 315 Hz / 400 Hz third-octave bands at some edge locations (Figure 3.11). General road traffic produces significant sound energy in the 500 Hz frequency band and heavy transport generates high levels of sound below 250 Hz. This traffic noise blanketing combined with the ground-effect dip typically lying between 250 and 800 Hz due to destructive interference from the surface (Attenborough 1991) provides a legitimate reason for such an ‘acoustic window’ to exist. The average dominant frequency of traffic noise for the Kuranda Range was found to be 1 kHz (Section 2), with amplitude dips in some of the lower frequency bands at some roadside locations providing spectra opportunities for vocalisations by birds such as pigeons and doves that call at these low frequencies to adjust their calls to suit the area of least traffic noise interference (Figure 3.12).

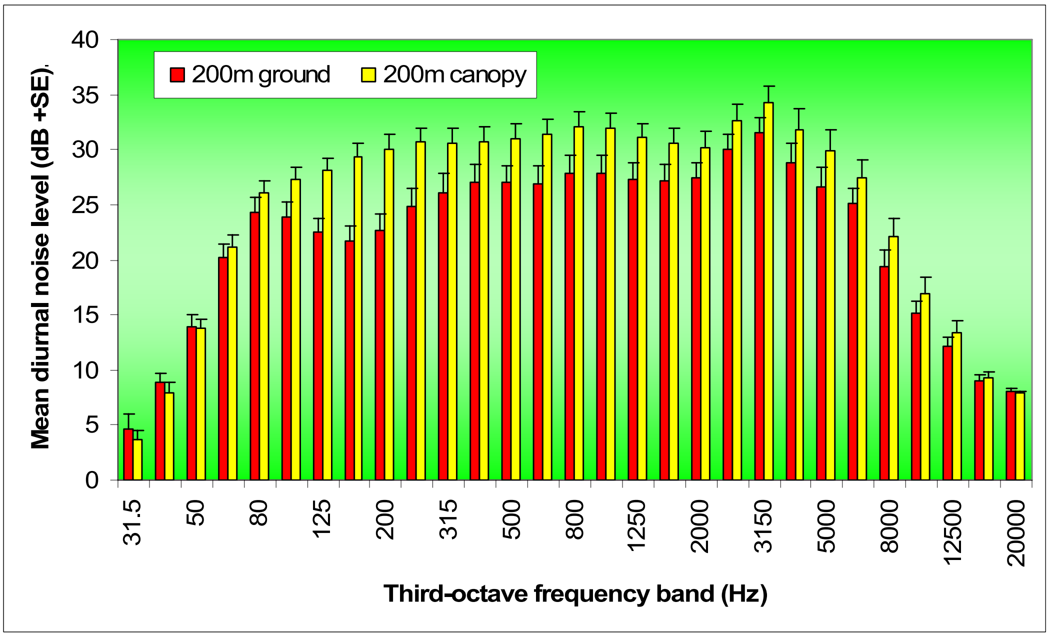


Figure 3.11: Mean interior diurnal noise spectrum from all transects used in the 2005 Kuranda Range Road traffic noise study showing the ground level ‘acoustic window’ centered on the 160 Hz third-octave band.

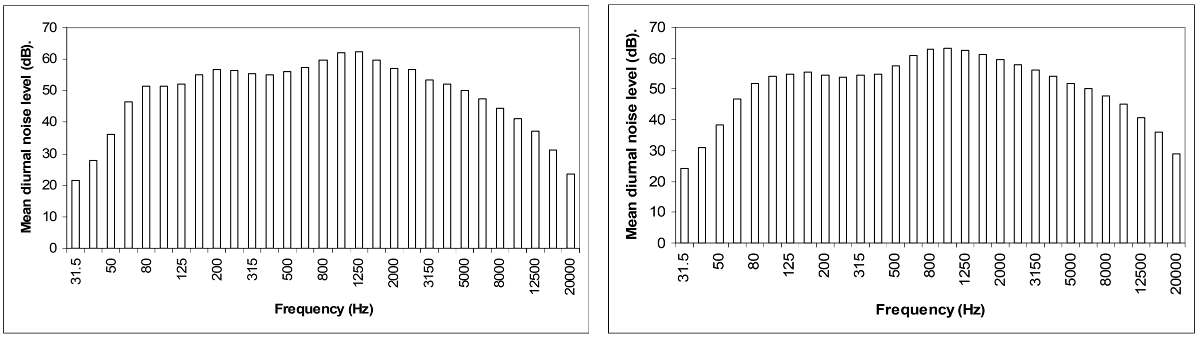


Figure 3.12: Mean roadside diurnal noise spectra from Lookout Sign transect (*left*) and Mareeba Sign transect (*right*) at one metre above the ground (2005 Kuranda Range traffic noise study) showing 'acoustic windows' around the 400 Hz (*left*) and 250 Hz (*right*) third-octave bands.

Recordings of songs from chicks of the Southern Cassowary *Casuarius casuarius johnsoni* at the one hundred metre point of the Streets Creek transect displayed mean dominant frequencies of 2228 Hz for one call type and 3778 Hz for another. These frequencies are significantly higher than those for calls of the adult birds, which produce narrow bandwidth notes around 100 Hz (Stewart 1996). Chick call-notes occupy sections of the acoustic spectrum which in the vicinity of the highway are heavily impacted by traffic noise (compare noise levels Figures 3.11 and 3.12). Chick call-notes are likely to suffer considerable blanketing from traffic noise at that location due to the new highway alignment nearby. Cassowaries are likely to vacate this area during the construction phase due to increased human presence. Whether they would re-inhabit the existing Streets Creek refuge following construction is speculative. Birds choosing to do so would be exposed to a serious impact on chick-to-chick and chick-to-parent communication due to saturation of their vocalisation bands by traffic noise. No research has yet been undertaken to establish any correlations between dominant frequency of song and habitation distances from highways by birds in wet tropical regions.

3.5 Conclusions

Several avian species inhabiting tropical rainforests adjacent to the Kuranda Range were found to exhibit at least one form of vocal plasticity in an effort to overcome the effects of traffic noise acoustic blanketing. Three rainforest passerine birds raised the dominant frequency of their songs by between 4.1% (Graceful Honeyeater) and 9.9% (Spotted Catbird). As songs from these three species were easily identified, and presented some of the most abundant vocalisations on the portion of song-files examined, it is likely that further examination of a similar volume of songs would identify other species that make similar compensatory pitch adjustments to their song.

3.6 Recommendations

Only a limited amount of data analysis of birdsong has been undertaken for avian species inhabiting the Wet Tropics. No studies have investigated the possible metabolic costs, increased predatory risks, and reduced success in mate attraction or food location associated with pitch adjustment by tropical rainforest birds. Neither have studies examined the effects of traffic noise blanketing on other elements of vocalisations of tropical rainforest birds such as call-spacing, mean minimum and mean maximum frequency, amplitude adjustment, repertoire modification, signal success and cognition. Further research into the impact of traffic noise into any of the abovementioned behavioural or physiological characteristics of avian activity should be an important consideration in any program designed to monitor or ameliorate the perturbation of such noise into adjacent habitats.

Initially, future research should focus on the large amount of song data collected in this project that remains to be analysed. This would increase both the database of species adopting song modification to traffic noise masking, and identify those less-common avian species missed in the species richness surveys.

Pitch adjustments to songs are likely to have metabolic costs for species because of a possible requirement to use more energy to achieve a different pitch, which may result in less energy available for growth and reproduction. Pitch adjustments may also alter the ability of other birds of the same species to detect the song or alter the likelihood of predators detecting the individual. Such changes could, in turn, reduce the fitness of individuals. Therefore, to reduce the need for such changes in song frequencies, reduction of traffic noise propagated into the rainforest should be a priority in design of roads traversing areas of high conservation value such as the Wet Tropics World Heritage Area.

Noise Disturbance along Highways

Section 4:

Effect of distance from edges on avian populations and biodiversity

4. Effect of distance from edges on avian populations and biodiversity

Gregory Dawe and Miriam Goosem

Summary

Bird communities living adjacent to the Kuranda Range section of the Kennedy Highway where it traverses Wet Tropics rainforest were studied in relation to edge impacts that might arise from traffic noise. Avian population density and species richness surveys were conducted at two locations immediately after the wet season (December to March), and again in early spring. Surveys utilising acoustic and visual identification were undertaken along two groups of five transects running parallel to the highway at ten, thirty, fifty, one hundred, and two hundred metres from the forest edge.

Bird abundance increased with distance from the road edge and significantly more birds were observed at two hundred metres inside the forest than at the road edge. A strong positive correlation was also found between distance from the highway and species richness at one of the two sites. Abundance of species most dependent on rainforest increased significantly with distance into the forest with greatest abundances found in the forest interior (one hundred and two hundred metres from the edge). Species richness of rainforest-dependent birds was also greatest at these interior zones. Overall, individuals and species more dependent on rainforest tended to inhabit the interior zone, while opportunistic species not normally associated with rainforest appeared along the edge zone.

Abundance of insectivores increased towards the forest interior, whereas frugivores and omnivores did not exhibit any obvious pattern with distance, other than slight avoidance of the road edge. However, nectarivore individuals were centered on the forest interior and avoided the road edge almost entirely. Although the observed edge effects cannot be attributed entirely to traffic noise, given the variety of other impacts on vegetation occurring in the vicinity of road edges, there is circumstantial evidence to suggest that road noise was a contributor to the edge effect from the presence of species that otherwise avoided the road edge in a zone thirty metres in from the road where the zone was an acoustic refuge caused by the protection of a topographic ridge. Similarly, a group which appeared to avoid the road edge was also one in which members reacted to traffic noise by altering the frequency of their song.

Birds known or likely to occur on the range were assessed with regards to likely impacts of traffic noise, using data from Section 4 and Section 3 of this report. We recommend mitigating the penetration of noise along the highway edge, particularly in areas known currently to have high diversity and abundance. Further research to ascertain other areas where high diversity and abundance is a feature of bird populations should be considered.

4.1 Introduction

The effects of traffic and associated noise have mostly been studied with an anthropogenic focus. However, several researchers have extended the scope of studies on health and nuisance effects of noise on human subjects to include effects of noise on wildlife. Most of this research has been concentrated in temperate parts of the northern hemisphere, complementing other work on a range of road effects including roadkill (Ervin *et al.* 2001; Goosem 2001; Gibbs and Steen 2005), predator and opportunistic species (Bautista *et al.* 2004), chemical ingestion (Van Bohemen and Van der Laak 2003), road avoidance and habitat fragmentation (Haskell 2000; Brotons and Herrando 2001; Gibeau *et al.* 2002).

A variety of birds (Reijnen *et al.* 1997; Reijnen *et al.* 2002; Rheindt 2003; Weiserbs and Jacob 2003), frogs (Pellet *et al.* 2004a) and deer (Barrett 1976) appear to avoid areas exposed to high levels of traffic noise. However, avoidance of traffic noise has not been examined within tropical rainforest bird species, although edge effects on birds have been found in Amazonian rainforests where traffic is minimal (Laurance 2004; Laurance *et al.* 2004).

Noise disturbance along highways may affect sensitive fauna. Groups affected could include both birds and amphibians that use aural communication and other groups disturbed by increased noise. For example, almost twenty percent of woodland areas in the Netherlands were noise-affected for sensitive species such as the cuckoo (Reijnen *et al*. 2002), and total bird population densities across all species were reduced once noise reached an average of 42 dB (Forman *et al*. 2003). Noise disturbance is also known to cause problems for certain frog species.

Acoustic surveys in Germany by Rheindt (2003) found declines in bird diversity, species richness and average bird abundance in forest one hundred metres from a two-lane Bavarian motorway (50,000 vehicles/day), compared with a control transect isolated from traffic noise by 750 metres of deciduous forest. This change in abundance was independent of the mean body weight per species. Not all species (three out of fifteen species) were reduced in abundance near the motorway. Species with higher dominant song frequencies were found to occur in greater abundance close to the motorway than those species with lower pitched song (Rheindt 2003), suggesting that traffic noise could be a causative factor in avoidance. Reijnen and others (1995) had previously shown that sixty percent of forty-six woodland bird species existed at reduced densities near roads. Car visibility, pollution and collision-induced mortality were considered as possible contributors to density decline, however these factors were adjudged ‘unimportant’ compared to the influence of traffic noise on species density. Mean traffic estimates for coniferous woodland roads was 45,319 vehicles per day and for deciduous woodland, 33,334 vehicles per day (Reijnen *et al.* 1995). Noise effects in deciduous forests penetrated to distances between 40-1,500 metres at traffic volumes of 10,000 vehicles per day, and 70-2,800 metres for traffic volumes of 60,000 vehicles per day. For coniferous woodland, distances to which birds were affected ranged from 50-790 metres (10,000 vehicles per day) and 100-1,750 metres (60,000 vehicles per day). Rheindt (2003) concurred with this distance. Weiserbs and Jacob (2003) found a linear correlation between breeding-bird population densities in a Belgian forest and distance from sources of traffic noise. These researchers suggested that the disappearance of several sensitive species from the forest may be linked to exposure to traffic noise (Weiserbs and Jacob 2003).

Breeding bird densities in agricultural grasslands were strongly affected by traffic intensity (Reijnen *et al*. 1996). Densities of all twelve grassland bird species surveyed were reduced. Traffic volumes of 5,000 vehicles per day produced disturbance distances of between 20-1,700 metres for the various species. These distances expanded to between 65-3,530 metres depending on species for grasslands adjacent roads carrying 50,000 vehicles per day. At that traffic level, all species had population density losses of 12-44% up to five hundred metres from the highway, while five species, Lapwings *Vanellus vanellus*, Shovellers *Anas clypeata*, Skylarks *Alauda arvensis*, Blacktailed Godwits and Oystercatchers displayed population reductions of 14-44% up to 1,500 metres from the traffic noise source (Reijnen *et al.* 1996).

Not all studies have found a correlation between traffic noise exposure and avian territory selection, with claims that endangered Golden-cheeked Warblers in Texas do not prefer to inhabit areas with lower levels of traffic noise (Centre for Bioacoustics Research 1999). However, as populations of this species are already low, it is possible that other factors such as loss of preferred habitat or food sources may be driving this bird's apparent indifference to noise-pollution with regards range selection. A more-extensive study on grassland birds near Boston (USA) by Forman and others (2002) did find a significant correlation between occupation and both the size of the patch of grassland remnant and the distance from roads. That study found that low traffic volumes of between 3,000 and 8,000 vehicles per day produced no significant effect on the distribution of grassland birds. However, for traffic volumes between 8,000 and 15,000, a significant reduction in regular breeding numbers was noted within the first four hundred metres from the road. At traffic levels between 15,000 and 30,000 vehicles per day, both breeding bird densities and overall population densities were reduced out to distances of seven hundred metres from the two-lane highway. This effect was extended to 1,200 metres from a multilane highway with a traffic level of 30,000 vehicles per day (Forman *et al.* 2002).

When Kuitunen and others (2003) examined breeding success of Pied Flycatchers *Ficedula hypoleuca* with respect to traffic density, they found no correlation between population density and distance from roads, however did find a significant decrease in fledgling numbers per breeding attempt in nest-boxes closer to the road. The researchers suggested that the more direct impact of parent-bird traffic mortality may have played a greater role than traffic noise in this reduction in fledglings due to reduced nestling nutrition (Kuitunen *et al.* 2003).

4.2 Methods

4.2.1 Location

Bird surveys recording population counts and species richness were conducted at sites on the Kuranda Range Road and at two control sites in far northern Queensland during two different seasons of 2005. Two 200-metre transects were laid out perpendicular to a two-lane bitumen highway (Kuranda Range Road) connecting the narrow coastal plain near Cairns to the plateau region in the interior. A series of five parallel ninety-metre long secondary transects ran at ninety degrees from these transects at distances of ten, thirty, fifty, one hundred, and two hundred metres from the edge of the rainforest (Figure 4.1). Sample points were marked at distances of ten, fifty, and ninety metres along each of these secondary transects as sites for the undertaking of fifteen minute acoustic and visual surveys for birds. The two transect groups used for these surveys were located on the downstream Cairns side of Streets Creek bridge (transect start elevation 350 metres) and on the upstream Kuranda side of lower Avondale Creek (transect start elevation 115 metres).

Two control sites, each consisting of two ninety-metre long transects running parallel to the road were set up at locations along Black Mountain Road, an unsealed ex-forestry track subject to infrequent traffic usage. The two transects at each control site were established at ten metres and one hundred metres from the forest edge, with the two control sites separated by a distance of approximately two kilometres; the closest being about four kilometres from the Kuranda Range Road junction.

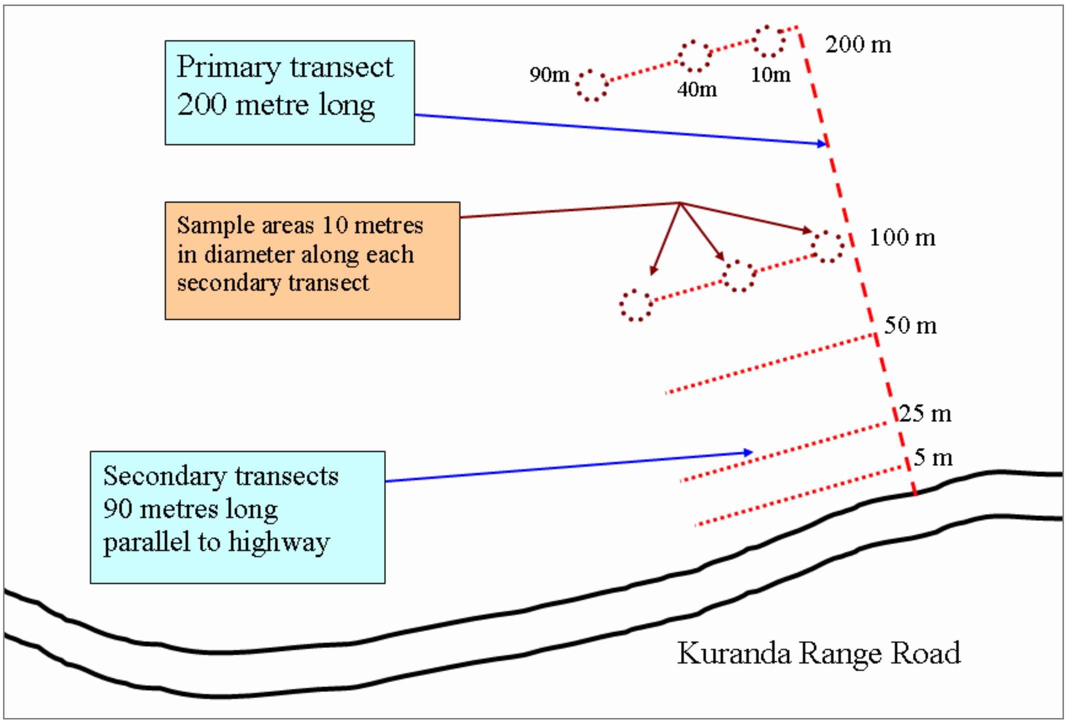


Figure 4.1: Design of sampling regime at each site of bird surveys.

4.2.2 Avian species recorded and their conservation status

Sixty-four bird species were recorded during the 2005 surveys (Appendix 4.1). Fourteen of these species are either endemic to the Wet Tropics or are regionally endemic subspecies. Five other species are of special conservation interest, with the Square-tailed Kite and White-rumped Swiftlet being listed as *Rare* under the Queensland Nature Conservation (Wildlife) Regulation 1994 (reprint as in force December 2005). The Southern Cassowary is listed as *Endangered* under the same legislation, *Vulnerable* under the World Conservation Union Red List of Threatened Species 2001, and *Endangered* nationally under the *Environment Protection and Biodiversity Conservation Act* 1999. The Rufous Owl and Double-eyed Fig-parrot are both described as *Vulnerable* under the *Queensland Nature Conservation Act* 1992.

4.2.3 Climate

The year 2005 saw an extended wet season over northeastern Australia, with inclement weather present during many of the bird surveys. Time constraints on the project and other professional commitments by the consultant ornithologist severely limited the days available for field surveys. This resulted in field data often being collected during less than optimum weather conditions or time periods. However, where possible, surveys were undertaken during dry weather.

4.2.4 Survey structure

Two replicate surveys were conducted during the early morning or late afternoon at each of the Kuranda Range Road sites in the May-July period (end of wet season), with another series comprising three surveys at each site in late August-October (spring – dry season). Two surveys were also undertaken at each of the control sites during both survey periods. Population and species richness surveys of fifteen minutes by one observer and one data recorder were conducted at each site as described by Warren and Shochat (2004). Only one observer was used for all surveys to ensure consistency. Birds present within a ten-metre radius of the observer at each point along the secondary transects were identified by acoustical and/or visual observation, with species flying over the vertical boundaries of the site also included in the data.

4.2.5 Data analysis

The effect of distance from the highway on bird populations was examined using Pearson product-moment correlation. Linear regression analysis examined the effect of distance from the highway on both bird abundance and species richness. Univariate analysis of variance compared abundance between all transects and between transects in the forest interior (two hundred metres) with abundance at the forest edge adjacent to the road. Species richness was also examined using independent t-tests.

4.3 Results

4.3.1 Effects of distance on combined bird data from all 2005 surveys

Bird numbers were moderately positively correlated with distance (Pearson correlation coefficient = 0.310, n = 50, *P* = 0.028). Linear regression analysis demonstrated a significant fit to the equation y = 0.049x + 15.123 ($F_{1, 48}$ = 5.113, *P* = 0.028).

Although visual inspection of plotted bird population data indicated a general increase over distance from the edge (Figure 4.2), univariate analysis of variance showed no significant difference in mean population levels between the five distance transects (*P* = 0.261). However, average populations at two hundred metres from the edge were significantly larger than populations at ten metres from the edge ($t_{13.128}$ = -2.263, n = 10, *P* = 0.041).

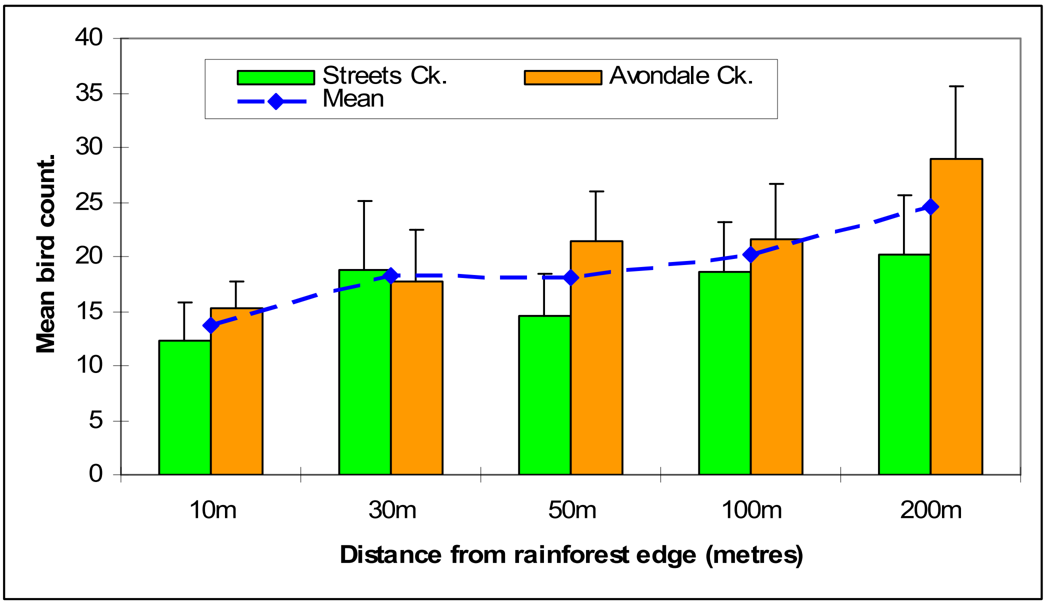


Figure 4.2: Avian population distributions in relation to distance from road edge for both Kuranda Range sites in 2005 surveys (Mean ± SE for each distance transect).

Although avian biodiversity at the edge appeared reduced in comparison with other distance locations (Figure 4.3), species richness was found to be only weakly positively correlated with distance from the highway (r = 0.177, n = 50, *P* = 0.220). Linear regression analysis on the limited data available produced a non-significant equation ($F_{1,\ 48}$ = 1.545, *P* > 0.2). Independent sample t-tests on species numbers from the two greatest separation distances could find no significant difference in species richness between populations occupying edge zones and those at 200 metres from the highway when all bird species were combined (*P* = 0.107).

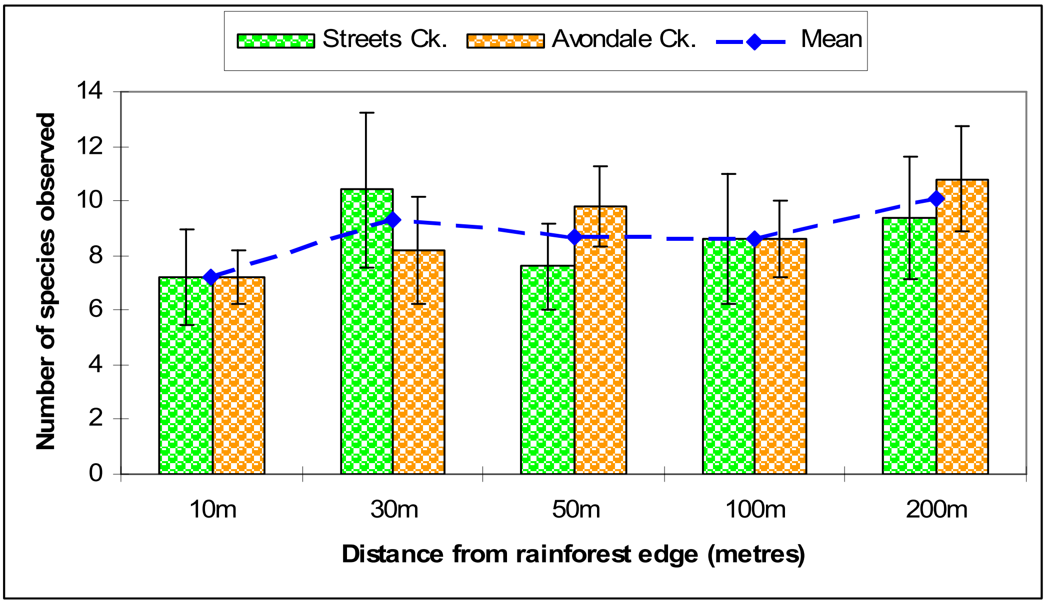


Figure 4.3: Avian species richness in relation to distance from the road edge (Mean ± SE for each distance transect) for both Kuranda Range sites in 2005 surveys.

4.3.2 Habitat guild composition of Kuranda Range bird communities

All bird species were included in the combined examination of habitat, strata and feeding guild distributions. Seven habitat guilds (NR=1…RO=7) based on Williams' (2006) rainforest specialisation index were assigned to each species using the following codes:

NR .... Species not found in rainforest.
OR .... Species occasionally recorded in rainforest.
UR .... Species uses rainforest as a suboptimal / marginal habitat.
CR .... Species commonly recorded in rainforest; however rainforest is not its core habitat.
RM .... Rainforest is the species' main habitat; however it is common in other forest habitats.
RC .... Rainforest is the species' core habitat, but it also occurs in adjacent wet sclerophyll forest.
RO .... Rainforest obligate.

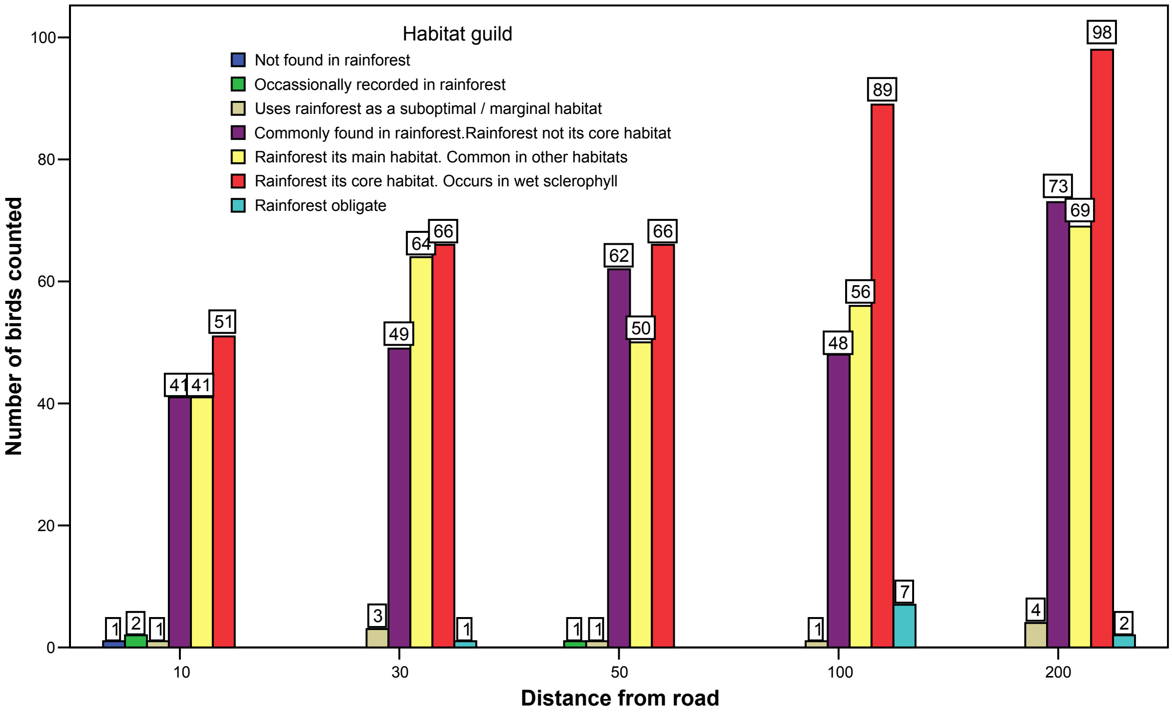


Figure 4.4: Total abundance in each habitat guild for all species recorded at five distances from the rainforest edge adjacent to the Kuranda Range Road.

Table 4.1: Mean abundance counts in habitat guilds for five surveys along each distance transect parallel to the Kuranda Range Road at Streets Creek and Avondale Creek, 2005.

Distance	Habitat guild						
	NR	OR	UR	CR	MR	RC	RO
10m	0.1	0.2	0.1	4.1	4.1	5.1	0
30m	0	0	0.3	4.9	6.4	6.6	0.1
50m	0	0.1	0.1	6.2	5	6.6	0
100m	0	0	0.1	4.8	5.6	8.9	0.7
200m	0	0	0.4	7.3	6.9	9.8	0.2

Examination of the abundance distributions for those species highly dependent on rainforest (guilds RO and RC) revealed reductions in both species and populations in the edge zone (Figure 4.4). Visual examination of plots of mean bird abundance for core rainforest users and rainforest obligates revealed large differences in bird numbers between the ten-metre zone and the two zones furthest into the interior (Figure 4.5). Bird abundance in these two guilds displayed a strong positive correlation against distance (r = 0.9013), with the data fitting well to the linear regression equation $y = 0.025x + 5.6466$. However, insufficient data for each transect resulted in Analysis of Variance of rainforest dependent birds across all the distance treatments showing no significant differences in mean bird counts between the five parallel distance transects (F = 1.969, df = 4, P = 0.12). Fisher Exact analysis found populations from these two guilds have greater proportional representation at the 100 metre and 200 metre zones than at zones closer to the highway (P = 0.029) (Figure 4.6).

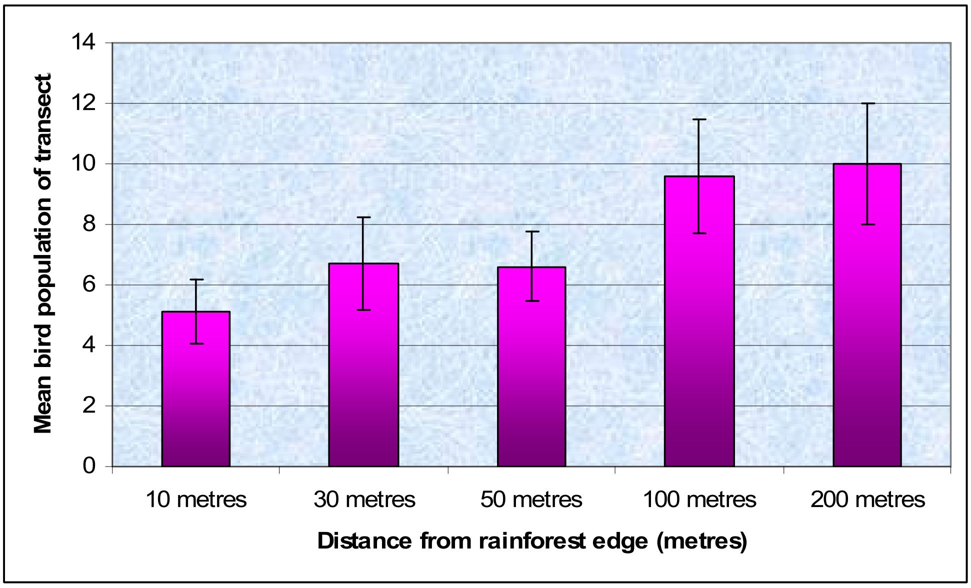


Figure 4.5: Mean bird abundance counts from five surveys at each of the Kuranda Range transect locations for habitat guilds dependent on rainforest (RC and RO) at five distances from the rainforest edge.

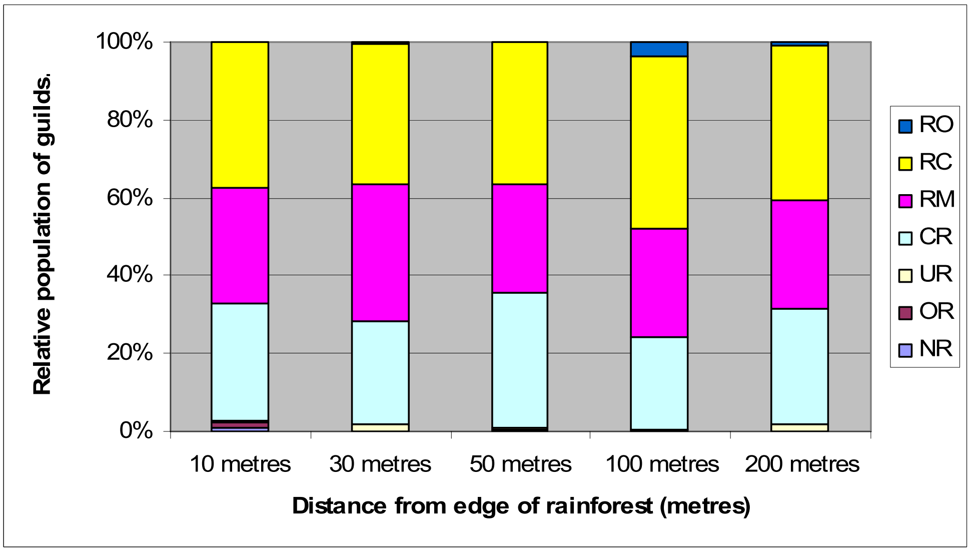


Figure 4.6: Proportional distributions of bird abundance in habitat guilds in relation to distance from the road edge for all Kuranda Range 2005 surveys.

The two interior zones also had the greatest proportions of species from the three habitat guilds (RM, RC and RO) most dependent on rainforest (Figure 4.7). The greatest numbers of species relying on rainforest for their core habitat were found at forest interior zones (Figure 4.8).

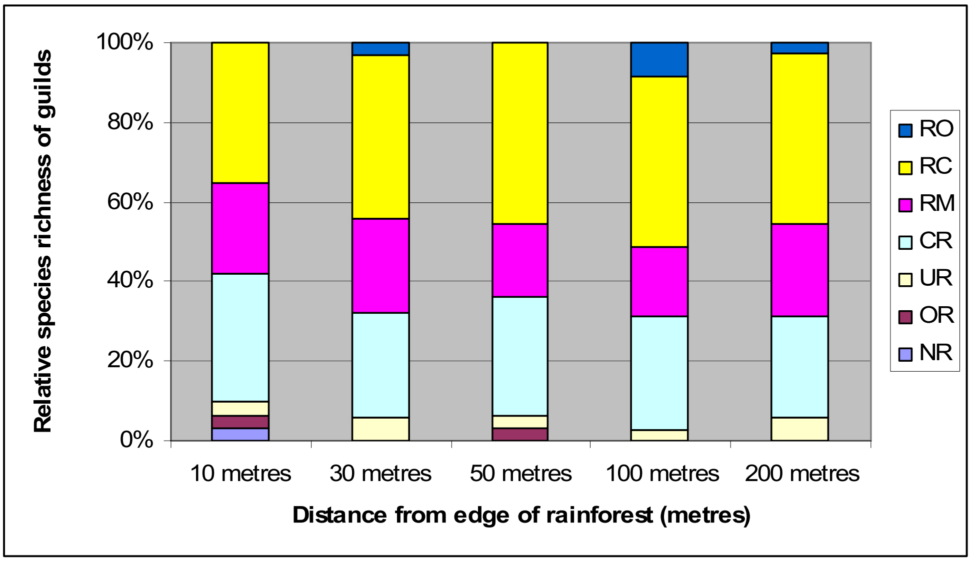


Figure 4.7: Proportions of species representing each habitat guilds at five distances from the rainforest edge adjacent to the Kuranda Range Road.

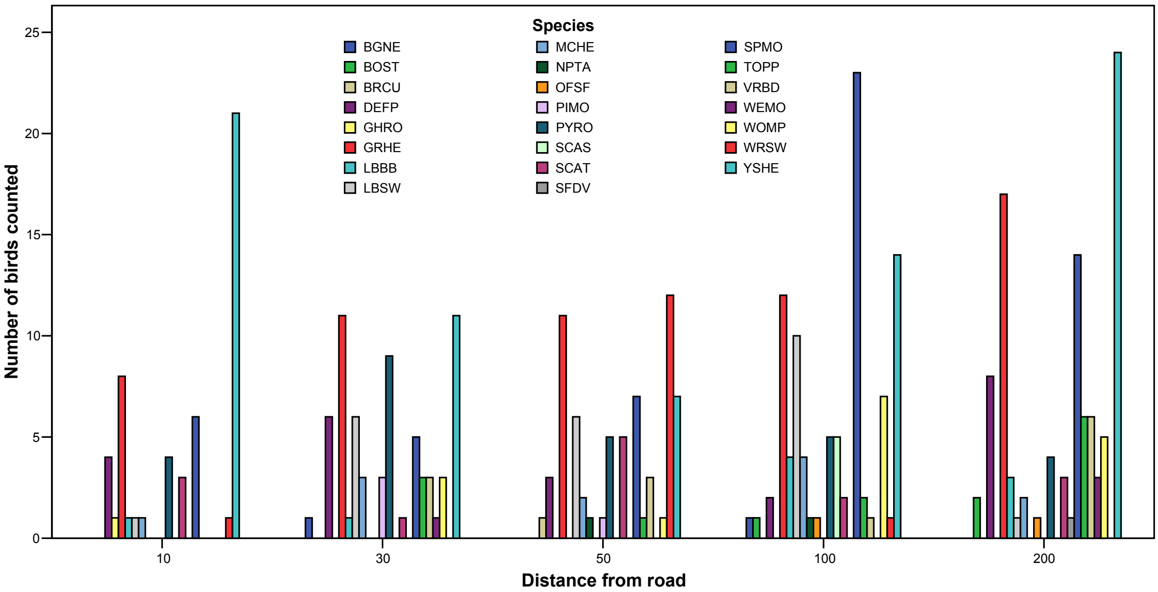


Figure 4.8: Bird abundance and species richness in relation to distance from the road edge from all 2005 Kuranda Range surveys for species relying on rainforest as their core habitat (RC and RO).

Mean species richness during the two survey periods (comprising ten surveys at each of the five transect distances) of birds relying on rainforest as their core or only habitat, similarly indicated a reduction in species richness near the edge (Figure 4.9). However, insufficient species data within these guilds limited the significance of this result (ANOVA of species richness across the five distance treatments: F = 1.147, df = 4, P = 0.350). Factors associated with the surveys such as weather or time of day may have considerably influenced the results, being only marginally non-significant (F = 2.145, df = 9, P = 0.051).

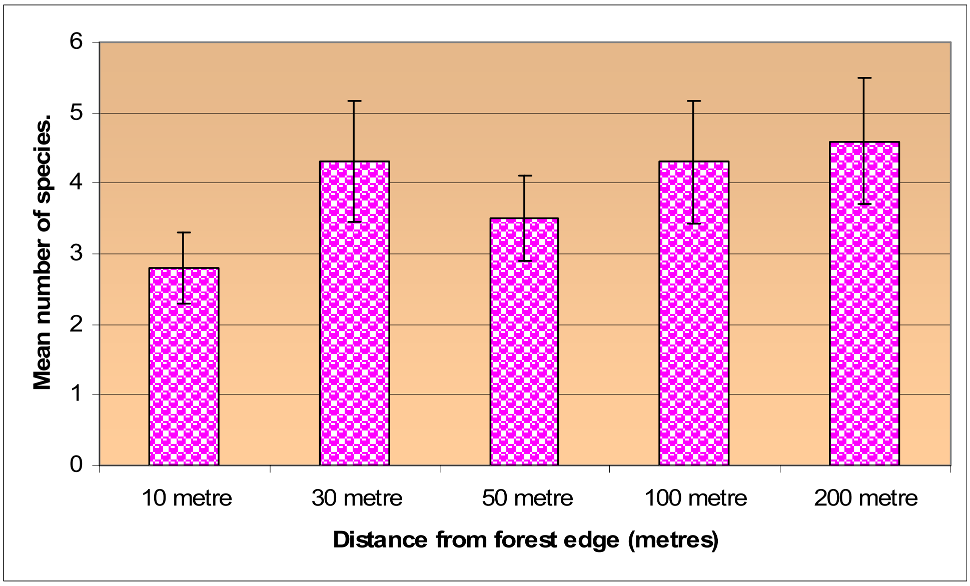


Figure 4.9: Mean number of species from five surveys at each Kuranda Range transect location for spcies relying on rainforest as core habitat (RC and RO) in relation to distance from the rainforest edge.

4.3.3 Avian feeding and strata guild composition from combined 2005 Kuranda Range surveys

Abundance of birds in feeding guilds

Feeding guilds adapted from Lawson (2004) and J. Moloney's unpublished doctoral thesis (personal communication) were assigned to surveyed species as follows:

1. Insectivores;
2. Frugivores;
3. Granivores;
4. Carnivores;
5. Omnivores; and
6. Nectarivores

Where species were absent from these two references, feeding and strata guilds were assigned according to observational reports listed in selected volumes of the Handbook of Australian, New Zealand and Antarctic Birds (Higgins 1999; Higgins and Peter 2002).

The relative composition of bird communities across feeding guilds varied significantly with distance ($\chi^2 = 82.116$, df = 16, $P < 0.0005$). Abundance of insectivores tended mainly to increase with distance into the forest interior (Figures 4.10, 4.11, 4.12). Frugivores and omnivores did not differ markedly in their distribution pattern across distance, increasing marginally at distances furthest from the edge and avoiding the edge itself, while nectarivore numbers were concentrated at the furthest interior distance. Distribution of this group, along with the insectivores, did not demonstrate the greater recruitment in the 30 metre zone shown by the other guilds (Figure 4.12).

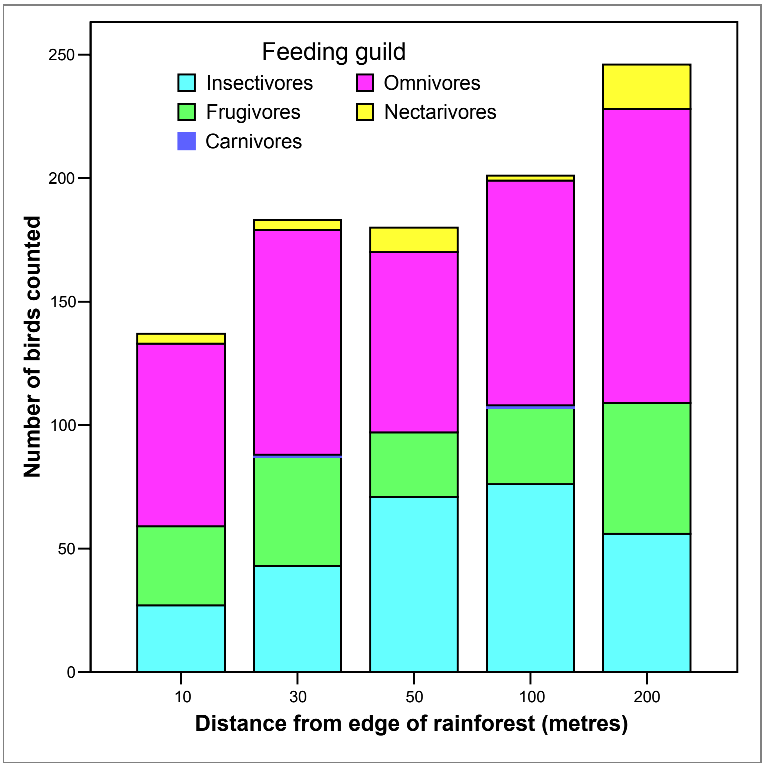


Figure 4.10: Abundance of all birds divided into feeding guilds from all surveys at five distances from the rainforest edge.

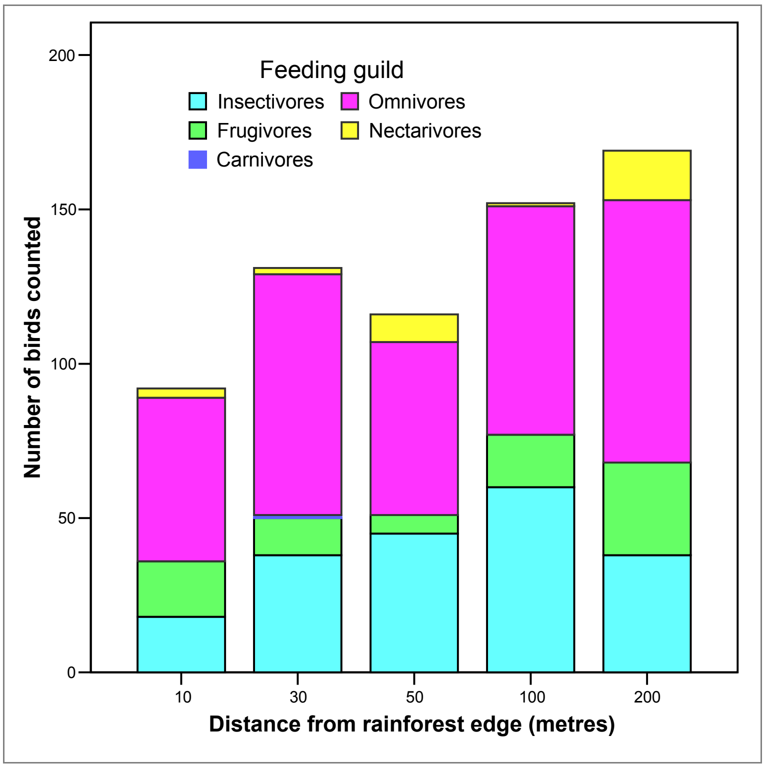


Figure 4.11: Abundance of all birds reliant on rainforest habitats (guilds RM, RC and RO) from all surveys at five distances from the rainforest edge.

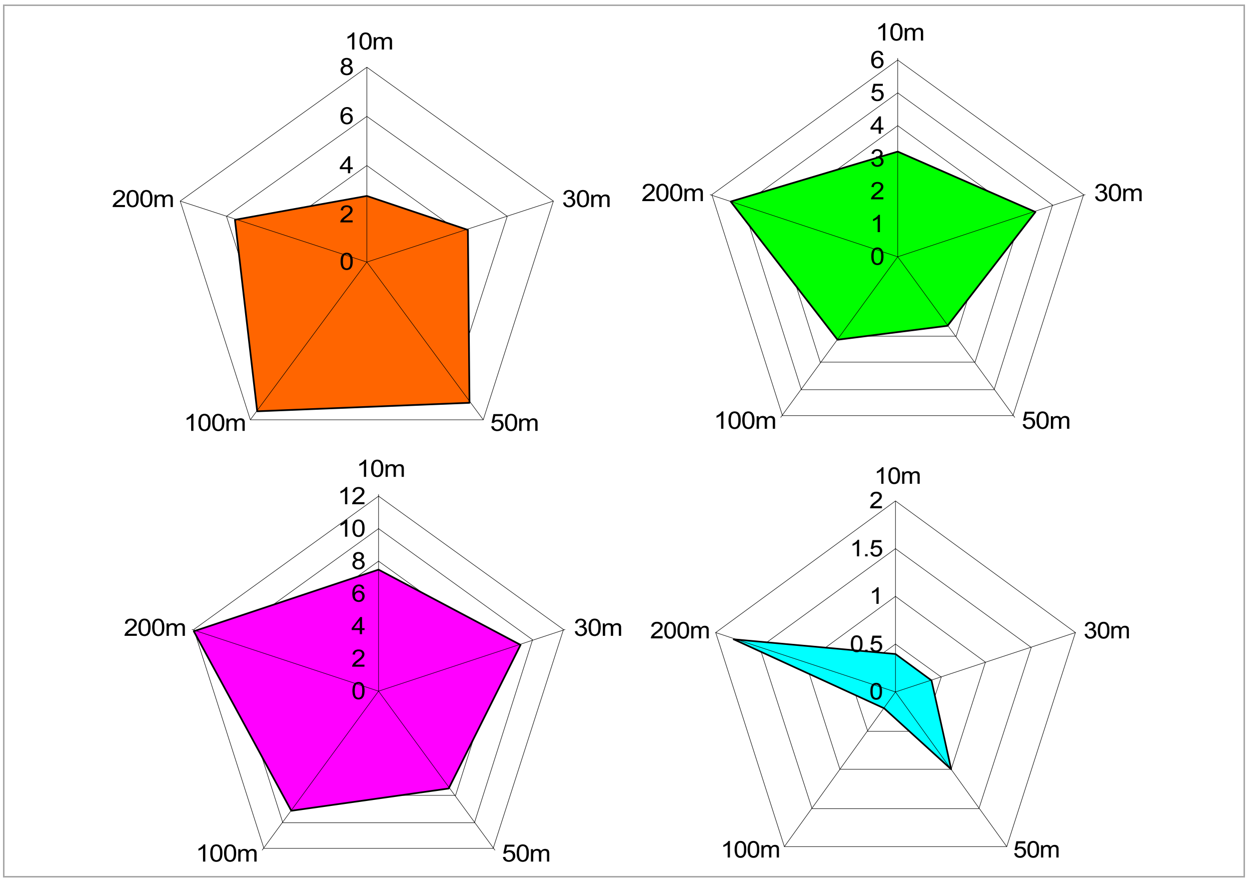


Figure 4.12: Mean abundance of insectivores (Top L), frugivores (Top R), omnivores (Lower L) and nectarivores (Lower R) in relation to edge distance.

Abundance of birds in strata guilds

Occupational strata guilds from Lawson (2004) and J. Moloney were assigned to surveyed species as follows:

1. Ground to two metres above ground;
2. More than two metres above ground, up to and including the canopy; and
3. Canopy and emergents only.

Abundance of birds in these three strata guilds showed no obvious pattern, other than the general increase from edge to interior for understorey, and to a lesser extent, canopy species (Figure 4.13).

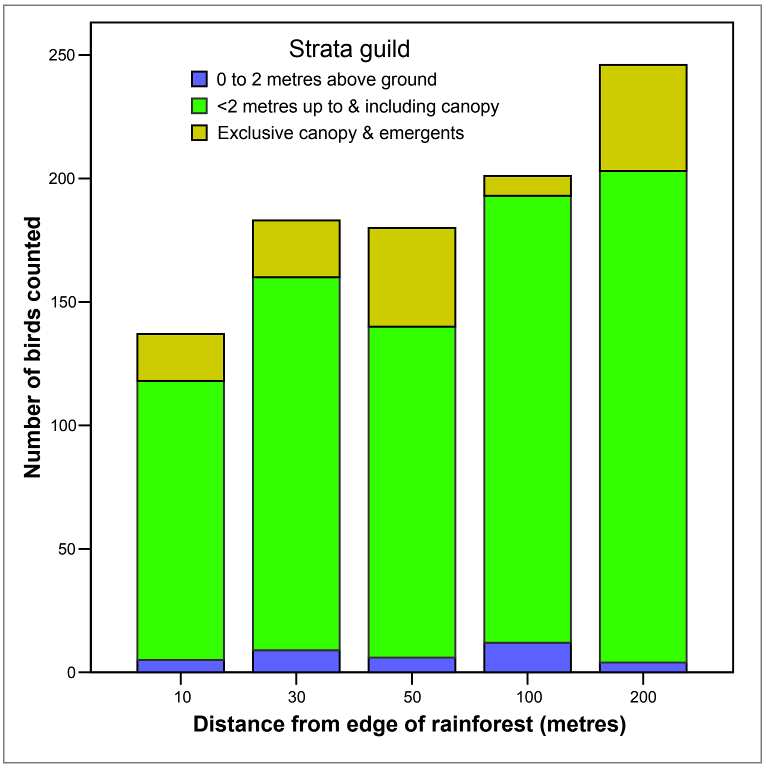


Figure 4.13: Total bird abundance from all surveys at five distances from the rainforest edge divided according to preferred habitation height.

4.3.4 Seasonal and locational influences on avian populations

Overall bird abundance along the Kuranda Range transects displayed little variation between surveys (Figure 4.14). Abundance at each sample point along the Kuranda Range transects averaged 12.7 during the end of wet season surveys and 12.5 for the spring surveys; indicating little seasonal influence on bird numbers. However bird abundance did vary across the seasons at the control sites, with an average of 9.5 birds recorded at each sample point in the wet season compared to 15.1 birds in spring.

Although only forty percent of total survey time was spent on the end of wet season surveys, this contributed 44.4% of the total bird counts along the Kuranda Range transects. The Kuranda Range transects displayed far less seasonality than the control sites, where the end of wet season surveys produced only 38.6% of that area's total population count for a fifty-percent time expenditure (two recording sessions per site for both ‘end of wet season’ and ‘spring’ surveys).

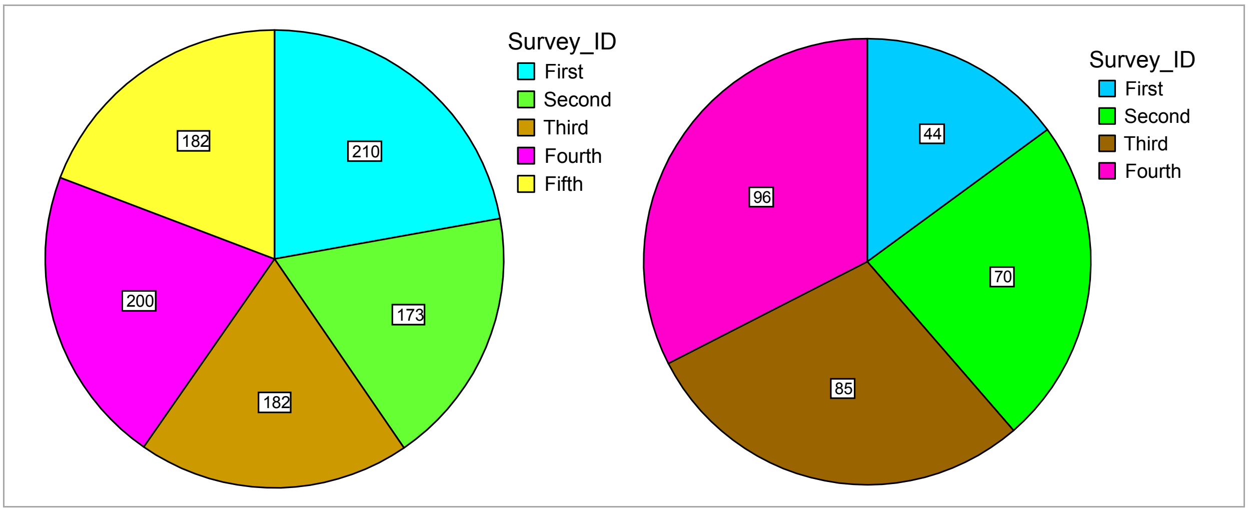


Figure 4.14: Combined bird abundance from each survey for Kuranda Range (*left*) and control sites (*right*).

There was no significant difference in mean avian abundance or species richness at all sample points between the two Kuranda Range transect locations at Streets Creek and Avondale Creek (abundance: t = -1.357, df = 48, P = 0.181; species richness: t = 0.998, df = 48, P = 0.323). However, when data from individual sample points were divided according to location and season, differences in both mean population density and species richness appeared at some distances from the edge and at the controls (Figures 4.15 and 4.16).

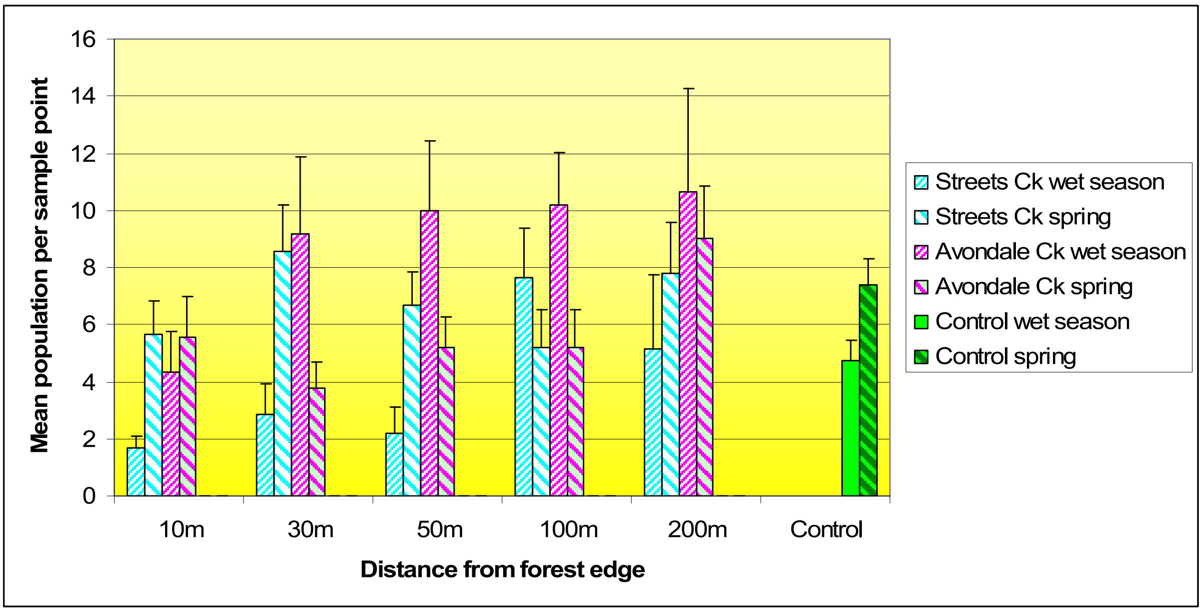


Figure 4.15: Mean bird populations at each 2005 survey sample point[4].

---

[4] Three ten-metre radius sample points positioned at ten, fifty and ninety metres along each of the five distance transects.

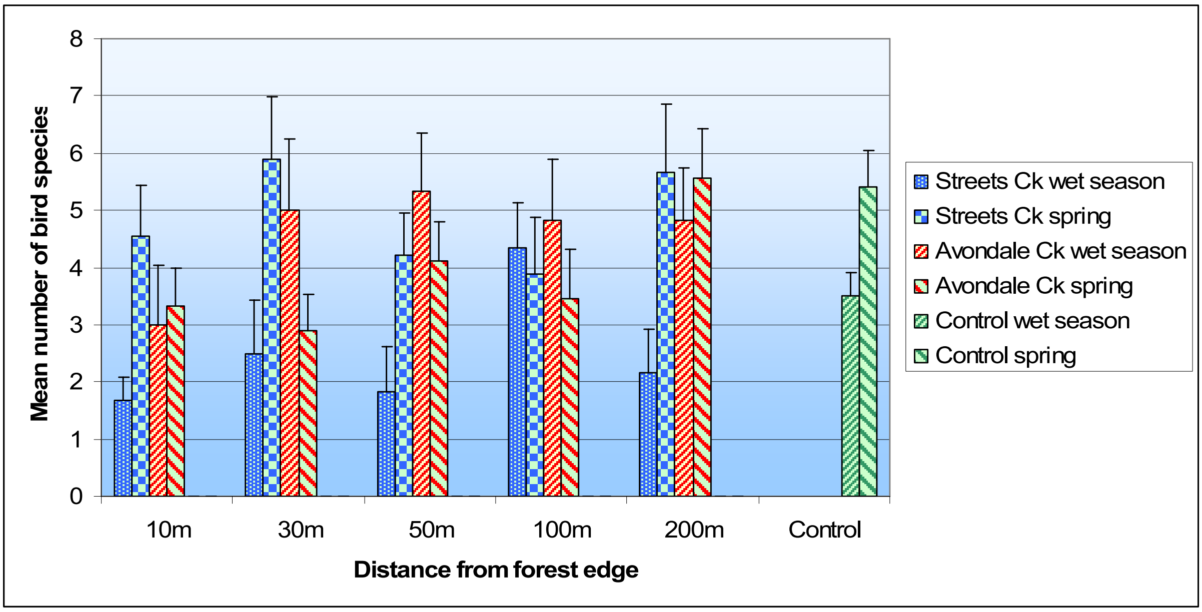


Figure 4.16: Mean numbers of species at each 2005 survey sample point.

Seasonal factors affected bird abundances at both ten metres from the edge and at one hundred metres on the Kuranda Range Road transects (Table 4.2). However no significant differences in bird numbers were attributable to location on the Kuranda Range (Streets Creek or Avondale Creek). Seasonality affected species richness on the one hundred metre control site transects, while both species richness and bird abundance varied significantly between each of the control sites at ten metres from the edge of Black Mountain Road (Table 4.2).

Table 4.2: Independent sample t-tests[1] on avian population density and species richness comparing transect locations and seasons.

Effect driver[2]	Site	Data	t-statistic	df	*P*
season	Kuranda Range at 10m	abundance	-2.052	28	0.050
season	Kuranda Range at 100m	abundance	2.451	28	0.021
location	control sites at 10m	abundance	-2.694	22	0.013
location	control sites at 10m	species	-2.986	22	0.007
season	control sites at 100m	species	-2.328	22	0.029

[1] Table only displays results significant at alpha ≤ 0.05.

[2] Seasonality (wet season or spring) OR Location (Streets Creek or Avondale Creek; Control site 1 or Control site 2).

4.4 Discussion

4.4.1 Edge effects in bird abundance and species richness

Results indicated a pronounced edge effect appearing as lower bird densities and reduced species richness immediately adjacent to the highway (Figures 4.2 and 4.3) with abundances gradually increasing with distance into the forest interior. Although bird abundances were only statistically significantly different between the ten and two hundred metre transects, other significant distance combinations and species richness / distance relationships may have been hidden due to the paucity of replicate data. Seasonal factors and poor weather conditions during 2005 survey periods may have reduced the potential for significant results. This is highlighted by the extent of error associated with the mean abundance and species richness from individual sample points and by the considerable difference in means between the two Kuranda Range sites and between seasons across the same distance (Figures 4.15 and 4.16). Statistically, this factor was particularly evident at the control sites with their considerable location and seasonal differences for both bird abundance and species richness (Table 4.2). Data from the two control sites were combined in the above plots; resulting in the smaller range of error displayed in the graphs. This variability in the 2005 control data suggests that replication in a second year of data collection would be a sensible precaution to further examine significance of results in terms of significant edge changes between closer transects in the Kuranda Range locations.

Although further data collection would be desirable, this recognisable edge effect concurs with many overseas studies regarding birds in temperate zones, particularly grassland and woodland habitats (Reijnen *et al.* 1997; Forman *et al*. 2002; Reijnen *et al.* 2002; Rheindt 2003; Weiserbs and Jacobs 2003). The majority of these studies postulated that traffic noise was the most likely contributor to reductions in bird abundance and diversity. However the overseas studies were mainly undertaken in areas of much greater traffic volume than the Kuranda Range Road. For example, traffic levels in the German study were 50,000 vehicles per day (Rheindt 2003) and Dutch research was carried out in woodlands adjacent to roads carrying 10,000 to 60,000 vehicles per day (Reijnen *et al.* 2002). This compares with the mean daily vehicle volume on the Kuranda Range in 2005 ranging between about 6,200 in March to 7,400 in August. Traffic noise would therefore be expected to be proportionally less than the European examples. Species-dependent edge effect distances which correlated with traffic volume (10,000-60,000 vehicles per day) ranged from 40-2,800 metres in woodland, coniferous and deciduous temperate forests. In our study, mean species richness and bird abundance had failed to reach an asymptote at two hundred metres, so calculation of effect distance is not possible – the effect may extend further than two hundred metres. Similarly, traffic noise had not reached ambient levels at two hundred metres inside the forest (Section 2). Similar traffic levels to the Kuranda Range were recorded during studies of breeding bird edge effects in temperate agricultural grassland (5,000 vehicles per day) with edge effect distances that varied between 20-1,700 metres depending on species (Reijnen *et al.* 1996).

Edge effects evidenced by changes in bird abundance and species diversity can be observed in the alteration to the species composition of the bird community (Figures 4.6 and 4.7) in terms of habitat guild near the road edge, where there are no rainforest obligates and where a small percentage of birds from habitat other than rainforest or which find rainforest habitat marginal for their habitation are making use of the road edge.

Edge effects in bird abundance and species richness along roads have also been observed in areas of Amazonian tropical rainforest where traffic noise is not a factor due to the road carrying only a few vehicles per day (Laurance 2004). Edge effects were most noticeable in several feeding guilds, particularly specialised Amazonian ant-following birds and other insectivores. Total bird captures and insectivores increased with distance from the edge, whereas captures of nectarivores and frugivores did not vary significantly (Laurance 2006). In the Kuranda Range study, total bird observations also increased with distance from the roadside, insectivores were also one of the most obviously edge-affected guilds and frugivore variation was not significant. However, the results of the Kuranda Range study differ from the Amazon study, in that near the Kuranda Range Road the nectarivores were concentrated in the forest interior and appeared to avoid the edge. The Laurance (2004) study was restricted to tropical rainforest dependent birds. The potential for ingress of birds of other habitats was severely restricted by the location of sites inside an extremely large expanse of rainforest, although rainforest-dependent edge/gap insectivores did increase near the road (Laurance 2006). In our study, we also saw evidence that birds from habitats other than rainforest were penetrating the rainforest along the roadside – particularly at the ten metre transect, with occasional intrusions by birds that find rainforest suboptimal habitat to two hundred metres. Therefore, it appears that although similarities are seen between the edge effects on birds of a highway with relatively high traffic volumes compared with a wide road clearing with little traffic, there are also some differences. These differences might be attributable in part to traffic noise, as this and the amount of traffic movement is the main difference between the roads in the two studies. Several of the nectarivores, a guild which shows a different pattern near the highway compared to a low traffic volume road, are species which have been shown to alter their dominant song frequencies in Section 3 and so appear to be affected in some way by traffic noise. However, it must be remembered that Amazonian and Australian bird species are very different, particularly in the variety of insectivorous guilds.

4.4.2 Effect of weather and time of day on bird observations

Poor weather conditions may have reduced the calling rate of birds during the surveys, thereby limiting the number of observations; these being reliant on birdsong for the majority of the identifications. Of the 1,242 birds observed at all control and Kuranda Range sites, 731 were identified by song only, while only 244 were identified solely by visual features or behavioural displays. Although still-wind conditions accounted for most observations (837 out of 1,242), little variation in survey counts was attributed to the degree of cloud cover (635 birds observed during overcast conditions and 541 in sunny conditions). On Kuranda Range the impact of weather on bird counts was most noticeable when surveys were unavoidably conducted during periods of light rain; these surveys generating data for only 46 birds. Under conditions of light rain and strong winds only five birds were recorded. Of the 150 point surveys conducted on Kuranda Range in 2005, 55% were undertaken in overcast or rainy conditions, with over ten percent of all surveys being conducted in moderate wind conditions. Survey time also influenced the data, with morning surveys on average yielding greater numbers of birds and higher species counts (Figure 4.17).

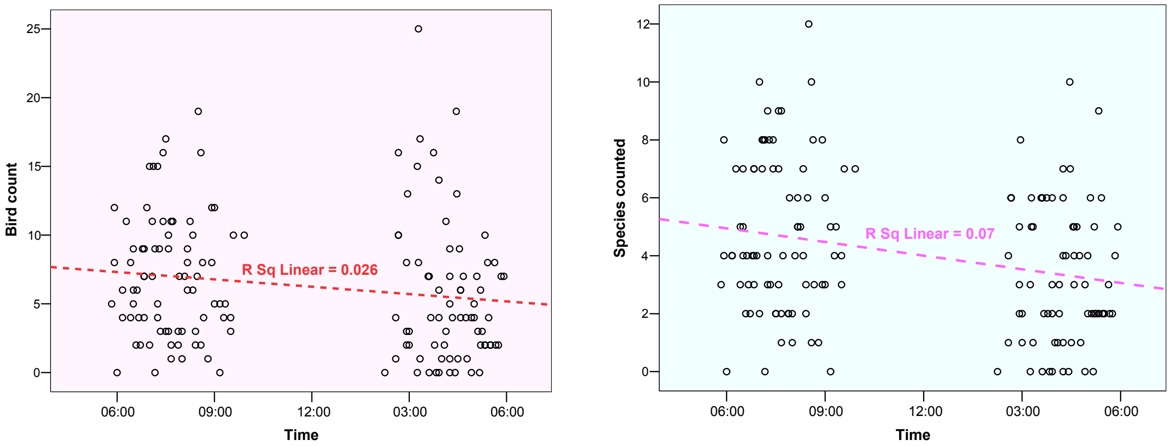


Figure 4.17: Bird abundance (*left*) and species counts (*right*) comparing diurnal survey time periods, Kuranda Range 2005.

4.4.3 Increased abundances in area close to current road at Streets Creek

Visual examination of data revealed an unexpected phenomenon of bird congregation directly behind the edge zone at Streets Creek (Figures 4.2 and 4.14). This zone (along the thirty metre transect) appeared to recruit birds from the next interior zone, resulting in lower densities for at least the fifty metre zone, before re-establishment of higher population densities by one hundred metres from the highway. The effect was most pronounced for species richness (Figures 4.3 and 4.15), particularly of omnivores and frugivores (Figure 4.10) and for those species more dependent on rainforest habitat (Figure 4.9). The effect was hidden when data from both transect locations were combined (Figures 4.5 and 4.8). At Streets Creek this thirty-metre zone is near the edge of an area designated as an acoustic refuge due to it being sheltered to some extent from traffic noise because of the presence of a topographic ridge between the road and the thirty to fifty metre zone (Section 2). Recent noise collection in this area is described in another report (Dawe and Goosem, 2007). This increase in species abundance and diversity in the potential acoustic refuge provides circumstantial evidence that traffic noise is one of the factors that cause edge avoidance by birds in other areas.

The birds reliant on rainforest (habitat guilds six and seven), are also those of most conservation interest (other than the raptors). These guilds feature greater representation in the interior for both species and population counts (Figures 4.5 and 4.8). Although the mean species richness within these two guilds appears similar for the thirty metre and one hundred metre transects (Figure 4.9), examination of the medians and distributions in the box and whisker plots (Appendix 4.2) suggests a greater richness in the one hundred metre zone. This also highlights the effect climatic and temporal conditions have on such surveys, with the generally poor weather and less than ideal survey times generating few data, whereas bursts of sunny calm conditions, when combined with dawn chorus survey times, gave results well above the median. Outliers from such population / species richness data produces higher mean counts for those distance zones, which may not be truly representative of normal bird distributions.

4.4.4 Bird species with high conservation or World Heritage status likely to be affected by traffic noise

Table 4.3 shows bird species that are known or expected to occur on the Kuranda Range which have a high conservation status or Wet Tropics World Heritage value and which have the potential to be affected by traffic noise. The noise impact levels were determined by the data collected with respect to bird song dominant frequency, the dominant frequency of song for those which were not recorded in Section 3 and those which appear to avoid the edge from the data collected in this study.

Table 4.4 is a non-exhaustive list of bird species that are known or likely to occur in the Kuranda Range area that appear likely to be affected by traffic noise. The majority of these species have been suggested by the results of Section 3. Either they have a low dominant call frequency or have been shown that they alter, may alter (but currently there is insufficient data) or similar species alter that dominant song frequency near the edge of the highway. There are many other mainly rainforest dependent species for which we do not have sufficient data to categorise their likelihood of being affected by traffic noise, although many of these are likely to demonstrate similar patterns to those seen in the bird survey data, i.e. avoidance of the very edge of the road and increasing abundance with distance from the road.

Table 4.3: Birds with high conservation or Wet Tropics World Heritage status known or expected to occur in the Kuranda Range area; habitat used; source of record; and likely impact of traffic noise.

Family	Species	Conservation status	Origin status	Occurrence	Habitat	Record source	Noise impact
Casuariidae	*Casuarius casuarius johnsonii*	E, vu, EN		Recorded	6	1, 2, 3	1
Accipitridae	*Accipiter novaehollandiae*	R		Recorded	6	2	7
	Erythyrotriorchis radiatus	E, vu, V		Possible	4		7
Psittacidae	*Cyclopsitta diophthalma*	V		Recorded	5	2, 3	4
Strigidae	*Ninox rufa*	V		Probable	3		1
Tytonidae	*Tyto multipunctata*		WT	Probable	5		1
Meliphagidae	*Lichenostomus frenatus*		WT	Possible	5		3
	Xanthotis macleayana		WT	Recorded	5	2, 3	5
Petroicidae	*Heteromyias albispecularis*		WT	Recorded	5	1, 2, 3	5
Orthonychidae	*Orthonyx spaldingii*		WT	Recorded	5	2, 3	5
Pachycephalidae	*Colluricincla boweri*		WT	Recorded	6	1, 2, 3	4

Conservation status: R – rare under *Nature Conservation Act (Qld.)* 1992; E – endangered under *Nature Conservation Act (Qld.)* 1992; en – endangered in World Conservation Union Red List; cr – critically endangered under World Conservation Union Red List; vu – vulnerable in World Conservation Union Red List; EX – extinct under *Environmental Protection and Biodiversity Conservation Act* 1999; EN – Endangered under *Environmental Protection and Biodiversity Conservation Act* 1999.

Origin status: WT – Wet Tropic endemic; I – introduced.

Habitat: 0 – not found in rainforest; 1 – occasionally recorded in rainforest; 2 – uses rainforest as marginal habitat; 3 – commonly recorded in rainforest but rainforest is not core habitat; 4 – rainforest is main habitat, but common in other forest environments; 5 – rainforest is core habitat but also occurs in adjacent wet sclerophyll forest; 6 – rainforest obligate (Williams 2006).

Record source: 1 – road kill (Goosem 2000; Goosem and Weston in prep); 2 – recorded in impact assessment studies (NRA 2003; IAS Addendum 2004); 3 – recorded in other assessments.

Noise impact: 1 – likely interference with low frequency call; 2 – possible interference with low frequency call; 3 – unlikely interference with call; 4 – possible song change; 5 – probable song change; 6 – known song change; 7 – unlikely impact of either type.

Table 4.4: Birds known or likely to occur on the Kuranda Range with the potential to be impacted by traffic noise because of known low dominant song frequencies for at least one call type or known or likely alteration to song frequencies.

Family	Species	Conservation Status	Origin Status	Occurrence	Habitat	Record source
Casuariidae	*Casuarius casuarius johnsonii*	E, vu, EN		Recorded	6	1, 2, 3
Megapodiidae	*Megapodius reinwardt*			Recorded	4	1, 2, 3
Columbidae	*Chalcophaps indica*			Recorded	5	1, 2, 3
	Columba leucomela			Recorded	5	2
	Ducula bicolour			Recorded	5	2
	Geopelia humeralis			Recorded	1	1, 2, 3
	Geopelia striata			Recorded	0	1, 2
	Lopholaimus antarcticus			Probable	5	
	Macropygia amboinensis			Recorded	5	1, 2, 3
	Ptilinopus magnificus			Recorded	5	2, 3
	Ptilinopus regina			Recorded	5	2, 3
	Ptilinopus superba			Recorded	5	2, 3
Strigidae	*Ninox novaeseelandiae*			Recorded	3	1, 2
Tytonidae	*Tyto multipunctata*		WT	Probable	5	
Podargidae	*Podargus papuensis*			Recorded	4	1, 2
	Podargus strigoides			Probable	1	
Pittiidae	*Pitta versicolor*			Recorded	5	1, 2, 3
Acanthizidae	*Gerygone magnirostris*			Recorded	3	1, 2
Meliphagidae	*Lichenostomus frenatus*		WT	Possible	5	
	Meliphaga gracilis			Recorded	5	1, 2, 3
	Meliphaga lewinii			Probable	5	
	Meliphaga notata			Recorded	5	1, 2, 3
	Philemon buceroides			Recorded	3	2
	Xanthotis macleayana		WT	Recorded	5	2, 3
Petroicidae	*Heteromyias albispecularis*		WT	Recorded	5	1, 2, 3
	Orthonyx spaldingii		WT	Recorded	5	2, 3
Pachycephalidae	*Colluricincla boweri*		WT	Recorded	6	1, 2
	Colluricincla megarhyncha			Recorded	4	1, 2, 3
	Pachycephala pectoralis			Recorded	4	1, 2, 3
	Pachycephala simplex			Recorded	3	1, 2, 3
Dicruridae	*Monarcha leucotis*			Recorded	5	3
	Monarcha melanopsis			Recorded	5	3
Campephagidae	*Coracina lineata*			Recorded	4	2, 3
	Coracina tenuirostris			Recorded	2	3
	Lalage leucomela			Recorded	3	2, 3
Oriolidae	*Oriolus flavicinctus*			Recorded	3	2, 3
	Sphecotheres viridis			Recorded	3	1, 2, 3
Artamidae	*Cracticus quoyi*			Recorded	4	2, 3
Ptilinorhynchidae	*Ailuroedus melanotis*			Recorded	5	1, 2, 3
Cuculidae	*Chrysococcyx russatus*			Recorded	4	3
	Chrysococcyx minutillus			Recorded	4	3

Conservation Status: R – rare under *Nature Conservation Act (Qld.)* 1992; E – endangered under *Nature Conservation Act (Qld.)* 1992; en – endangered in World Conservation Union Red List; cr – critically endangered under World Conservation Union Red List; vu – vulnerable in World Conservation Union Red List; EX – extinct under *Environmental Protection and Biodiversity Conservation Act* 1999; EN – Endangered under *Environmental Protection and Biodiversity Conservation Act* 1999.
Origin status: WT – Wet Tropic endemic; I – introduced.
Habitat: 0 – not found in rainforest; 1 – occasionally recorded in rainforest; 2 – uses rainforest as marginal habitat; 3 – commonly recorded in rainforest but rainforest is not core habitat; 4 – rainforest is main habitat, but common in other forest environments; 5 – rainforest is core habitat but also occurs in adjacent wet sclerophyll forest; 6 – rainforest obligate (Williams 2006).
Source: 1 – road kill (Goosem 2000; Goosem and Weston in prep); 2 – recorded in impact assessment studies (NRA 2003; IAS Addendum 2004); 3 – recorded in other assessments.

4.5 Conclusions

The Kuranda Range Road currently produces an edge effect which results in lower bird population densities and reduced species richness along a zone extending to at least twenty metres into the adjacent rainforest. A 'hot spot' of bird occupation appears to exist around thirty metres from the rainforest edge, possibly due to protection from traffic noise in one site. However, results from control sites suggest possible edge effects at these sites also, as well as indicating site differences between the two control locations. Despite the shortage of adequate replication of data from both the control sites and from end of wet season surveys, it appears likely that road traffic along the existing Kuranda Range Road is impacting on both bird population densities and species richness close to the edge. It also appears that avian species most dependent on rainforest habitat are moving away from the edge zones, and that some opportunist species not normally associated with rainforest are moving into the edge of the highway corridor. We suggest that traffic noise is a likely contributor to some of these edge effects, due to the difference between guilds affected in this research compared to other studies without traffic noise, the presence of greater diversity and abundance in the potential acoustic refuge and the demonstration in Section 3 that at least some species in guilds that appear to avoid the road also alter their song dominant frequency.

4.6 Recommendations and management implications

Future highway realignment or upgrades are likely to impact local bird communities, particularly around the zone with greater abundances and diversity than expected, which was found thirty metres from the edge. Any major horizontal displacement from the current highway footprint would considerably affect bird communities which inhabit the existing one hundred and two hundred metre interior zones. As these zones are currently areas of high avian species richness and population density relative to zones closer to the highway, a program of accurate monitoring and minimal disturbance needs to be employed in order to ensure successful re-establishment of bird communities in the current edge zones following their expected displacement from their current habitat. In the short term, regenerated areas available due to re-alignment are unlikely to adequately compensate for habitat lost by the upgrade, due mainly to the gap in re-establishment time. In time these areas may be colonised by interior rainforest bird species, subject to the success of the rehabilitation strategies implemented.

Reducing the amount of traffic noise entering the forest adjacent to the highway is likely to reduce edge effects in bird abundance and species composition. Noise barriers could also contribute to a fence and funnel strategy that prevents animals entering the roadway, although this is unlikely to affect the majority of birds. Noise mitigation should especially concentrate on areas currently shown to have high bird diversity and abundance such as the area near the road adjacent to Streets Creek, and to areas with similar potential to support high bird populations.

4.7 Further research

Other areas adjacent to the existing Kuranda Range Road with similar topographic characteristics to the Streets Creek transects should be examined for similar near-edge recruitment zones. Replication of data collection and further transect replication would strengthen the edge effect examination and possibly allow more detailed examination of guilds and common species.

Inter-relationships between seasonality, guilds, climate and survey time should be modelled in order to produce calibrations to accurately weight bird survey data. New surveys should examine bird occupancy and habitat quality under multi-lane highway bridges to assess the degree of useful habitat gain and occupancy potential for rainforest dependent species.

References

Abbott, P. and Harris, G., 1999. *The Calculation of Road Traffic Noise: Implications of Changing to* L_{Aeq}. Paper delivered to Institute of Acoustics Conference, Crowthorne, Berkshire, UK: Transport Research Laboratory.

Aguas, A., Esaguy, N., Grande, N., Castro, A., Castelo Branco, N., 1999. Effect of low frequency noise exposure on BALB/c mice splenic lymphocytes. *Aviation Space and Environmental Medicine* 70, A128-31. Online: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieveanddb=PubMed&list_uids=10189169&dopt=Abstract

Alves Ppereira, N. and Castelo Branco, M., 1999. Vibroacoustic disease: the need for a new attitude towards noise. In: P. Ferraz de Abreu and J. Joanaz de Melo (eds.) Public Participation and Information Technologies. CITIDEP and DCEA-FCT-UNL, 2000 (Online article) (Accessed 13-05-2005) http://www.citidep.pt/papers/articles/alvesper.htm

American Academy of Pediatrics, 1997. Noise: A Hazard for the Fetus and Newborn. *Pediatrics* 100, 724-727 (Accessed 20-04-2005) http://aappolicy.aappublications.org/cgi/content/full/pediatrics;100/4/724

Anjos, L., 2003. Bioacoustics and Biodiversity Bird Point Counts. Transcript from XIX Bioacoustics Conference Brazil. www article (accessed 13-5-2005) http://www.cultura.ufpa.br/ibac/ibacabs.htm#N

ASK Consulting Engineers, 2004. Kennedy Highway (Kuranda Range Road) Noise Issues Report, 2867R doc 29. Spring Hill, Queensland: ASK Consulting Engineers.

ASK Consulting Engineers, 2006. Kennedy Highway (Kuranda Range Road) Noise Issues Report No. 2. Spring Hill, Queensland: ASK Consulting Engineers.

Attenborough, K., 1991. Noise pollution. In: R. Hamilton and R. Harrison (eds.), *Highway Pollution*, London: Elsevier.

Aubin, T., 2003. Penguins and their noisy world. XIX International Bioacoustics Congress, Para, Brazil, August 2003 (Accessed 13-05-2005) http://www.cultura.ufpa.br/ibac/ibacabs.htm#N

Aubin, T., and Jouventin, P., 1998. Cocktail-party effect in King Penguin colonies. *Proceedings of the Royal Society of London: Biological Sciences* 265, 1665-1667.

Aubin, T., Jouventin, P. and Hildebrand, C., 2000. How penguins use their two-voice system to recognize each other. *Proceedings of the Royal Society of London: Biological Sciences* 267, 1081-1087.

Audacity, 2004, Version 1.2.3 http://audacity.sourceforge.net/

Austroads, 2005. *Modelling, Measuring and Mitigating Road Traffic Noise*. Research Report No. AP-R277/05. Project manager S. Isles, Sydney: Ausroads Incorporated.

Babisch, W., 2000. Traffic Noise and Cardiovascular Disease: Epidemiological Review and Synthesis. *Noise and Health* 2, 9-32.

Babisch, W., Ising, H., Kruppa, B. and Wiens, D., 1994. The incidence of myocardial infarction and its relation to road traffic noise: The Berlin case-control study. *Environment International* 20, 469-474.

Barrass, A. and Cohn, L., 1983. Preliminary results of inhibition of phonotaxis by highway noise for several species of anurans. *American Zoologist* 23, 882.

Barrass, A. and Cohn, L., 1984. Variation of the spacing of calling male *Bufo woodhousei* and *Hyla cinerea* near roadway noise. *American Zoologist* 24, 15A.

Barrett, R., 1976. Some effects of vehicles on wintering deer within the Eldorado National Forest. US Forest Service (Accessed 27-05-2005) http://nohvcclibrary.forestry.uga.edu/SCANNED%20FILES/W-0011-effects%20of%20vehicles%20on%20wintering%20deer.pdf

Bautista, L., Garcia, J., Calmaestra, R., Palacin, C., Martin, C., Morales, M., Bonal, R. and Vinuela, J., 2004. Effect of weekend road traffic on the use of space by raptors. *Conservation Biology* 18, 726-732.

Beckers, G., Goossens, B. and Ten Cate, C., 2003. Perceptual salience of acoustic differences between conspecific and allospecific vocalisations in African collared-doves. *Animal Behaviour* 65, 605-614.

Bernhard, R. and Wayson, R., 2005. An Introduction to Tyre/Pavement Noise of Asphalt Pavement. Final Research Report Number: SQDH 2005-1. Joint Transportation Research Program (JTRP), Institute for Safe, Quiet and Durable Highways (SQDH), Purdue University (Accessed 13-05-2005) http://meweb.ecn.purdue.edu/~sqdh/

Brotons, L. and Herrando, S., 2001. Reduced bird occurrence in pine forest fragments associated with road proximity in a Mediterranean agricultural area. *Landscape and Urban Planning* 57, 77-89.

Brown, A., 1990. Measuring the effect of aircraft on sea birds. *Environment International* 16, 587-592.

Brumm, H., 2003. Implications of vocal directionality how a songbird changes its singing behaviour depending on the context of communication. XIX International Bioacoustics Congress, Para, Brazil, August 2003 (Accessed 13-05-2005) http://www.cultura.ufpa.br/ibac/ibacabs.htm#N

Brumm, H., 2004. The impact of environmental noise on song amplitude in a territorial bird. *Journal of Animal Ecology* 73, 434-440.

Brumm, H. And Slabbekoorn, H. 2005. Acoustic communication in noise. *Advances in the Study of Behaviour* 35, 151-209.

Brumm, H. and Todt, D., 2002. Noise-dependent song amplitude regulation in a territorial songbird. *Animal Behaviour* 63, 891-897.

Buger, J., 1981. Behavioural responses of herring gulls *Larus Argentatus* to aircraft noise. *Environmental Pollution (Series A)* 24, 177-184.

Bureau of Meteorology, 2006. *Daily Observations for Cairns Queensland*, Cairns Aero Weather Station, No. 031011. Records from June to October 2005, Australian Bureau of Meteorology.

Busnel, R., 1978. Introduction. In: J. Fletcher and R. Busnel (eds.) *Effects of Noise on Wildlife*, New York: Academic Press. pp. 7-22.

Busnel, R. and Mebes, H., 1975. Hearing and communication in birds: the cocktail-party-effect in intraspecific communication. *Life Sciences* 17, 1567-1569.

Campbell, J. and Isles, S., 2001. *Environmental Noise Management Manual*. Environment and Community Policy Branch, Roads and Traffic Authority NSW (Accessed 13-07-2004) http://www.rta.nsw.gov.au/environment/downloads/environmental_noise_management_manual_v1_0.pdf

Catchpole, H., 2004. Frogs Freaked by Traffic, Croak Louder. ABC Science Online Wednesday 27th October, 2004 (Accessed 19-04-2005) http://www.abc.net/science/news/enviro/EnviroRepublish_1227378.htm

Centre for Bioacoustics Research, 1999. The Effect of Roadway Traffic Noise on Territory Selection by Golden-cheeked Warblers. Conrad Blucher Institute for Surveying and Science, Center for Bioacoustics, Texas A&M University Corpus Christi, Texas 78412 (Accessed 13-05-2005) http://bioacoustics.cbi.tamucc.edu/research/

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

Cohen, J., 1988. *Statistical Power Analysis for the Behavioral Sciences*, Hillsdale, NJ: Erlbaum.

Creel, S., Fox, J., Hardy, A., Sands, J., Garrott, P. and Peterson, R., 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. *Conservation Biology* 16, 809-814.

Cynx, J., Lewis, R., Tavel, B. and Tse, H., 1998. Amplitude regulation of vocalisations in noise by a songbird, *Taeniopygia guttata*. *Animal Behaviour* 56, 107-113.

Dawe, G., 2005. Traffic noise and its influence on the song of tropical rainforest birds. BSc Hons. Thesis, James Cook University, Cairns.

Dawe, G. and Goosem, M., 2007. Nocturnal noise levels and impacts on anuran habitats on Kuranda Range. Report to Queensland Department of Main Roads, June 2007.

Dawe, G. and Goosem, M., 2008. Vehicle noise attenuation through tropical rainforest at ground and lower canopy levels: distance penetrated by noise disturbance. *Journal of Environmental Management*, in press.

De Sousa Pereira, A., Aguas, A., Grande, N., Mirones, J., Monteiro, E. and Castelo Branco N., 1999. The effect of chronic exposure to low frequency noise on rat tracheal epithelia. *Aviation Space and Environmental Medicine* 70, A86-90 (Accessed 13-05-2005) http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=10189161&dopt=Abstract

Dent, M., Larsen, O. and Dooling, R., 1997. Free-field binaural unmasking in budgerigars (*Melopsittacus undulates*). *Behavioral Neuroscience* 111, 590-598.

Develey, P. and Stouffer, P., 2001. Effects of roads on movements by understory birds in mixed-species flocks in Central Amazonian Brazil. *Conservation Biology* 15, 1416-1422.

Donavan, P. (in press). Vehicle Exterior Noise. In: M. Crocker (ed.) *Handbook of Noise and Vibration Control*, New York: John Wiley and Sons.

Dunnet, G., 1977. Observations on the effects of low-flying aircraft at seabird colonies on the coast of Aberdeenshire, Scotland. *Biological Conservation* 12, 55-63.

Ervin, E. L., Fisher, R. N. and Crooks, K. R., 2001. Roads and toads: Amphibian mortality in relation to rainfall, roadway surface moisture, and traffic volume. Abstract in Proceedings of the Conference of the Society for Conservation Biology, July 2001, Hilo, Hawaii.

European Union, 1996. Future Noise Policy [Green Paper] European Commission, Brussels 1996 (Accessed 28-07-2004) http://europa.eu.int/en/record/green/gp9611/noisesum.htm

Fahrig, L., Pedlar, J., Pope, S., Taylor, P. and Wegner, J., 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73, 177-182.

Ficken, R., Ficken, M. and Hailman, J., 1974. Temporal pattern shifts to avoid acoustic interference in singing birds. *Science* 183, 762.

Fletcher, N., 1992. *Acoustic Systems in Biology*, New York: Oxford University Press.

Forman, R. and Alexander, L., 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29, 207-231.

Forman, R., Reineking, B. and Hersperger, A., 2002. Road traffic and nearby grassland bird patterns in a suburbanizing landscape. *Environmental Management* 29, 782-800.

Forman, R., Sperling, D., Bissonette, J., Clevenger, A., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrentine, T. and Winter, T., 2003. *Road Ecology: Science and Solutions*, Washington: Island Press.

Gammon, D., Baker, M. and Tipton, J., 2005. Cultural divergence within novel song in the black-capped chickadee (*Poecile atricapillus*). *Auk* 122, 853-871.

Gahr, M., Sonnenschein, E. and Wickler, E. 1998. Sex difference in the size of the neural song control regions in a dueting songbird with similar song repertoire size of males and females. *Journal of Neuroscience* 18, 1124-1131.

Gibbs, J. and Steen, D., 2005. Trends in sex ratios of turtles in the United States: Implications for road mortality. *Conservation Biology* 19, 552-556.

Gibeau, M., Clevenger, A., Herrero, S. and Wierzchowski, J., 2002. Grizzly bear response to human development and activities in the Bow River Watershed, Alberta, Canada. *Biological Conservation* 103, 227-236.

Godard, R., 1991. Long-term memory of individual neighbours in a migratory songbird. *Nature* 350, 228.

Goosem, M. W., 2000. Impacts of roads and powerline clearings on rainforest vertebrates with emphasis on ground-dwelling small mammals. Unpub. PhD thesis. James Cook University, Townsville.

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

Goosem, M. and Weston, N. (in prep). *Road mortality on the Kennedy Highway, Kuranda Range section, 2005/2006: its application to connectivity issues for the proposed road upgrade*. Report to the Queensland Department of Main Roads.

Goudie, R. and Jones, I., 2004. Dose-response relationships of harlequin duck behaviour to noise from low-level military jet over-flights in central Labrador. *Environmental Conservation* 31, 289-298.

Grant, P., Grant, R. and Petren, K., 2000. The allopatric phase of speciation: the sharp-beaked ground finch (*Geospiza difficilis*) on the Galapagos Islands. *Biological Journal of the Linnean Society* 69, 287-317.

Grazuleviciene, R., Lekaviciute, J., Mozgeris, G., Merkevicius, S. and Deikus, J., 2004. Traffic noise emissions and myocardial infarction risk. *Polish Journal of Environmental Studies* 13, 737-741.

Haskell, D., 2000 Effects of forest roads on macroinveterate soil fauna of the Southern Appalachian Mountains. *Conservation Biology* 14, 57-63.

Higgins, P. J. 1999. *Handbook of Australian, New Zealand and Antarctic Birds. Volume 4. Parrots to Dollarbird.* Oxford University Press, Melbourne.

Higgins, P. and Peter, J. (eds.), 2002. *Handbook of Australian, New Zealand and Antarctic Birds, Volume 6, Pardalotes to shrike-thrushes*. Oxford, Oxford University Press.

Hofman W., Kumar A. and Tulen J., 1995. Cardiac reactivity to traffic noise during sleep in man. *Journal of Sound and Vibration* 179, 577-589.

Holschuh, C., 2001. Behavioural compensation for habitat induced differences in Black-capped chickadee (*Poecile atricapillus*) song transmission. BSc. thesis, University of British Columbia, Prince George.

Huisman, W. and Attenborough, K., 1991. Reverberation and attenuation in a pine forest. *Journal of the Acoustical Society of America* 90, 2664-2677.

IAS Addendum, 2004. Integrated Transport Study for Kuranda Range. IAS Addendum. Environment North, prepared for Queensland Department of Main Roads, September 2004.

Ilichev, V., Kamanskii, I. and Silaeva, O., 1995. Ecological and technogenous factors of noise-pollution of natural habitats of birds. *Russian Journal of Ecology* 26, 345-348.

Ising H. and Ising M., 2002. Chronic cortisol increases in the first half of the night caused by road traffic noise. *Noise and Health* 4, 13-21.

Jonasson, H. and Storeheier, S., 2001. *Nord 2000. New Nordic Prediction Method for Road Traffic Noise*, SP Rapport 2001:10, Boras, Sweden: Swedish National Testing and Research Institute.

Katti, M. and Warren, P., 2004. Tits, noise and urban bioacoustics. *Trends in Ecology and Evolution* 19, 109-110.

Krause, B., 2001. Loss of Natural Soundscape: Global implications of its effects on Humans and Other Creatures. Paper prepared for San Francisco World Affairs Council, 31 January 2001 (Accessed 19-04-2005) http://www.wildsanctuary.com

Kroodsna, D. E. 2004. The diversity and plasticity of birdsong. In: P. Marler and H. Slabbekoorn (eds.) *Nature's Music: The Science of Birdsong*. Elsevier Science, San Diego, USA, pp. 108-131.

Kuitunen, M., Viljanen, J., Rosso, E. and Stenroos, A., 2003. Impact of busy roads on breeding success in pied flycatchers *Ficedula hypoleuca*. *Environmental Management* 31, 79-85.

Laurance, S.G.W., 2004, Responses of understory rainforest birds to road edges in central Amazonia. *Ecological Applications* 14: 1344-1357.

Laurance, S.G.W., 2006. Rainforest roads and the future of forest-dependent wildlife: a case study of understory birds. In: W.F. Laurance and C. Peres (eds.). *Emerging Threats to Tropical Forests*, University of Chicago Press, Chicago, pp 253-267.

Laurance, S., Stouffer, P. and Laurance, W., 2004. Effects of road clearings on movement patterns of understory rainforest birds in Central Amazonia. *Conservation Biology* 18, 1099-1109.

Lawson, T., 2004. *A Landscape Ecology of Riparian Vegetation in the Mossman Catchment*, Unpublished BAppSci Thesis, School of Tropical Environmental Studies and Geography, James Cook University, Cairns, Australia.

Leader, N., Wright, J. and Yom-Tov, Y., 2005. Microgeographic song dialects in the orange-tufted sunbird (*Nectarinia osea*). *Behaviour* 137, 1613-1627.

Leonard, M. and Horn, A., 2005. Ambient noise and the design of begging signals' *Proceedings of the Royal Society. B. Biological Sciences* 272, 651-656.

Lohr, B., Wright, T. and Dooling, R., 2003. Detection and discrimination of natural calls in masking noise by birds: estimating the active space of a signal. *Animal Behaviour* 65, 763-777.

Macarthur, R., Geist, V. and Johnson, R., 1982. Cardiac and behavioural responses of mountain sheep to human disturbance. *Journal of Wildlife Management* 46, 351-358.

Marks, S. and Turton, S., 2000. Vehicular noise disturbance in rainforest. In: M. Goosem and S. Turton (eds). *Impacts of Roads and Powerlines on the Wet Tropics World Heritage Area – Stage 2.* Cooperative Research Centre for Tropical Rainforest Ecology and Management, Report 2, July 2002. Rainforest CRC and James Cook University, Cairns.

Mathevon, N., Aubin, T., Dabelsteen, T. and Vielliard, J., 2003. Are communication activities shaped by environmental constraints in reverberating and sound-absorbing forest habitats? XIX International Bioacoustics Congress, Para, Brazil, August 2003 (Accessed 13-05-2005) http://www.cultura.ufpa.br/ibac/ibacabs.htm#N

Moloney, J. M. 2005. *The effects of habitat fragmentation on bird communities in a naturally disturbed environment: the Wet Tropics lowlands*. PhD thesis. James Cook University, Townsville.

Morris, M., 1998. Birds killed on Trans-Canada Highway. Columbia Mountains Institute of Applied Ecology, Parks Canada, Revelstoke, BC (Accessed 27-04-2005) http://www.cmiae.org/

Munck, A., Guyre, P. and Holbrook, N., 1984. Physiological functions of glucocorticoids in stress and their relation to pharmacological actions. *Endocrine Reviews* 5, 25-48.

Naquib, M., 1996a. Ranging by song in Carolina wrens *Thryothorus ludovicianus*: effects of environmental acoustics and strength of song degradation. *Behaviour* 133, 541-559.

Naquib, M. and Wiley, H., 2002. Estimating the distance to a source of sound: mechanisms and adaptations for long-range communication. *Animal Behaviour* 62, 825-837.

NRA, 2003. *Kuranda Range Impact Assessment Study Ecological Issues*. Natural Resource Assessments, prepared for the Queensland Department of Main Roads, November 2003.

O'Connell-Rodwell, C., Wood, J., Rodwell, T., Shriver, D., Arnason, B. and Hart, L., 2003. *The impact of seismically transmitted elephant vocalisation play backs on wild African elephants and the implications for conservation*. Fifth Annual Bay Area Conservation Biology Symposium, University of California Berkeley, February, 2003 (Accessed 21-04-2005) http://www.cnr.berkeley.edu/consbio/symposium/papers_nz.html

Oliveira, M., Pereira, A., Castelo Branco, N., Grande, N. and Aguas, A., 2001. *In utero* and postnatal exposure of Wistar rats to low frequency/high intensity noise depletes the tracheal epithelium of ciliated cells. *Lung* 179, 225-32

Ouis, D., 2002. Annoyance caused by exposure to road traffic noise: an update. *Noise and Health* 4, 69-79.

Pallant, J., 2005. *SPSS Survival Manual*, Crow's Nest: Allen and Unwin.

Pandya, G., 2003. Assessment of traffic noise and its impact on the community. *International Journal of Environmental Studies* 60, 595-602.

Patricelli, G. M. and Blickley, J. L. 2006. Avian communication in urban noise: Causes and consequences of vocal adjustment. *Auk* 123, 639-649.

Pellet, J., Hoehn, S. and Perrin, N., 2004a. Multiscale determinants of tree frog (*Hyla arborea* L.) calling ponds in western Switzerland. *Biodiversity and Conservation* 13, 2227-2235.

Pellet, J., Guisan, A. and Perrin, N., 2004b. A concentric analysis of the impact of urbanization on the threatened European Tree frog in an agricultural landscape. *Conservation Biology* 18, 1599-1606.

Philcox, C., Grogan, A. and Macdonald, D., 1999. Patterns of otter *Lutra lutra* road mortality in Britain. *Journal of Applied Ecology* 36, 748-762.

Pizzey, G. and Knight, F., 1999. *The Graham Pizzey and Frank Knight Field Guide to the Birds of Australia*, (second edition), Sydney: Harper Collins.

QDMR, 2005. Queensland Department of Main Roads, Noise Counter Station No. 110005, Smithfield, Kennedy Highway ARP 32A/01.

Rabin, L., and Greene, C., 2002. Changes to acoustic communication systems in human-altered environments. *Journal of Comparative Psychology* 116, 137-141.

Rabin, L. R., McCowan, B., Hooper, S. L. and Owings, D. H., 2003. Anthropogenic noise and its effect on animal communication: An interface between comparative psychology and conservation biology. *International Journal of Comparative Psychology* 16, 172-192.

Reijnen, R. and Foppen, R., 1994. The effects of car traffic on breeding bird populations in woodland. 1. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. *Journal of Applied Ecology* 31, 85-94.

Reijnen, R., Foppen, R., Braak, C. and Thissen, J., 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology* 32, 187-202.

Reijnen, R, Foppen, R. and Meeuwsen, H., 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grassland. *Biological Conservation* 75, 255-260.

Reijnen, R, Foppen, R. and Veenbaas, G., 1997. Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation* 6, 567-581.

Reijnen, R., Foppen, R., Veenbaas, G. and Bussink, H., 2002. Disturbance by traffic as a threat to breeding birds: evaluation of the effect and considerations in planning and managing road corridors. In: B. Sherwood, D. Cutler and J. Burton (eds.) *Wildlife and Roads: The Ecological Impact*, London: Imperial College Press, pp. 249-267.

Rheindt, F., 2003. The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? *Journal für Ornithologie* 144, 295-306.

Ryan, M. J. and Brenowitz, E. A. 1985. The role of body size, phylogeny and ambient noise in the evolution of bird song. *American Naturalist* 126, 87-100.

Sapolsky, R., 1992. Neuroendocrinology of the stress response. In: J. Becker, S. Breedlove and D. Crews (eds.) *Behavioural Endocrinology.* Cambridge (Massachusetts): MIT Press.

Sato T., Yano T., Bjorkman M. and Rylander R., 1999. Road traffic noise annoyance in relation to average noise level, number of events and maximum noise level. *Journal of Sound and Vibration* 223, 775-784.

Sattler, P.S. and Williams, R.D. (eds.), 1999. *The conservation status of Queensland's bioregional ecosystems*. Environment Protection Agency, Brisbane, Queensland.

Schueck, L., Marzluff, J. and Steenhof, K., 2001. Influence of military activities on raptor abundance and behaviour. *Condor* 103, 606-615.

Skiba, R., 2000. Possible 'Rain call' selection in the Chaffinch (*Fringilla coelebs*) by noise intensity: an investigation of a hypothesis. *Journal für Ornithologie* 141, 160.

Slabbekoorn, H., 2004. Habitat-dependent ambient noise: Consistent spectral profiles in two African forest types. *Journal of the Acoustical Society of America* 116, 3727-3733.

Slabbekorn, H., Ellers, J. and Smith, T., 2002. Birdsong and sound transmission: The benefits of reverberations. *Condor* 104, 564-573.

Slabbekoorn, H. and Peet, M., 2003. Birds sing at a higher pitch in urban noise. *Nature* 424, 267.

Slabbekoorn, H. and Smith, 2002a. Birdsong, ecology and speciation. *Philosophical Translations of the Royal Society, London, Biological Sciences Series* 357, 493-503.

Slabbekoorn, H. and Smith, 2002b. Habitat-dependent song divergence in the little greenbul: an analysis of environmental selection pressures on acoustic signals. *Evolution* 56, 1849-1858.

St. Claire, C., 2003. Comparative permeability of roads, rivers, and meadows to songbirds in Banff National Park. *Conservation Biology* 17, 1151

Stewart, D., 2002. *Australian Bird Calls: Tropical North-east*, Compact disc, Nature Sound, Mullumbimby, NSW.

Stewart, D., 1996, *Australian Bird Sounds, Queensland's Wet Tropics and Great Barrier Reef, The Smaller, or Passerine Birds*, Audio cassette, Nature Sound, Mullumbimby, NSW.

Tchernichovski, O., Mitra, P., Lints, T. and Nottebohm, F., 2001. Dynamics of the vocal imitation process: how a zebra finch learns its song. *Science* 291, 2564.

Tidemann, C., 2003. Displacement of a flying-fox camp using sound. *Ecological Management and Restoration* 4, 224-226.

Todt, D. and Geberzahn, N., 2003. Age-dependent effects of song exposure: song crystallization sets a boundary between fast and delayed vocal imitation. *Animal Behaviour* 65, 971-979.

Ujvari, M., Baagoe, H. and Madsen, A., 2004. Effectiveness of acoustic road markings in reducing deer-vehicle collisions: a behavioural study. *Wildlife Biology* 10, 155-159.

Van Bohemen, H. and Janssen Van de Lark, J., 2003. The influence of road infrastructure and traffic on soil, water, and air quality. *Environmental Management* 31, 50-68.

Vos, C. and Chardon, J., 1998. Effect of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. *Journal of Applied Ecology* 35, 44-56.

Warren, P., Katti, M., Ermann, M. and Brazel, A., (2006). Urban bioacoustics: it's not just noise. *Animal Behaviour* 7, 491-502.

Warren, P. and Shochat, E., 2004. *Point Count Bird Censuring*, Central Arizona – Phoenix Long-term Ecological Research (CAP LTER), Global Institute of Sustainability, Arizona State University (Accessed 10/01/2005) http://caplter.asu.edu/home/people/projShowDetails.jsp?projectId=34&party_id=2535

Waser, P. and Brown, C., 1986. Habitat acoustics and primate communication. *American Journal of Primatology* 10, 135-154.

Waser, P. and Waser, M., 1977. Experimental studies of primate vocalisation: specializations for long-distance propagation. *Zeitschrift für Tierpsychologie* 43, 239-263.

Weiserbs, A. and Jacob, J., 2003. Le bruit engendre par le trafic autoroutier influence-t-il la repartition des oiseaux nicheurs? *Aves* (Belgium) 39, 54-56.

Westcott, D. and Kroon, F., 2002. Geographic song variation and its consequences in the golden bowerbird. *Condor,* 104 (4).

World Health Organization, 2000. *Guidelines for Community Noise*. Geveva: World Health Organization.

Wiley, R. and Richards, D., 1978. Physical constraints on acoustic communication in the atmosphere: implications for the evolution of animal vocalisations. *Behavioral Ecology and Sociobiology* 33, 69-94.

Wiley, R.H. and Richards, D., 1982. Adaptations for acoustic communication in birds: sound transmission and signal detection. In: D.E. Kroodsma and E.H. Miller (eds.) *Acoustic Communication in Birds*. Academic Press, New York. pp 131-181.

Williams, S. E., 2006. *Vertebrates of the Wet Tropics Rainforests of Australia: Species Distributions and Biodiversity*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns, Australia.

Wollerman, L., 1999. Acoustic interference limits call detection in a neotropical frog *Hyla ebraccata*. *Animal Behaviour* 57, 529-536.

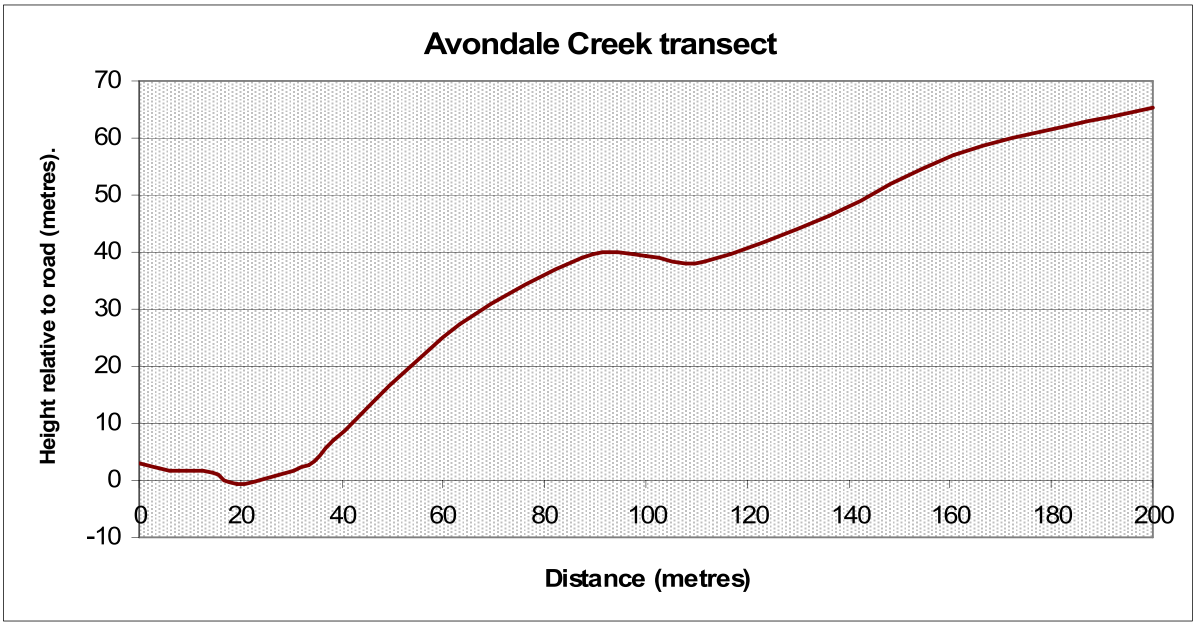
Wood, W. E. and Yezerinac, S. M. 2006. Song sparrow (*Melospiza melodia*) song varies with urban noise. *Auk* 123, 650-659.

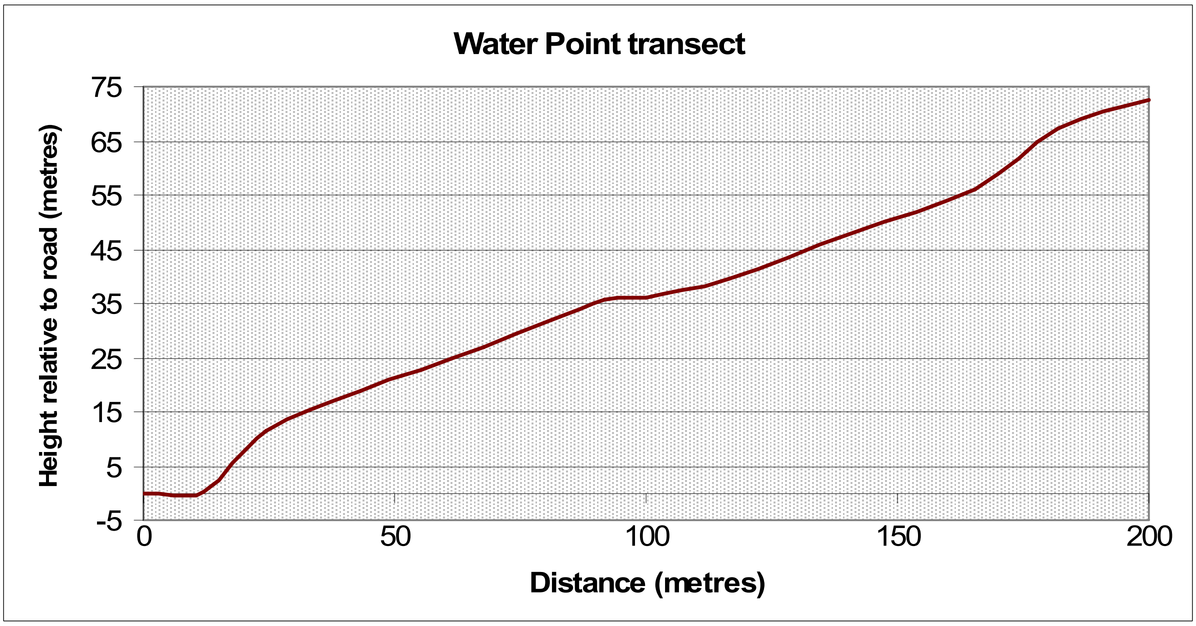
Noise Disturbance along Highways

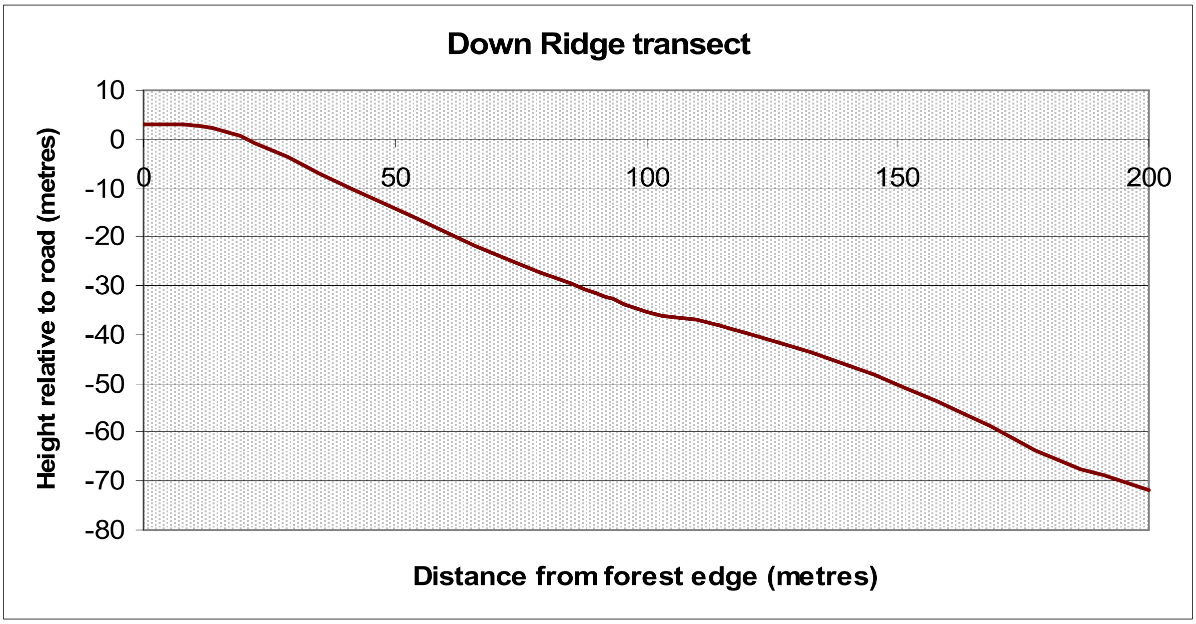
Appendix: Section 2
Traffic noise propagation through montane rainforest

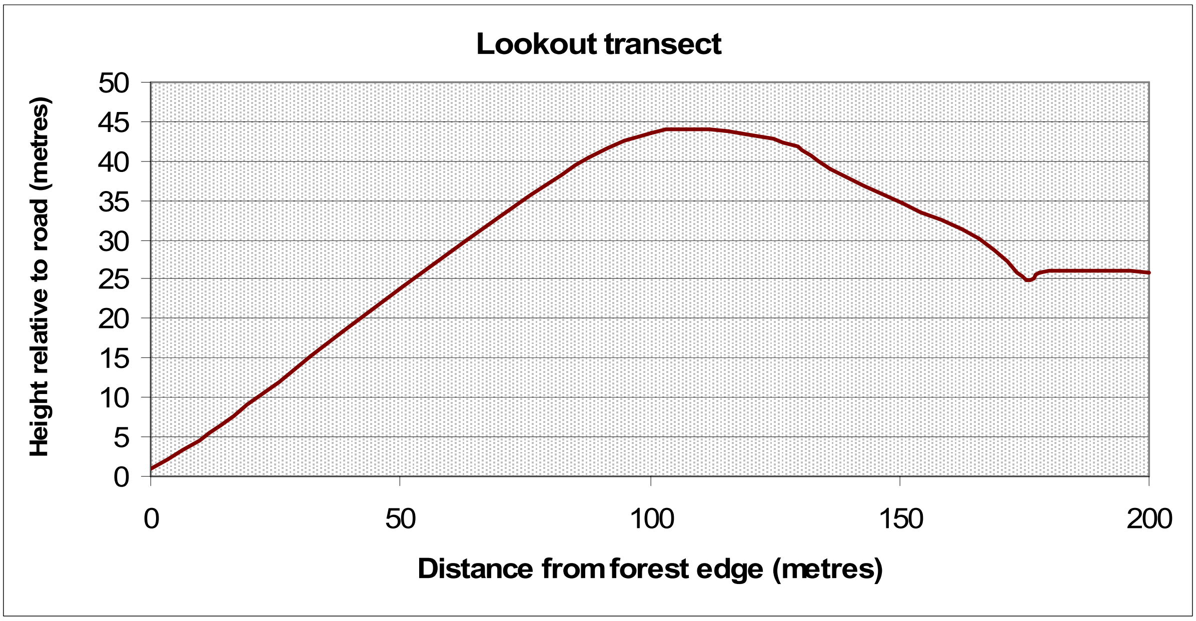
Appendix 2.1 – 2005 Noise Transect Profiles

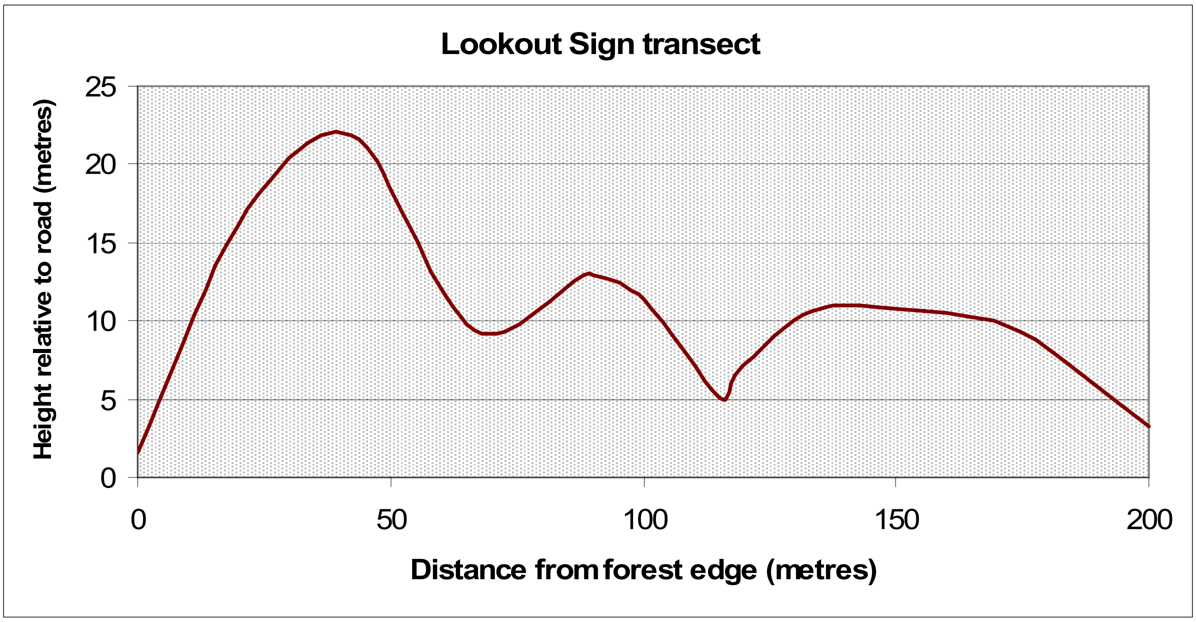
Heights and distances are taken from QDMR contour maps and profiles data, adjusted to local site data obtained using trigonometrical calculations from levels and distances obtained by hip-chain, laser rangefinders and GPS during pedestrian surveys of the sites.

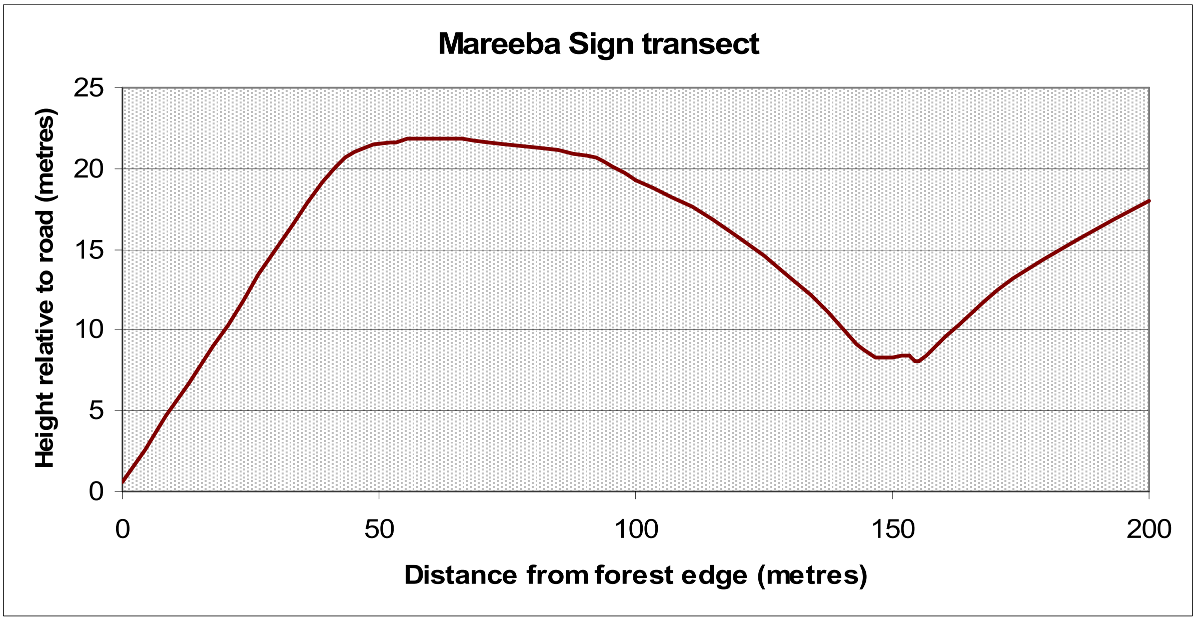


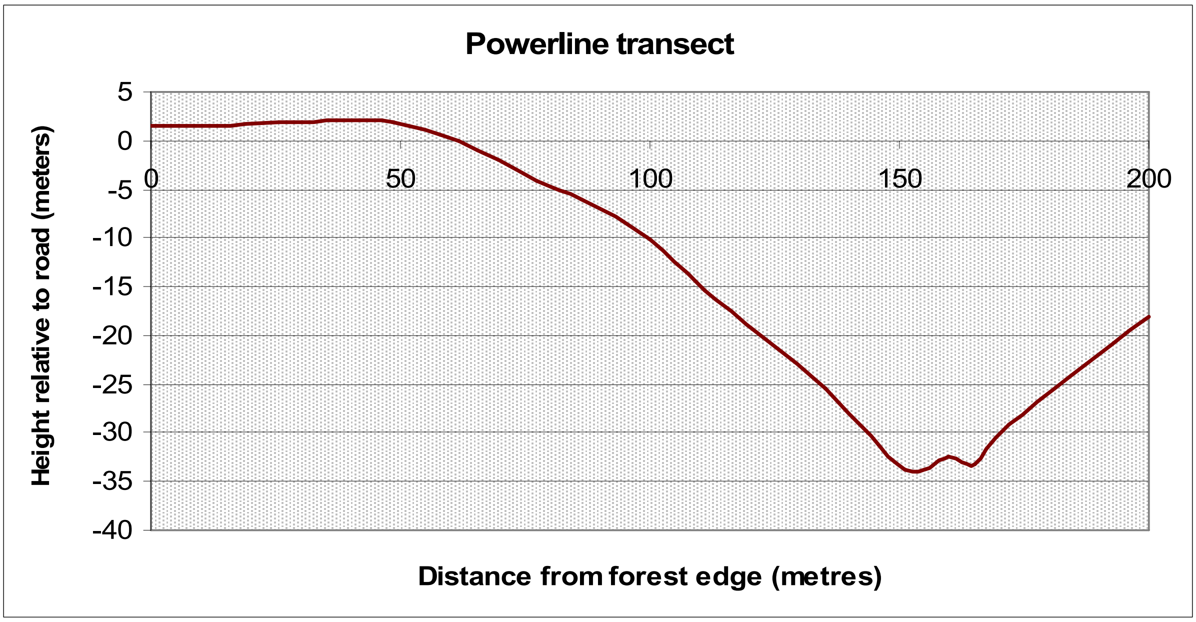


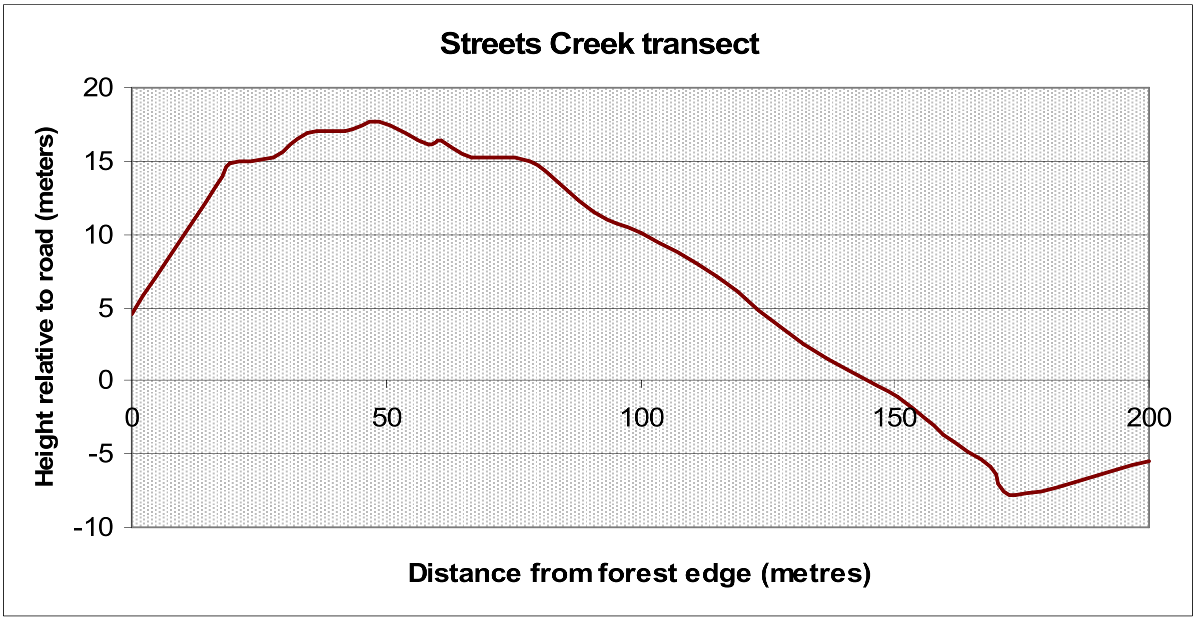

Down Ridge transect
Height relative to road (metres)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
50
100
150
200
Distance from forest edge (metres)


Lookout transect
Height relative to road (metres)
50
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
Distance from forest edge (metres)


Lookout Sign transect
Height relative to road (metres)
25
20
15
10
5
0
0
50
100
150
200
Distance from forest edge (metres)


Mareeba Sign transect
Height relative to road (metres)
25
20
15
10
5
0
0
50
100
150
200
Distance from forest edge (metres)


Powerline transect
Height relative to road (meters)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
50
100
150
200
Distance from forest edge (metres)


Streets Creek transect
Height relative to road (meters)
20
15
10
5
0
-5
-10
0
50
100
150
200
Distance from forest edge (metres)

Appendix 2.2 – Modelled and existing noise

Modelling of 'Ultimate' predicted L_{10} ground noise levels for the upgraded Kuranda Range Road adjacent to sites of 2005 noise data collection (centre of inserts indicate ground noise levels from Rainforest CRC 2005 field recordings). All maps are displayed 'north up'. Transect traverse distances are two hundred metres.

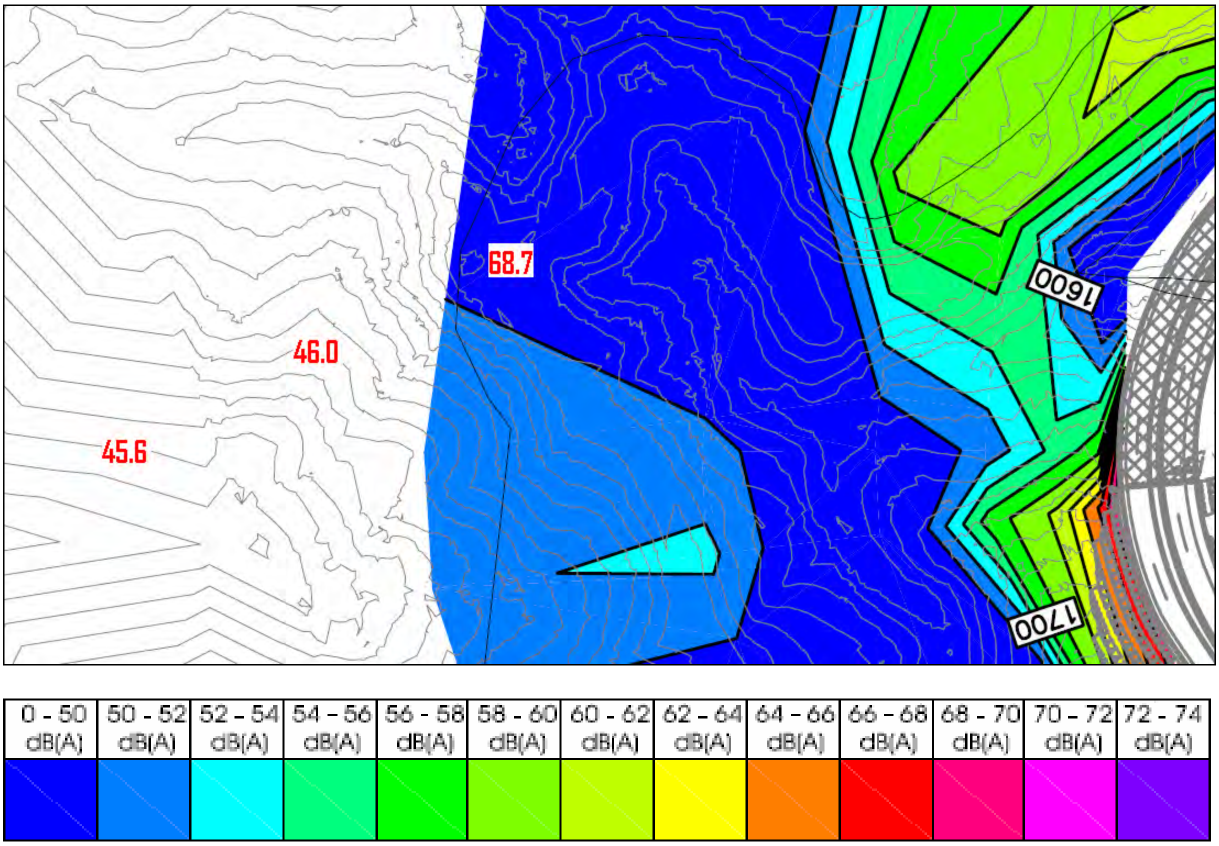


Figure A2.2.1: Avondale Creek transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

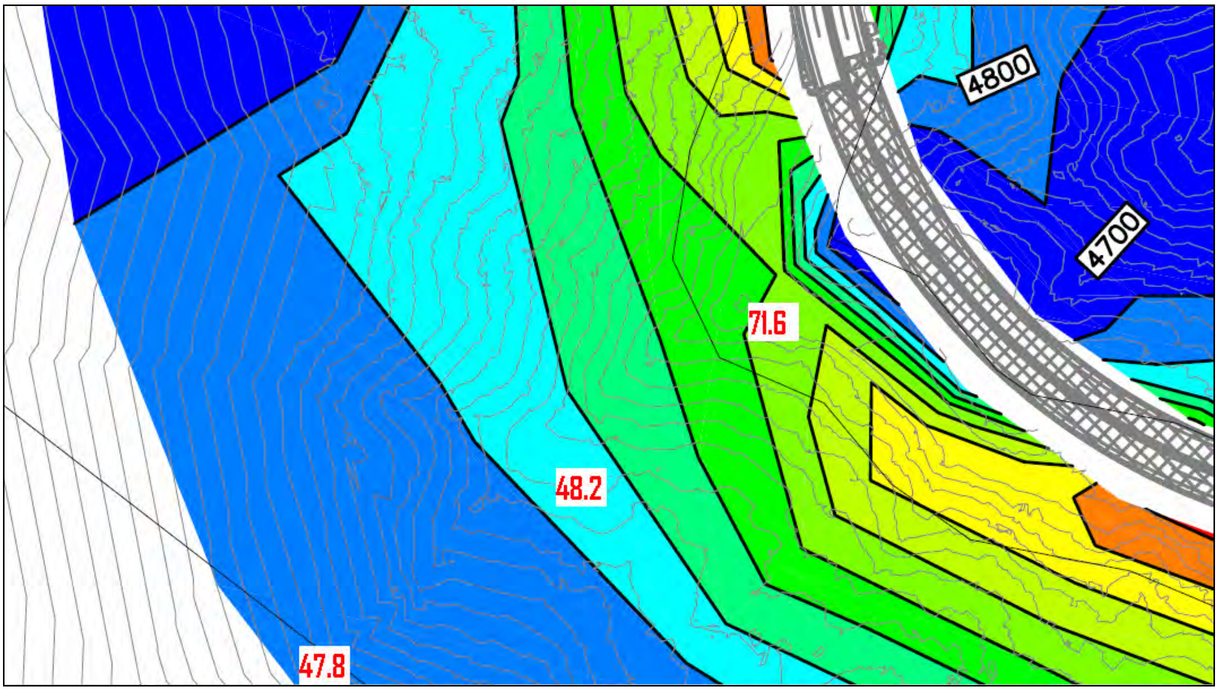


Figure A2.2.2: Water Point transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

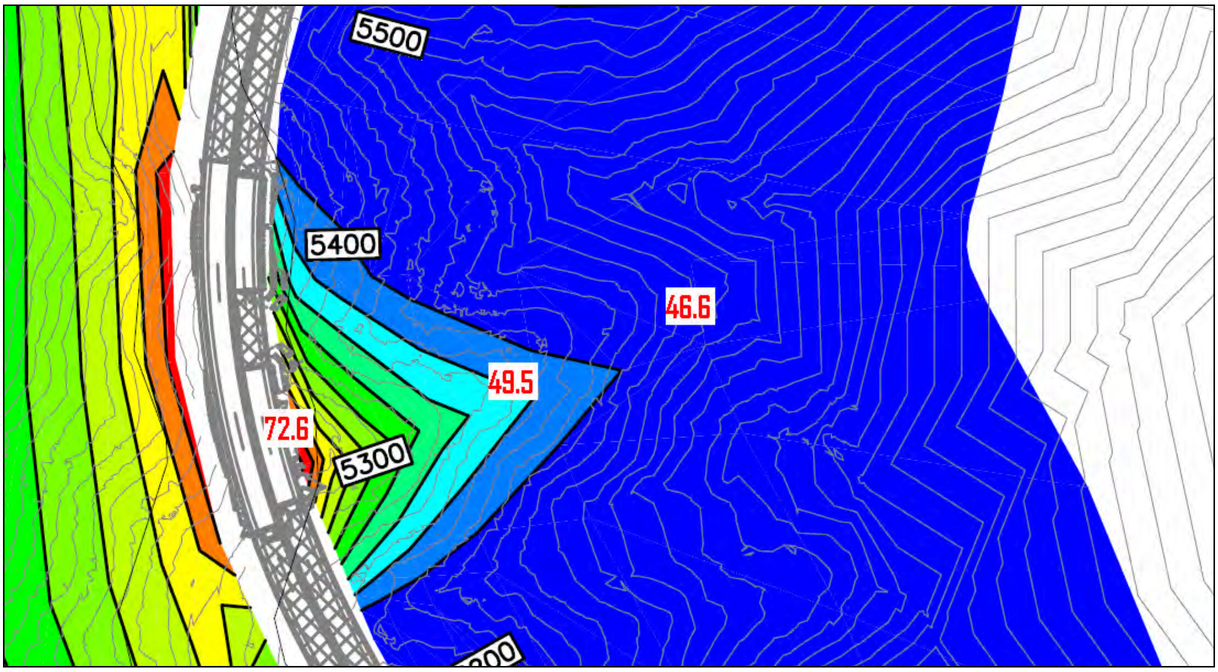


Figure A2.2.3: Down Ridge transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

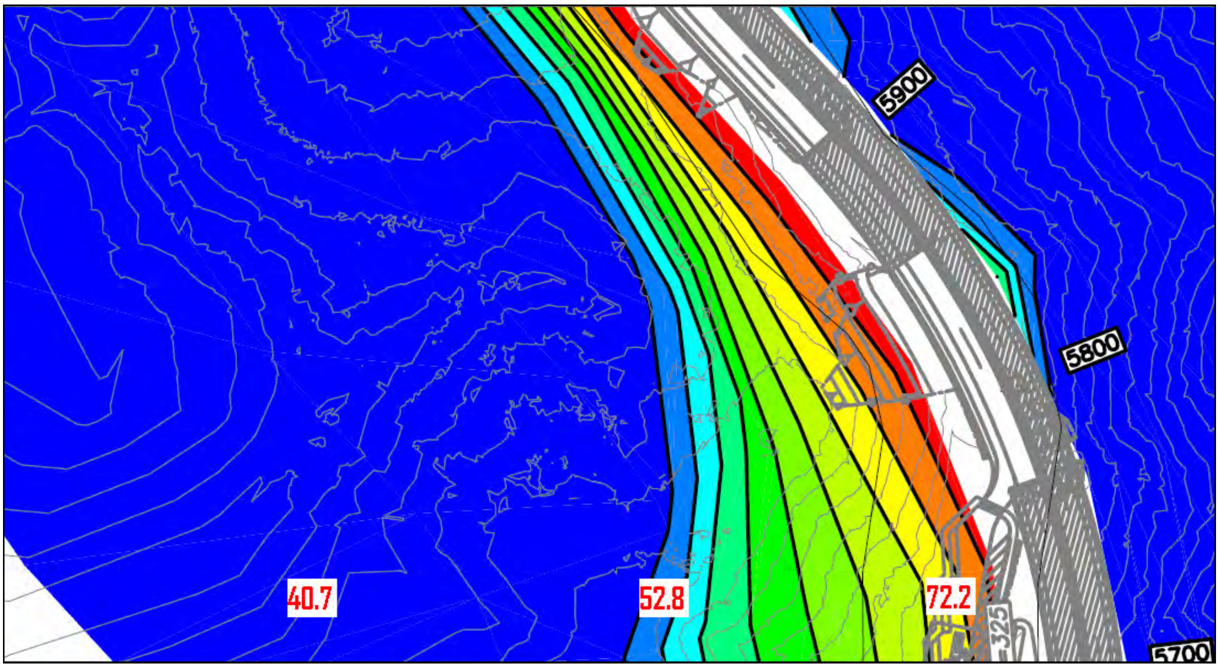


Figure A2.2.4: Lookout transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

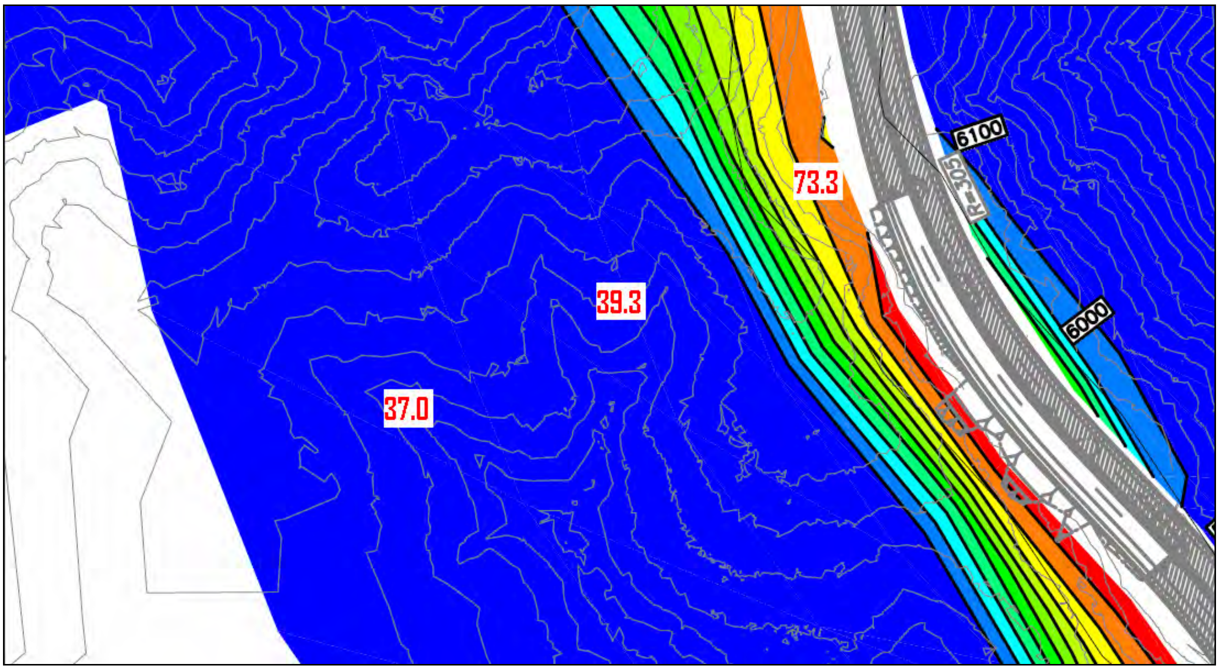


Figure A2.2.5: Lookout Sign transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

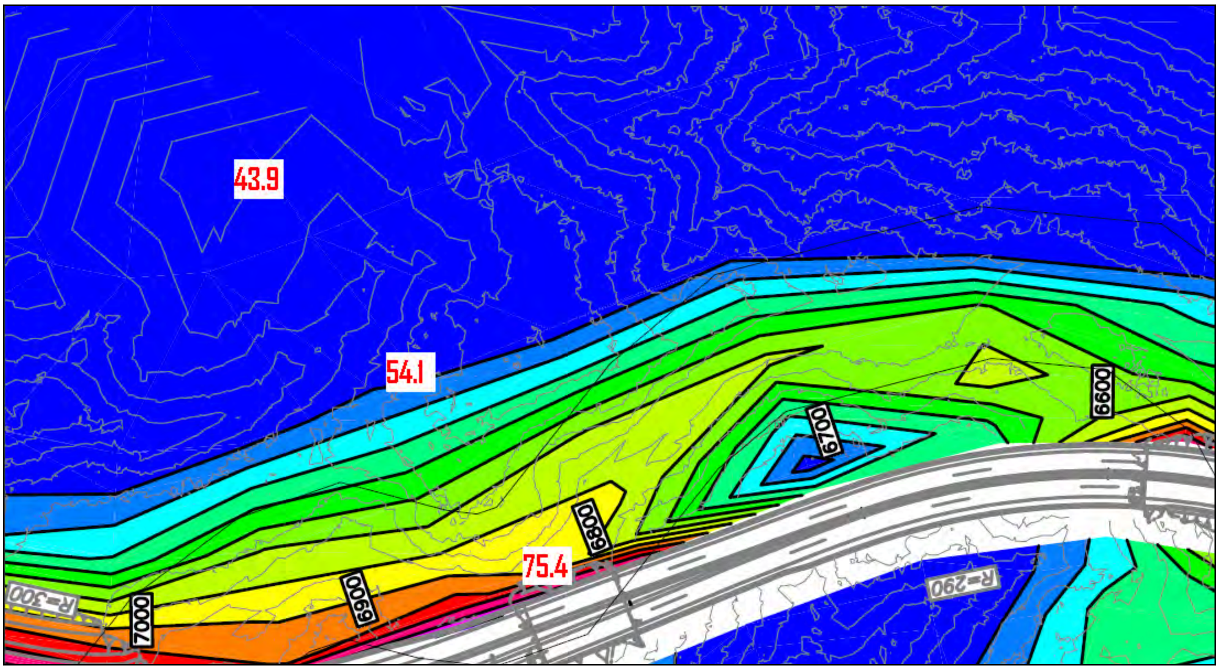


Figure A2.2.6: Mareeba Sign transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

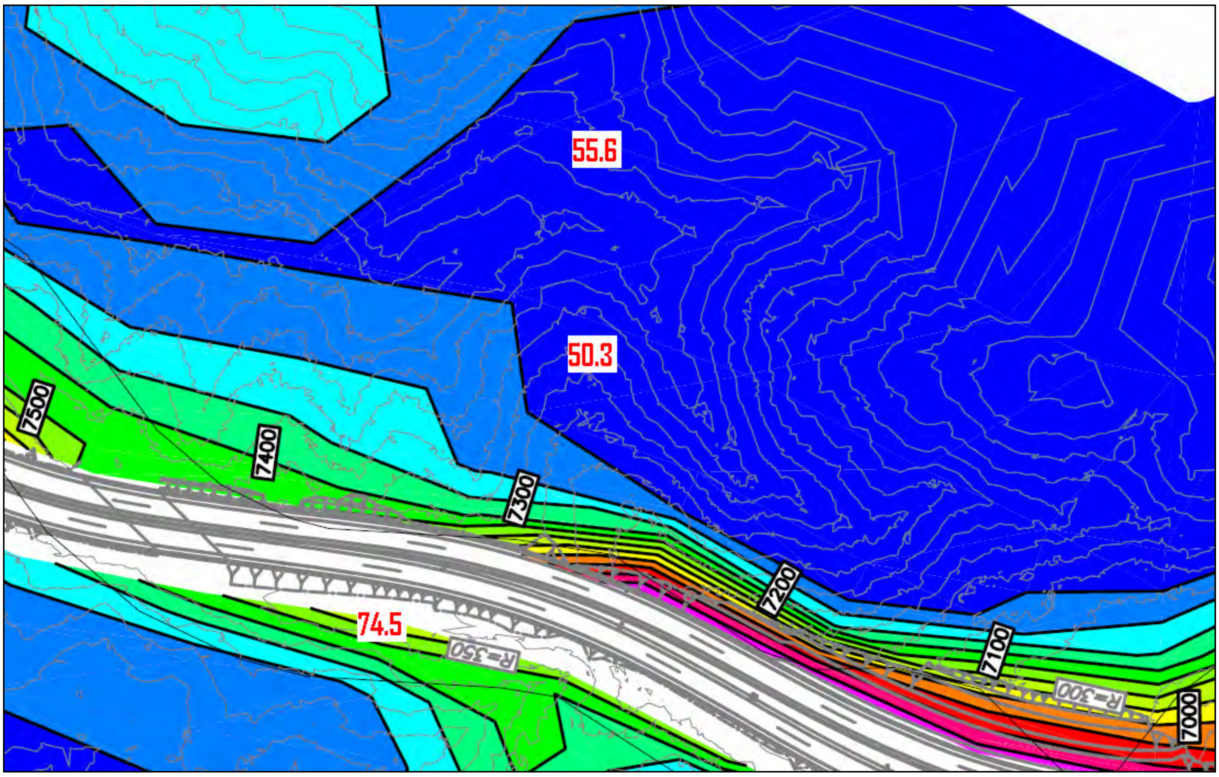


Figure A2.2.7: Powerline transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006). Edge recordings undertaken at opposite side of existing road from transect start to eliminate risk posed by high voltage hazard during canopy recordings.

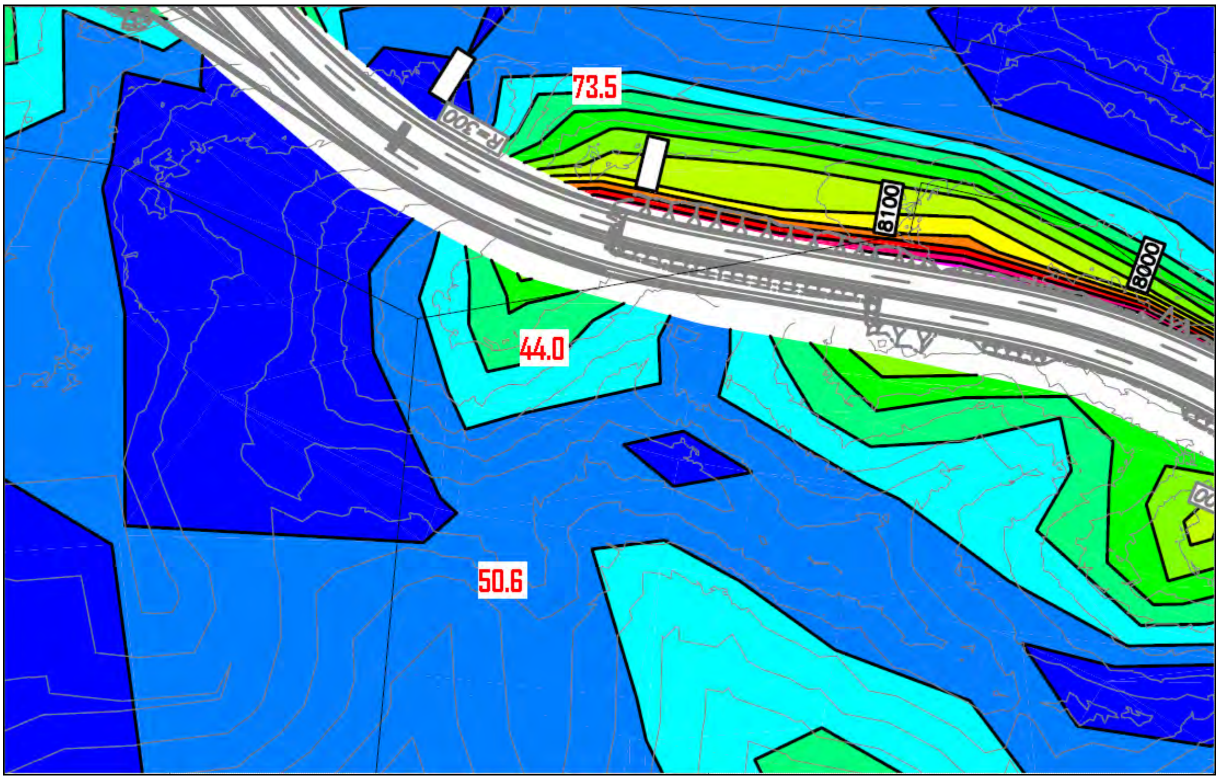


Figure A2.2.8: Streets Creek transect L_{10} current and predicted noise levels at one metre above the forest floor (modified from ASK Consulting Engineers 2867FIGA, C6, 2006).

Appendix 2.3 – Existing refugia locations

Potential locations of existing acoustic refugi and predicted 'Ultimate' ground L_{10} noise levels along the upgraded Kuranda Range Road (refugia boundary indicated by dotted green line).

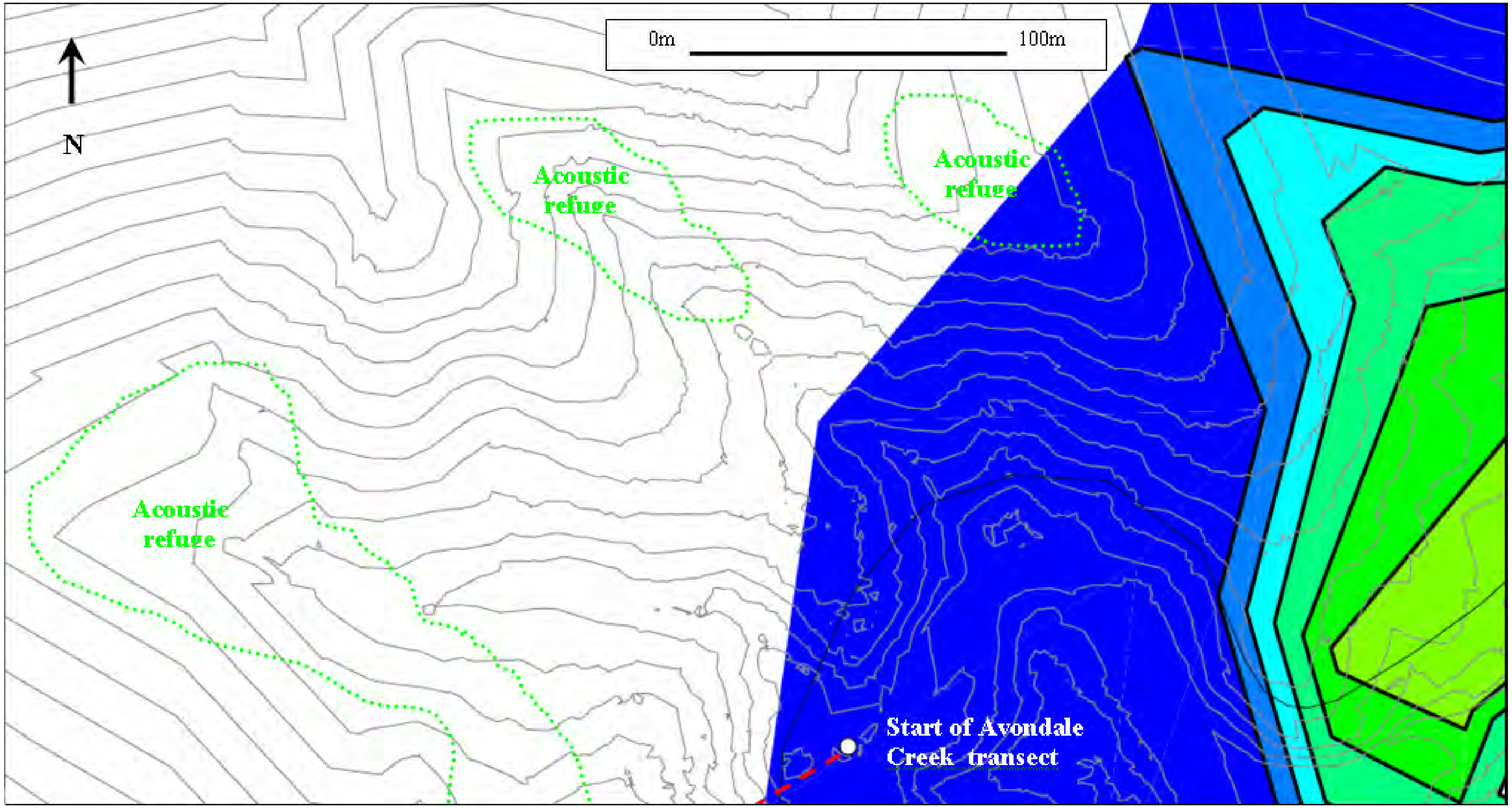


Figure A2.3.1: Acoustic refugia north of Avondale Creek transect (modified from ASK Consulting Engineers 2867FIGA, C11, 2004).

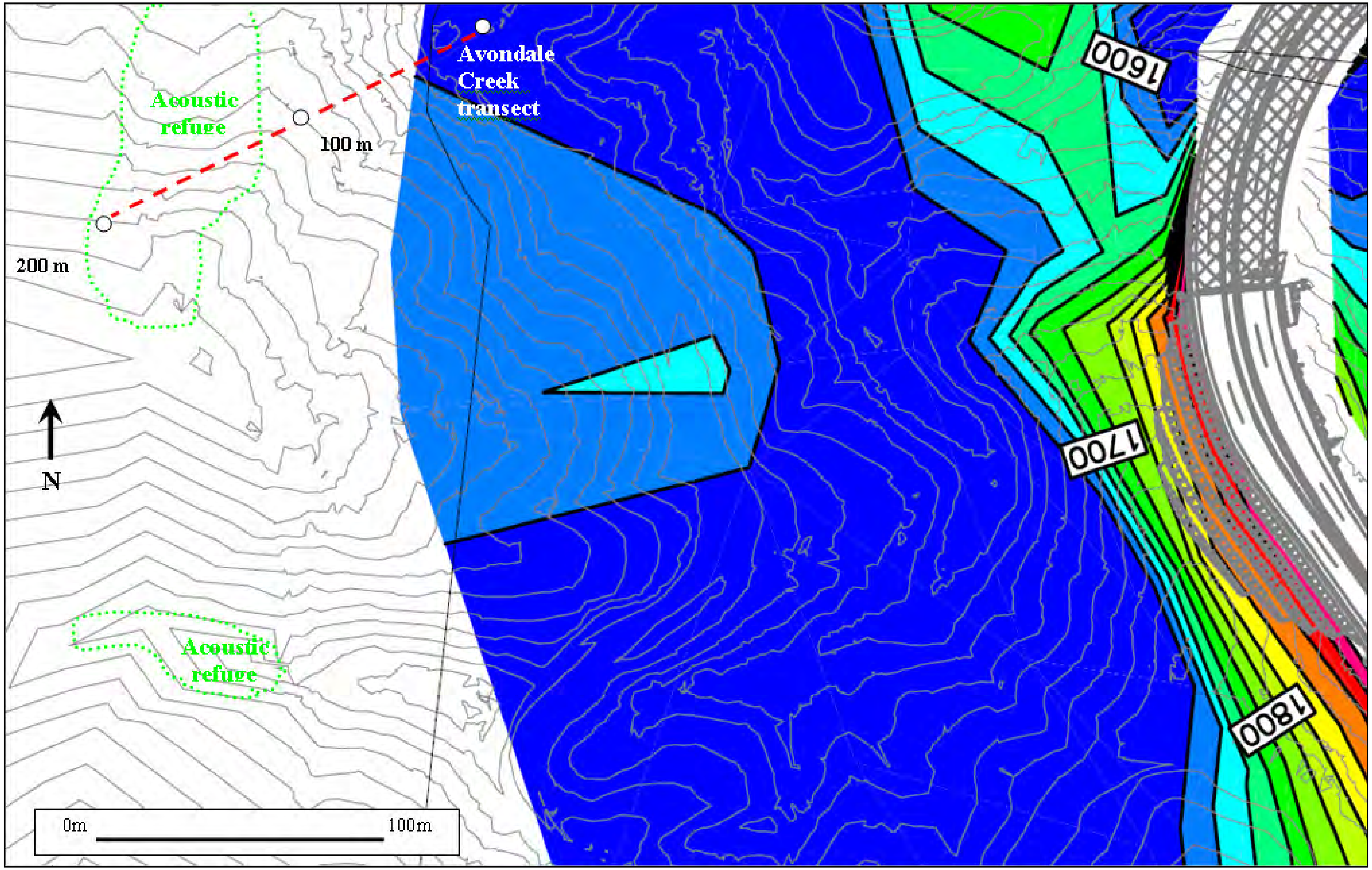


Figure A2.3.2: Acoustic refugia proximate to Avondale Creek transect (modified from ASK Consulting Engineers 2867FIGA, C11, 2004).

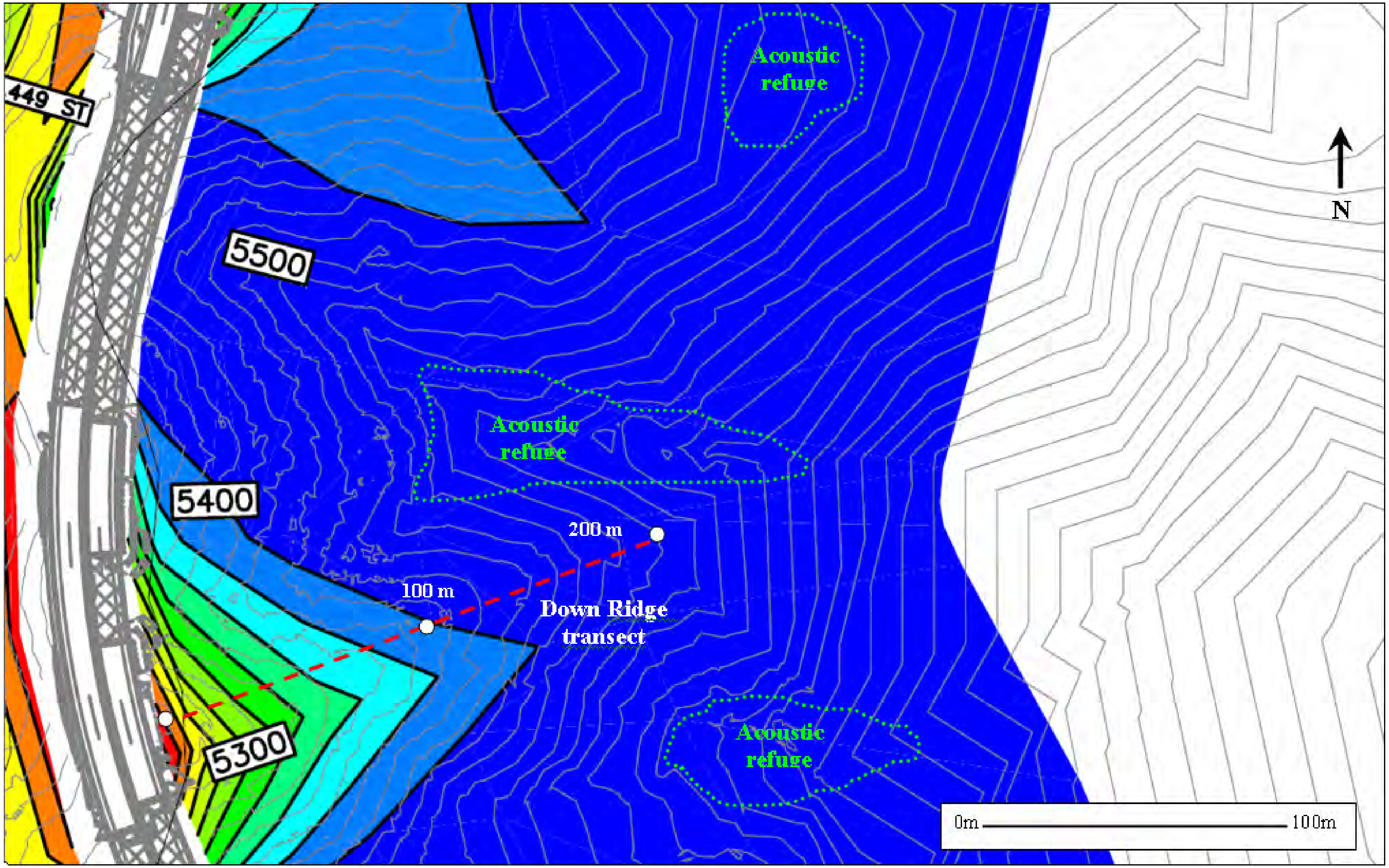


Figure A2.3.3: Acoustic refugia proximate to Down Ridge transect (modified from ASK Consulting Engineers 2867FIGA, C8, 2004).

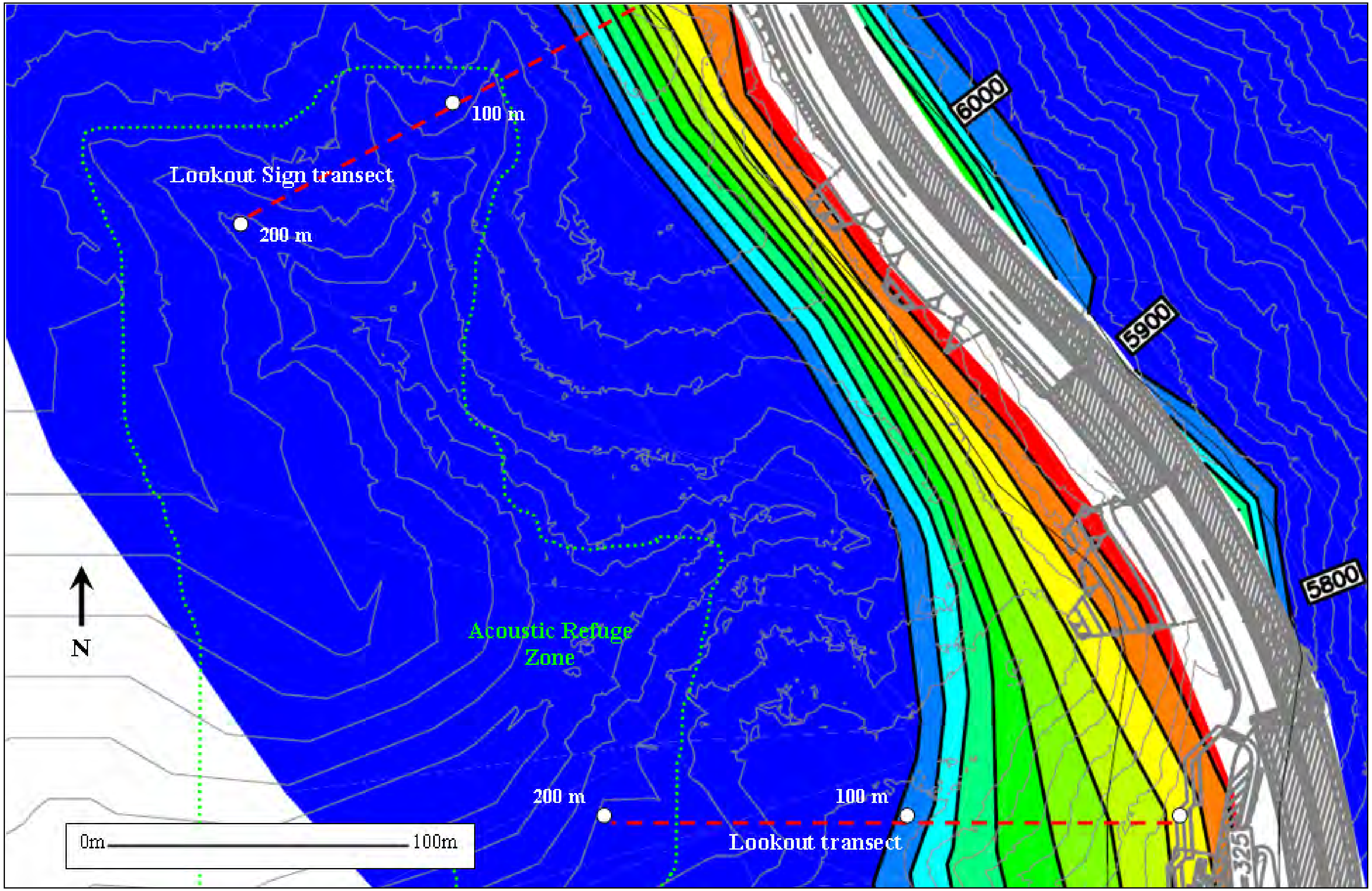


Figure A2.3.4: Acoustic refugia between Lookout and Lookout Sign transects (modified from ASK Consulting Engineers 2867FIGA, C7, 2004).

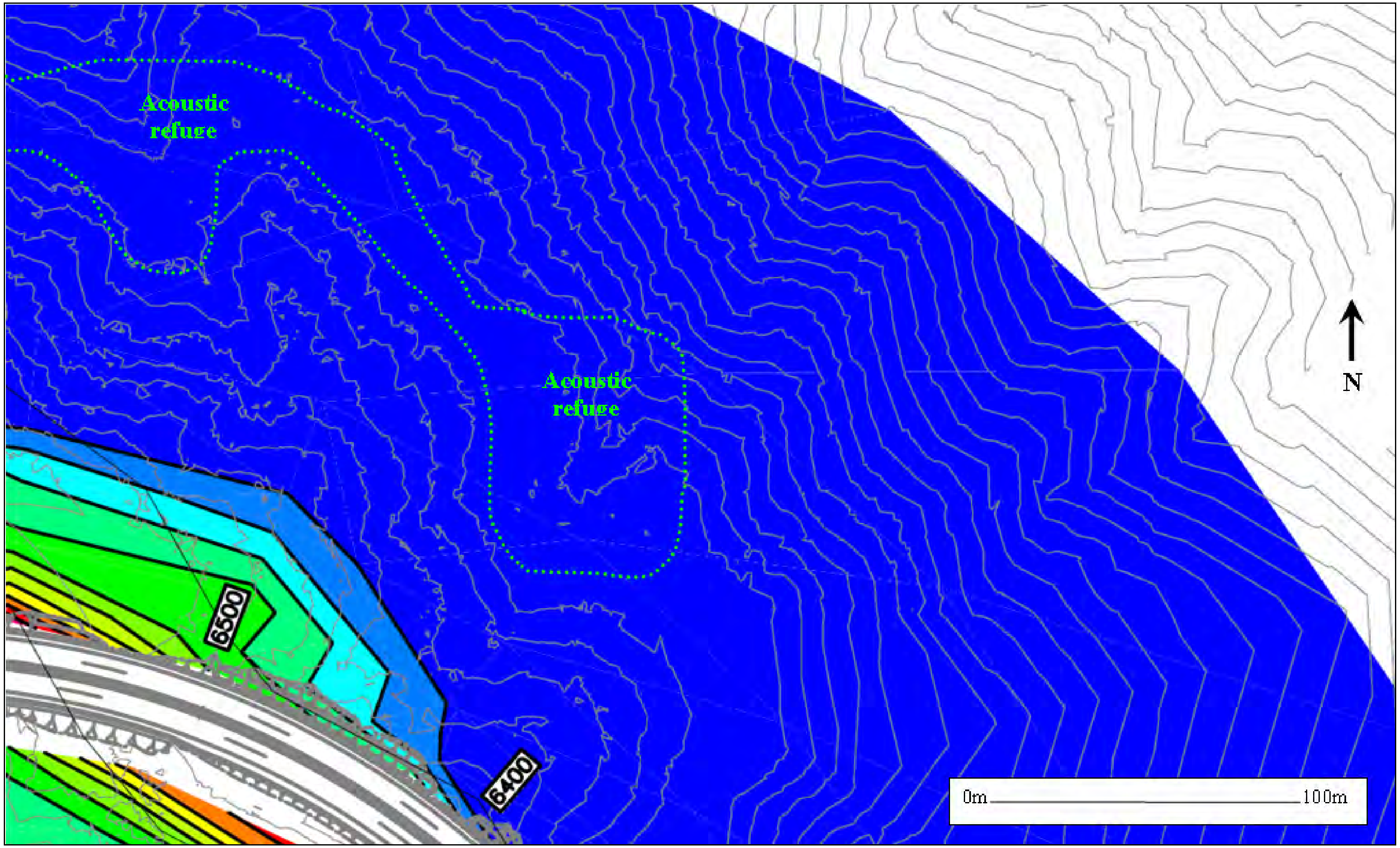


Figure A2.3.5: Acoustic refugia adjacent to Kuranda Range Road, north-south Ridge crossing (modified from ASK Consulting Engineers 2867FIGA, C6, 2004).

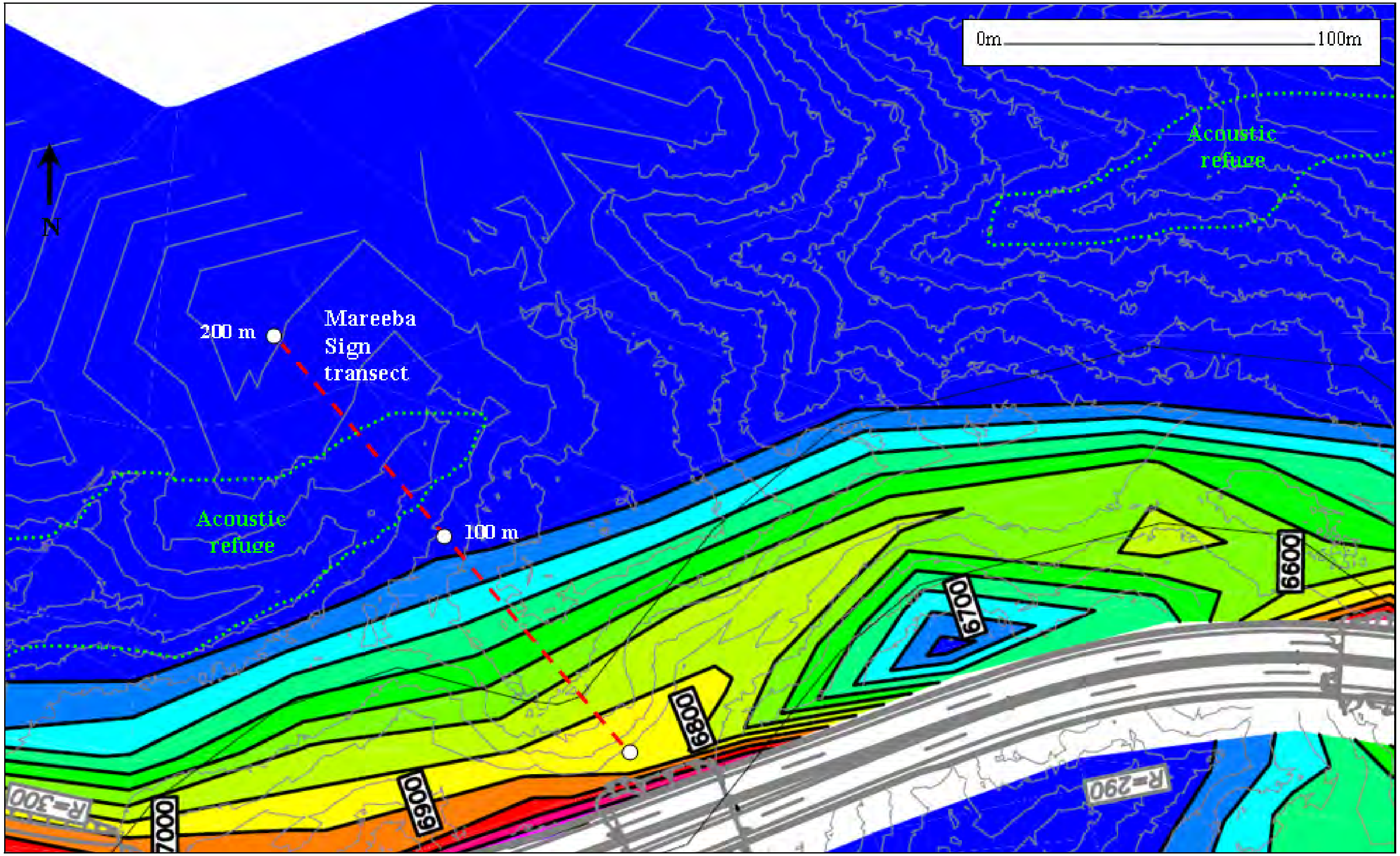


Figure A2.3.6: Acoustic refugia adjacent to Kuranda Range Road, north-south ridge, Macalister Range, (modified from ASK Consulting Engineers 2867FIGA, C6, 2004).

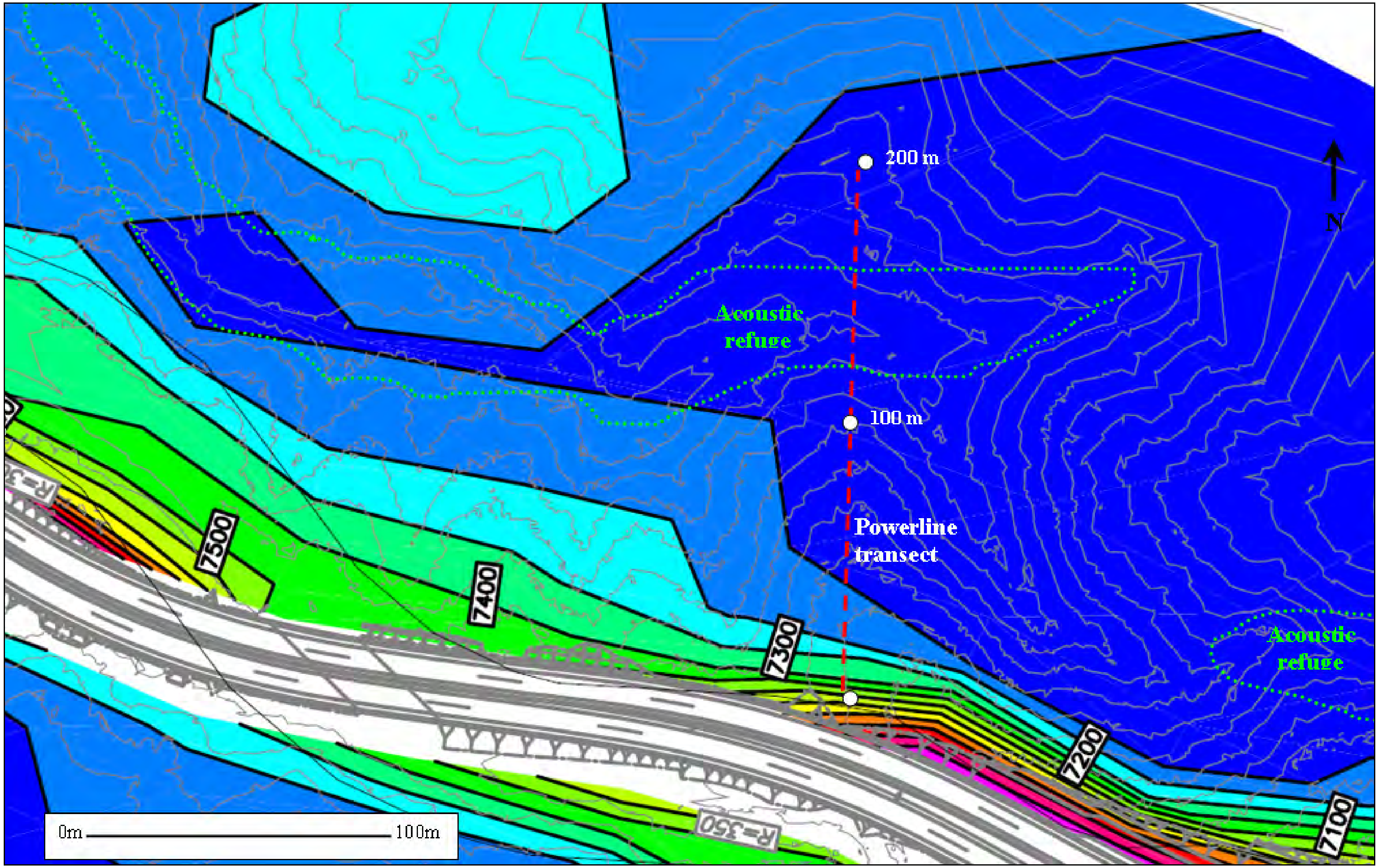


Figure A2.3.7: Acoustic refugia adjacent to Powerline transect, Kuranda Range Road (modified from ASK Consulting Engineers 2867FIGA, C5, 2004).

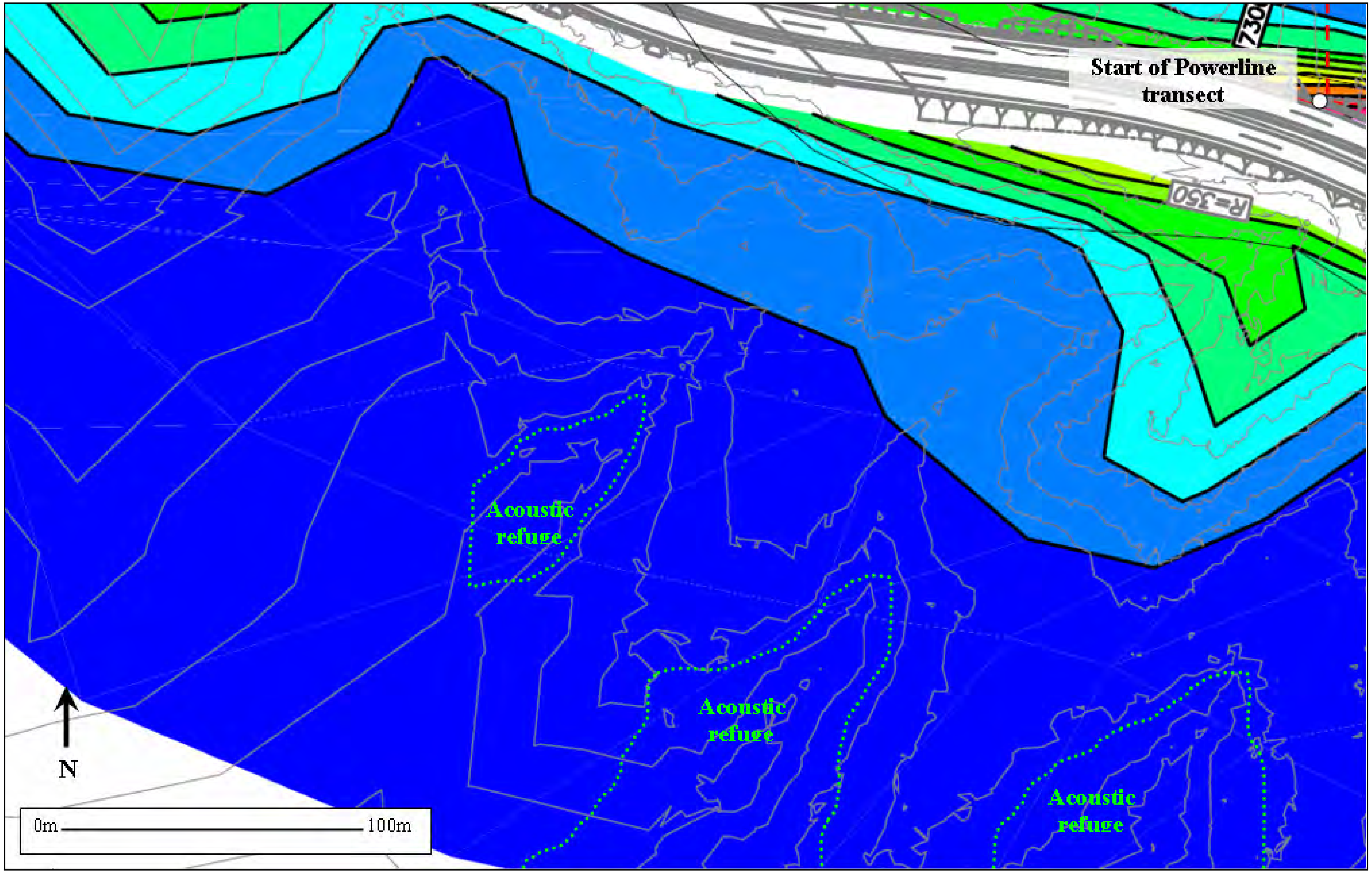


Figure A2.3.8: Acoustic refugia opposite Powerline transect, Kuranda Range Road (modified from ASK Consulting Engineers 2867FIGA, C5, 2004).

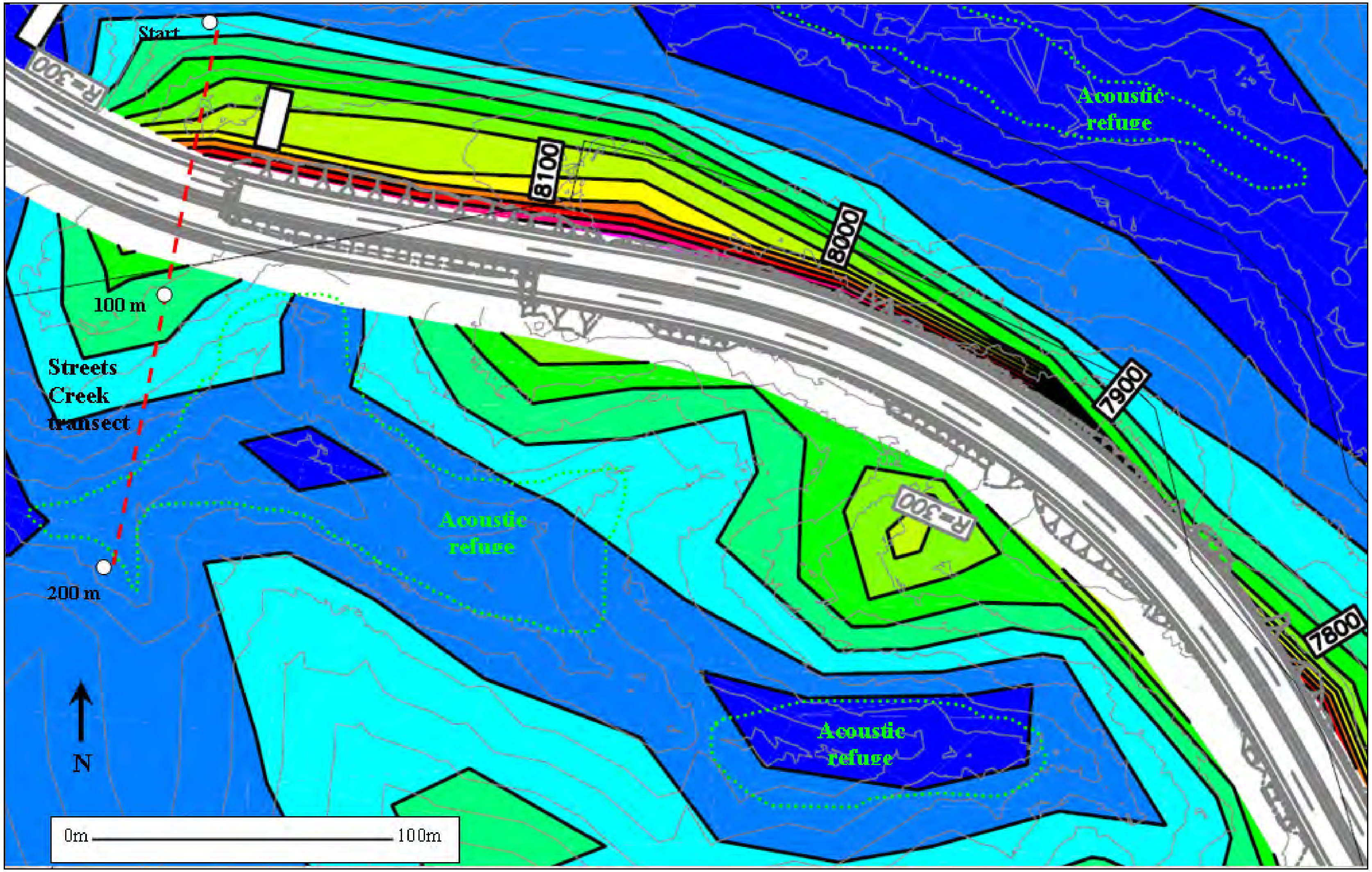


Figure A2.3.9: Acoustic refugia, Streets Creek area, Kuranda Range Road (modified from ASK Consulting Engineers 2867FIGA, C5, 2004).

Appendix 2.4 – Transect/highway edge photographs

Figure A2.4.1: Avondale Creek (AC) transect (starts behind Armco barrier near right traffic arrow). Photograph: Gregory Dawe, 2005.

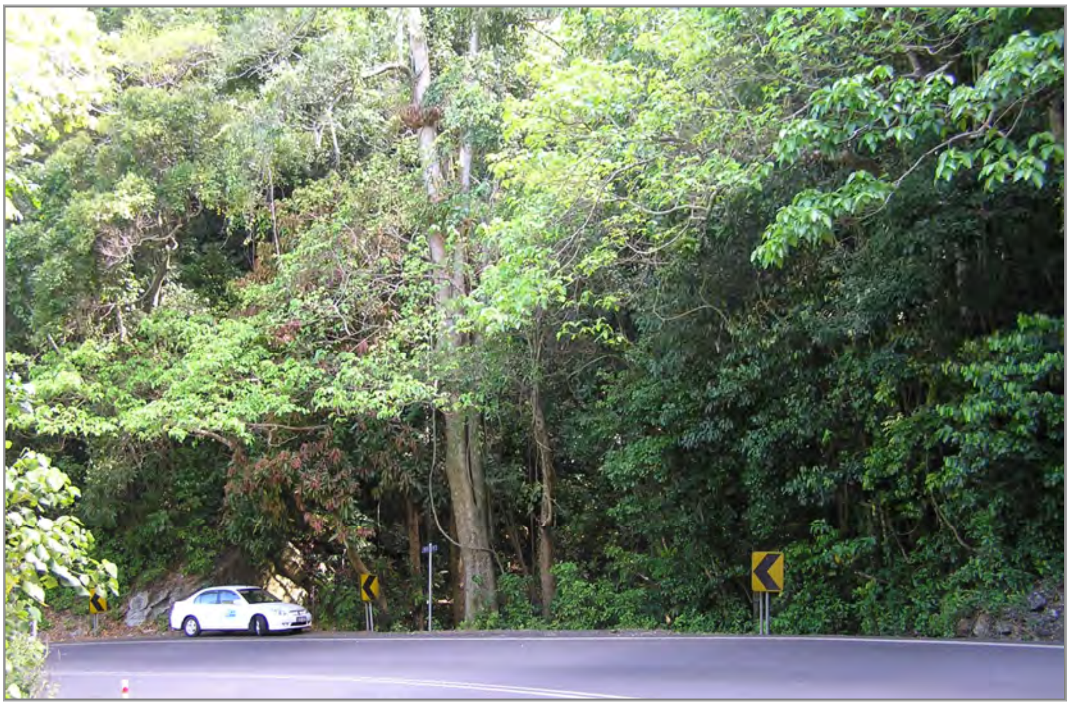


Figure A2.4.2: Water Point (WP) transect (starts behind vehicle). Photograph: Gregory Dawe, 2005.

Figure A2.4.3: Down Ridge (DR) transect (starts behind 50 km/h sign). Photograph: Gregory Dawe, 2005.

Figure A2.4.4: Lookout (LO) transect (starts behind 'Form One Lane' sign at the rear right of this photograph). Photograph: Gregory Dawe, 2005.

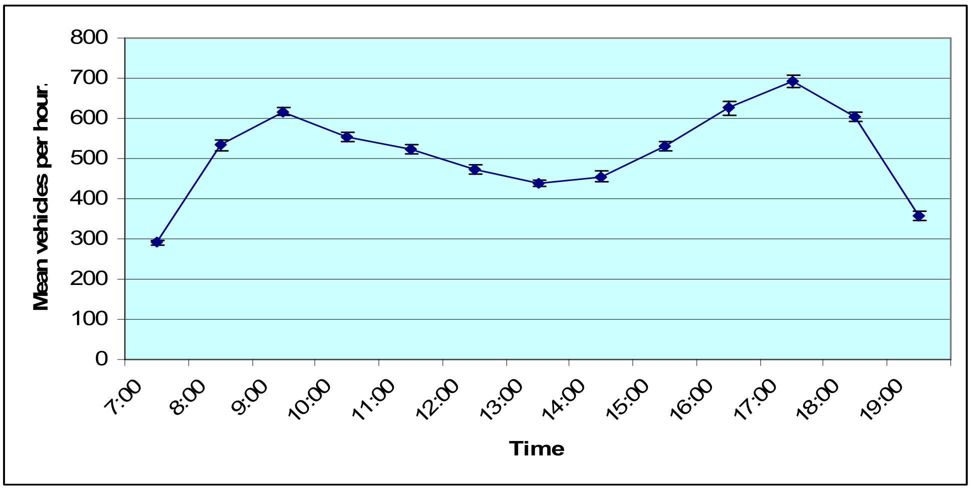
Figure A2.4.5: Lookout Sign (LS) transect (transect ascent starts behind guidepost at centre rear of this photograph). Photograph: Gregory Dawe, 2005.

Figure A2.4.6: Mareeba Sign (MS) transect (starts behind guidepost at centre of photograph). Photograph: Gregory Dawe, 2005.

Figure A2.4.7: Powerline (PL) transect (starts to the left of 'Slippery When Wet' sign). **Note:** powerline above starting point. Photograph: Gregory Dawe, 2005.

Figure A2.4: Streets Creek (SC) transect (starts behind caution sign past bridge). Photograph: Gregory Dawe, 2005.

Appendix 2.5 – Diurnal noise levels / vehicle flow patterns



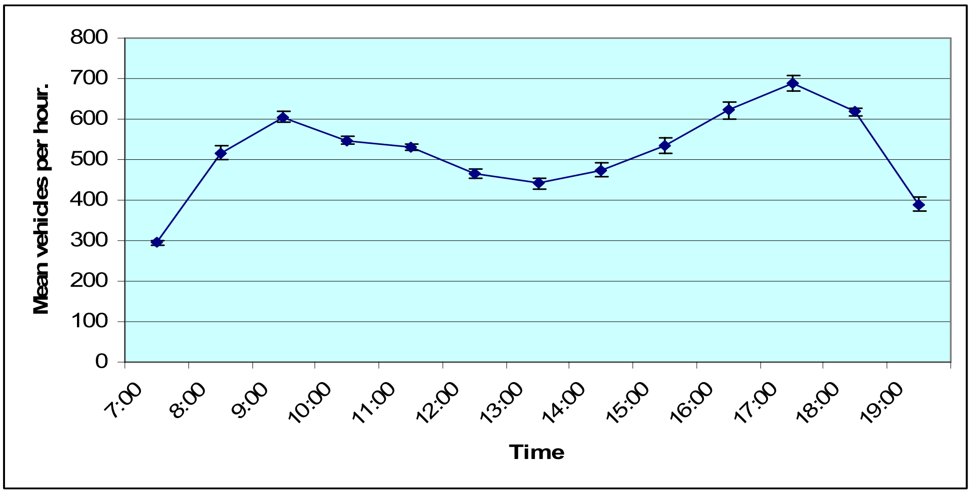
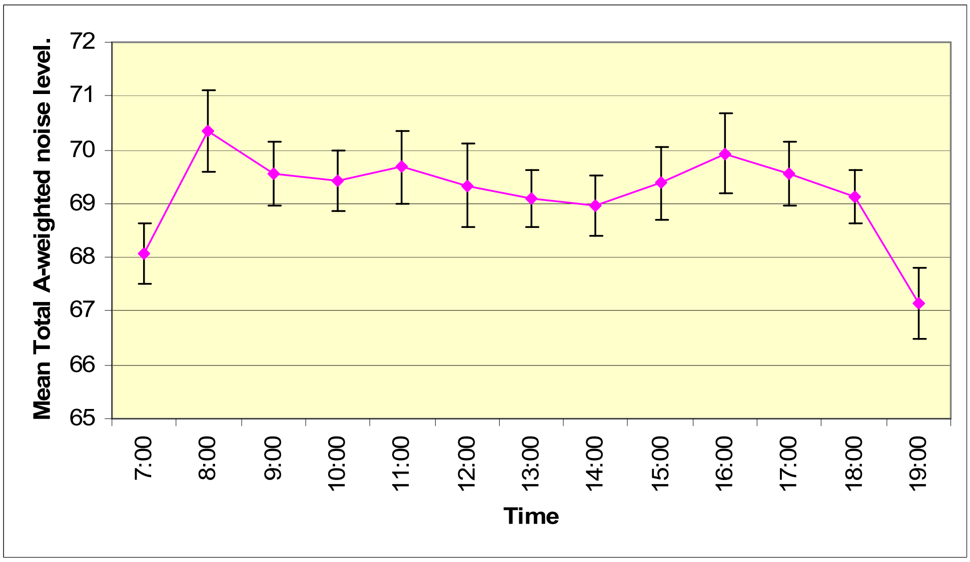


Figure A.2.5.1: Mean hourly traffic flows ± 1 SE corresponding to noise sampling for ground level (*top*) and lower canopy level (*bottom*).



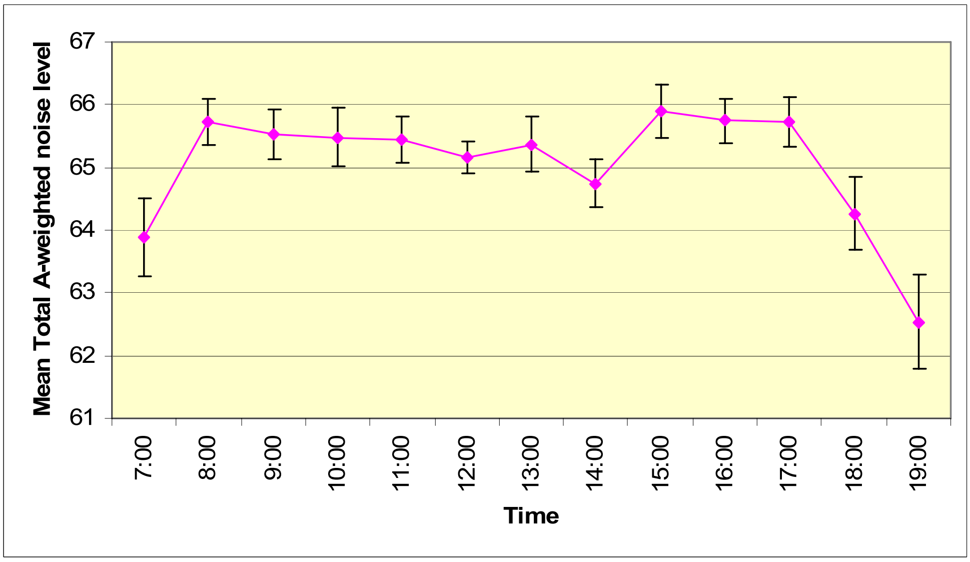


Figure A.2.5.2: Mean hourly total A-weighted edge noise levels ± 1 SE for all transects at ground level (*top*) and in lower canopy (*bottom*).

Noise Disturbance along Highways

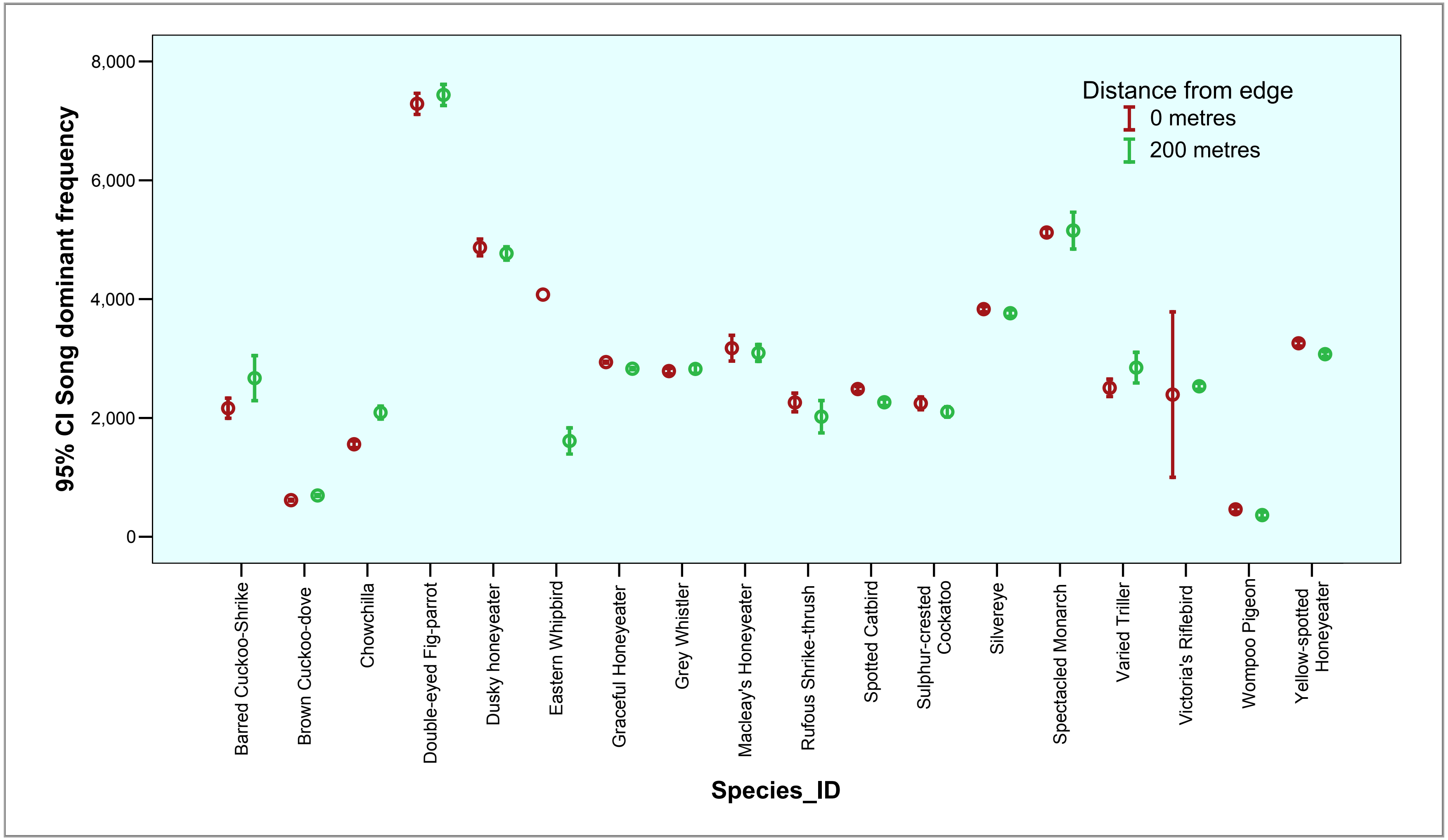
Appendix: Section 3
Effect of traffic noise on avian vocalisation

Appendix 3.1 – Avian species inhabiting the Kuranda Range as recorded for current study

CODE	Common name	Suitability for analysis	Reference			
			Call note	Alarm call	Song_1	Song_2
AZKF	Azure Kingfisher	1				
BCSH	Barred Cuckoo-shrike	3	2661		1706	2035
BFMO	Black-faced Monarch	2	3396		2173	
BGNE	Brown Gerygone	1			5567	
BLBB	Black Butcherbird	2	858		1517	1741
BOST	Bower's Shrike-thrush	2	2501		2470	1477
BRCU	Brown Cuckoo-dove	3			736	
CHOW	Chowchilla	3	890		1301	
CICB	Cicadabird	2	2887	2280	2632	2545
DEFP	Double-eyed Fig-parrot	1	6810		6579	7373
DUHE	Dusky Honeyeater	2	2973	2538/5135	2908	5914
EAWB	Eastern Whipbird	3	1477	2370/3340	3634	2345
EDOV	Emerald Dove	1			474	472
FIGB	Figbird	2	2969	2020	3013	
FGNE	Fairy Gerygone	2			5435	
FWRN	Fernwren	1	**2543**		**3565**	
GBCU	Gould's Bronze Cuckoo	3			2564	2852
GHRO	Grey-headed Robin	1			2275	
GOWH	Golden Whistler	1	2759		1908	1520/2387
GRFA	Grey Fantail	1			5367	
GRHE	Graceful Honeyeater	5	3003	2034/4168	2708	2968
GRWH	Grey Whistler	3			2679	
HFRB	Helmeted Friarbird	2	1426	1433	1648	
KPRT	King Parrot	2	2828			
LBBB	Lemon-breasted Boatbill	4	4182		3473	
LBCU	Little Bronze Cuckoo	1	3082		2812	
LBGE	Large-billed Gerygone	2	3054		3483	3066
LBSW	Large-billed Scrubwren	2	4903	4755	4078	**5049**
LFLY	Leaden Flycatcher	1	4227			
LICS	Little Cuckoo-shrike	1				
MCHE	Macleay's Honeyeater	4	2952		3067	3307
MTBD	Mistletoebird	4	6830			
MEST	Metallic Starling	2	2807/8152		4386	
NPTA	Noisy Pitta	2	1967		1974	
OFSF	Orange-footed Scrub-fowl	3	912		1287	1292
PIMO	Pied Monarch	2	2535	3921	3085	2596/2873

CODE	**Common name**	**Suitability for analysis**	**Reference**			
			Call note	**Alarm call**	**Song_1**	**Song_2**
PYRO	Pale-yellow Robin	2	**4939**		**6424**	
RALO	Rainbow Lorikeet	1				
RBEE	Rainbow Beeeater	2				
ROWL	Rufous Owl	1			305	210
RUFA	Rufous Fantail	2	6696			
RUST	Rufous (Little) Shrike-thrush	4	3079		1364/2729	2456
SCAS	Southern Cassowary	1	114.5	97		
SCAT	Spotted Catbird	4	2579		1937	
SCCT	Sulphur-creasted Cockatoo	1	2148			
SCHE	Scarlet Honeyeater	1				
SEYE	Silvereye	4			3552	3250
SFDV	Superb Fruit-dove	3	356		345	470
SPAR	Striated Pardalote	1				
SPDR	Spangled Drongo	3				
SPMO	Spectacled Monarch	5	5789		**3199**	
SQTK	Square-tailed Kite	1				
SUNB	Sunbird	3	4823	3525	3834	
TOPP	Topknot Pigeon	1				
TRSW	Tropical Scrubwren	1	3846		4579	
VATR	Varied Triller	3			2622	3076
VRBD	Victoria's Riflebird	3			2491	
WBWS	White-breasted Woodswallow	1				
WEMO	White-eared Monarch	1	2629		3552	
WOMP	Wompoo Pigeon	5	578		282	504
WRSW	White-rumped Swiftlet	1				
YOLE	Yellow Oriole	4	1555	1337	1222	
YSHE	Yellow-spotted Honeyeater	5	2735/5415	4665	3294	2945
YTSW	Yellow-throated Scrubwren	3			4522	
LFWR	Lovely fairy-wren	1			8200	

Appendix 3.2 – Dominant frequency of song for 18 Kuranda Range bird species



Noise Disturbance along Highways

Appendix: Section 4
Effect of traffic noise on avian populations and biodiversity

Appendix 4.1 – List of avian species recorded in 2005 Kuranda range survey

Table A4.1: Avian species of the Kuranda Range (including conservation status, and habitat / feeding / strata guilds). Species shaded green are of conservation interest according to five status classifications described by Williams (2006). Status code indicates species is listed as Rare (R), Vulnerable (V) or Endangered (E) under either the *Nature Conservation Act (Qld)* 2001, The World Conservation Union Red List of Threatened Species 2001, or the *Environment Protection and Biodiversity Conservation Act* 1999; or is endemic to the Wet Tropics or is a regionally endemic subspecies (ES). Habitat, feeding and strata guild classification are from Williams (2006), Lawson (2004) and Moloney (2005).

CODE	**Common name**	**Scientific name**	**Status**	**Habitat**	**Feeding**	**Strata**
KPRT	Australian King Parrot	*Alisterus scapularis*	ES	Rainforest its main habitat. Common in other habitats	Omnivores	Exclusive canopy and emergents
AZKF	Azure Kingfisher	*Alcedo azurea*		Rainforest its main habitat. Common in other habitats	Carnivores	0-2 metres above ground
BCSH	Barred Cuckoo-shrike	*Coracina lineata*		Rainforest its main habitat. Common in other habitats	Omnivores	Exclusive canopy and emergents
BLBB	Black Butcherbird	*Cracticus quoyi*		Rainforest its main habitat. Common in other habitats	Omnivores	<2 metres up to and including canopy
BFMO	Black-faced Monarch	*Monarcha melanopsis*		Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	<2 metres up to and including canopy
BOST	Bower's Shrike-thrush	*Colluricincla boweri*	Endemic	Rainforest obligate	Insectivores	<2 metres up to and including canopy
BRCU	Brown Cuckoo-dove	*Macropygia amboinensis*		Rainforest its core habitat. Occurs in wet sclerophyll	Frugivores	Exclusive canopy and emergents
BGNE	Brown Gerygone	*Gerygone mouki*	ES	Rainforest obligate	Insectivores	<2 metres up to and including canopy
CHOW	Chowchilla	*Orthonyx spaldingii*	Endemic	Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	0-2 metres above ground
CICB	Cicadabird	*Coracina tenuirostris*		Uses rainforest as a suboptimal / marginal habitat	Omnivores	Exclusive canopy and emergents
DEFP	Double-eyed Fig-parrot	*Cyclopsitta diophthalma*	**V**	Rainforest its core habitat. Occurs in wet sclerophyll	Frugivores	<2 metres up to and including canopy
DUHE	Dusky Honeyeater	*Myzomela obscura*		Commonly found in rainforest.	Omnivores	<2 metres up to and including

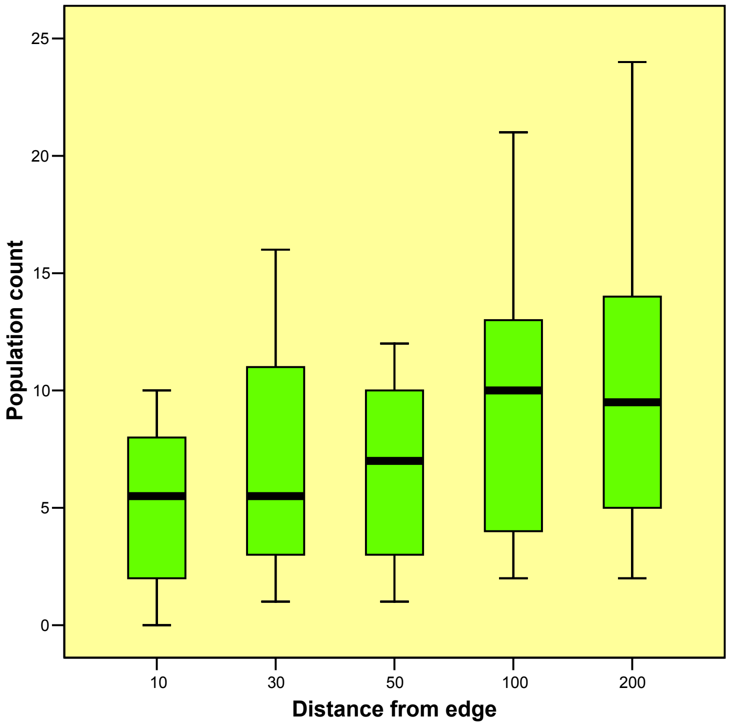
CODE	Common name	Scientific name	Status	Habitat	Feeding	Strata
				Rainforest not its core habitat		canopy
EAWB	Eastern Whipbird	*Psophodes olivaceus*	ES	Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	0-2 metres above ground
EDOV	Emerald Dove	*Chalcophaps indica*		Rainforest its core habitat. Occurs in wet sclerophyll	Frugivores	0-2 metres above ground
FGNE	Fairy Gerygone	*Gerygone palpebrosa*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	<2 metres up to and including canopy
FWRN	Fernwren	*Oreoscopus gutturalis*	Endemic	Rainforest obligate	Insectivores	0-2 metres above ground
FIGB	Figbird	*Sphecotheres viridis*		Commonly found in rainforest. Rainforest not its core habitat	Frugivores	<2 metres up to and including canopy
GBCU	Gould's Bronze-Cuckoo	*Chrysococcyx russatus*		Rainforest its main habitat. Common in other habitats	Insectivores	<2 metres up to and including canopy
GHRO	Grey-headed Robin	*Heteromyias albispecularis*	ES	Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	0-2 metres above ground
GOWH	Golden Whistler	*Pachycephala pectoralis*		Rainforest its main habitat. Common in other habitats	Insectivores	<2 metres up to and including canopy
GRFA	Grey Fantail	*Rhipidura fuliginosa*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	<2 metres up to and including canopy
GRHE	Graceful Honeyeater	*Meliphaga gracilis*		Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	<2 metres up to and including canopy
GRWH	Grey Whistler	*Pachycephala simplex*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	<2 metres up to and including canopy
HFRB	Helmeted Friarbird	*Philemon buceroides*		Commonly found in rainforest. Rainforest not its core habitat	Nectarivores	Exclusive canopy and emergents
LBBB	Lemon-breasted Boatbill	*Machaerirhynchus flaviventer*		Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	<2 metres up to and including canopy
LBGE	Large-billed Gerygone	*Gerygone magnirostris*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	<2 metres up to and including canopy
LBSW	Large-billed Scrubwren	*Sericornis magnirostris*		Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	<2 metres up to and including canopy

CODE	**Common name**	**Scientific name**	**Status**	**Habitat**	**Feeding**	**Strata**
LFLY	Leaden Flycatcher	*Myiagra rebucela*		Not found in rainforest	Insectivores	<2 metres up to and including canopy
LBCU	Little Bronze-Cuckoo	*Chrysococcyx minutillus*		Rainforest its main habitat. Common in other habitats	Insectivores	<2 metres up to and including canopy
LICS	Little Cuckoo-shrike	*Coracina papuensis*		Occasionally recorded in rainforest	Omnivores	<2 metres up to and including canopy
LFWR	Lovely Fairy-wren	*Malurus amabilis*		Uses rainforest as a suboptimal / marginal habitat	Insectivores	0-2 metres above ground
MCHE	Macleay's Honeyeater	*Xanthotis macleayana*	Endemic	Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	<2 metres up to and including canopy
MEST	Metallic Starling	*Aplonis metallica*		Rainforest its main habitat. Common in other habitats	Frugivores	<2 metres up to and including canopy
MTBD	Mistletoebird	*Dicaeum hirundinaceum*		Commonly found in rainforest. Rainforest not its core habitat	Frugivores	<2 metres up to and including canopy
NPTA	Noisy Pitta	*Pitta versicolor*		Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	0-2 metres above ground
OFSF	Orange-footed Scrub-fowl	*Megapodius reinwardt*		Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	0-2 metres above ground
PIMO	Pied Monarch	*Arses kaupi*	Endemic	Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	<2 metres up to and including canopy
PYRO	Pale-yellow Robin	*Tregellasia capito*	ES	Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	0-2 metres above ground
RALO	Rainbow Lorikeet	*Trichoglossus haematodus*		Rainforest its main habitat. Common in other habitats	Nectarivores	Exclusive canopy and emergents
RBEE	Rainbow Bee-eater	*Merops ornatus*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	<2 metres up to and including canopy
ROWL	Rufous Owl	*Ninox rufa*	**V**	Commonly found in rainforest. Rainforest not its core habitat	Carnivores	Exclusive canopy and emergents
RUFA	Rufous Fantail	*Rhipidura rufifrons*		Rainforest its main habitat. Common in other habitats	Insectivores	<2 metres up to and including canopy

CODE	Common name	Scientific name	Status	Habitat	Feeding	Strata
RUST	Rufous Shrike-thrush	*Colluricincla megarhyncha*		Rainforest its main habitat. Common in other habitats	Insectivores	<2 metres up to and including canopy
SCAS	Southern Cassowary	*Casuarius casuarius*	**E**	Rainforest obligate	Frugivores	0-2 metres above ground
SCAT	Spotted Catbird	*Ailuroedus melanotis*	ES	Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	<2 metres up to and including canopy
SCCT	Sulphur-crested Cockatoo	*Cacatua galerita*		Commonly found in rainforest. Rainforest not its core habitat	Omnivores	Exclusive canopy and emergents
SCHE	Scarlet Honeyeater	*Myzomela sanguinolenta*		Uses rainforest as a suboptimal / marginal habitat	Omnivores	Exclusive canopy and emergents
SEYE	Silvereye	*Zosterops lateralis*		Rainforest its main habitat. Common in other habitats	Omnivores	<2 metres up to and including canopy
SFDV	Superb Fruit-Dove	*Ptilinopus superbus*		Rainforest its core habitat. Occurs in wet sclerophyll	Frugivores	<2 metres up to and including canopy
SPAR	Striated Pardalote	*Pardalotus striatus*		Occasionally recorded in rainforest	Insectivores	<2 metres up to and including canopy
SPDR	Spangled Drongo	*Dicrurus bracteatus*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	<2 metres up to and including canopy
SPMO	Spectacled Monarch	*Monarcha trivirgatus*		Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	<2 metres up to and including canopy
SQTK	Square-tailed Kite	*Lophoictinia isura*	**R**	Not found in rainforest	Carnivores	Exclusive canopy and emergents
TOPP	Topknot Pigeon	*Lopholaimus antarcticus*		Rainforest its core habitat. Occurs in wet sclerophyll	Frugivores	Exclusive canopy and emergents
VATR	Varied Triller	*Lalage leucomela*		Commonly found in rainforest. Rainforest not its core habitat	Omnivores	<2 metres up to and including canopy
VRBD	Victoria's Riflebird	*Ptiloris victoriae*	Endemic	Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	<2 metres up to and including canopy
WEMO	White-eared Monarch	*Monarcha leucotis*	ES	Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	Exclusive canopy and emergents
WBWS	White-breasted Woodswallow	*Artamus leucorynchus*		Commonly found in rainforest. Rainforest not its core habitat	Insectivores	Exclusive canopy and emergents

CODE	Common name	Scientific name	Status	Habitat	Feeding	Strata
WRSW	White-rumped Swiftlet	*Collocalia spodiopygius*	**R**	Rainforest its core habitat. Occurs in wet sclerophyll	Insectivores	Exclusive canopy and emergents
WOMP	Wompoo Pigeon	*Ptilinopus magnificus*		Rainforest its core habitat. Occurs in wet sclerophyll	Frugivores	<2 metres up to and including canopy
SUNB	Yellow-bellied Sunbird	*Nectarinia jugularis*		Uses rainforest as a suboptimal / marginal habitat	Nectarivores	<2 metres up to and including canopy
YOLE	Yellow Oriole	*Oriolus flavocinctus*		Commonly found in rainforest. Rainforest not its core habitat	Frugivores	Exclusive canopy and emergents
YSHE	Yellow-spotted Honeyeater	*Meliphaga notata*		Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	<2 metres up to and including canopy
YTSW	Yellow-throated Scrubwren	*Sericornis citreogularis*		Rainforest its core habitat. Occurs in wet sclerophyll	Omnivores	0-2 metres above ground

Appendix 4.2 – Boxplots of species richness and population distributions over distance



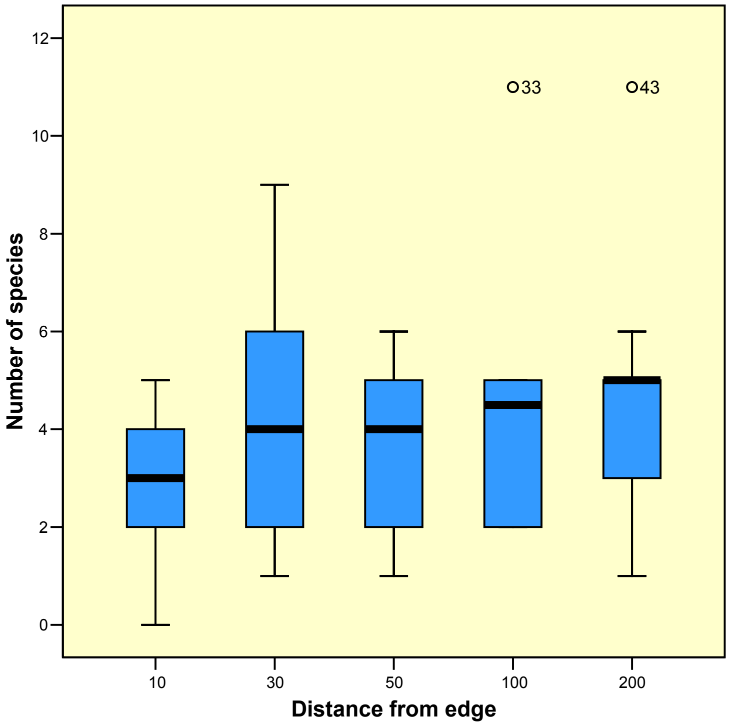


Figure A4.2: Median population counts (*top*) and species richness (*bottom*) for habitat guilds RC and RO along ten ninety-metre transects adjacent to the Kuranda Range Road in 2005.

Further information

Marine and Tropical Sciences Research Facility
PO Box 1762
CAIRNS QLD 4870

or

Marine and Tropical Sciences Research Facility
PO Box 772
TOWNSVILLE QLD 4810

Credits: **Southern cassowary** Wet Tropics Management Authority; **Hill Inlet in the Whitsundays** Department of Foreign Affairs and Trade - Overseas Information Branch; **Butterfly fish** Robert Thorn; **Rainforest fruits** Wet Tropics Management Authority; **Cover image strip** James Cook University.