



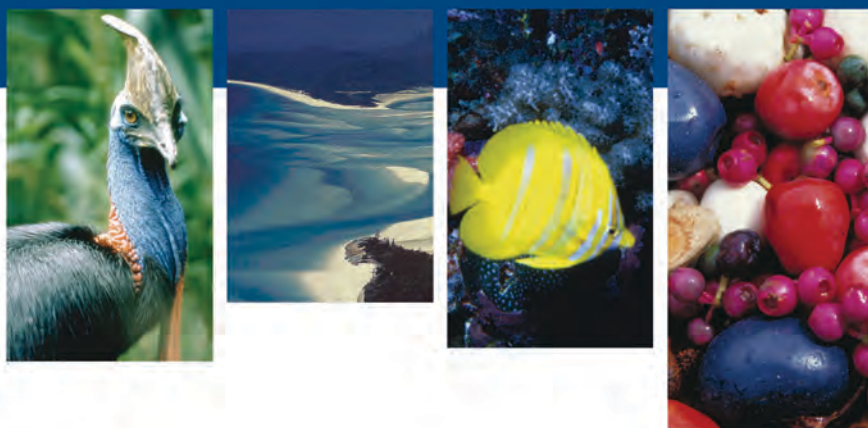
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Nocturnal noise levels and edge impacts on amphibian habitats adjacent to Kuranda Range road

Miriam Goosem, Conrad Hoskin and Gregory Dawe



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

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**Department of the Environment,
Water, Heritage and the Arts**

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Acronyms

AC	Avondale Creek
ANOVA.....	univariate analysis of variance
dB	decibels
DS	downstream
E	Endangered (species classification)
EPBC.....	Queensland <i>Environmental Protection and Biodiversity Conservation Act</i>
GPS.....	global positioning system
LC.....	Least Concern (species classification)
PC	personal computer
QDMR	Queensland Department of Main Roads
SC	Streets Creek
SEL.....	sound exposure level
SLM.....	sound level metre
SPL.....	sound pressure level
SVL.....	snout-vent length (of frog)
SVAN.....	noise metre
US	upstream
WP.....	water point

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.

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Terms of Reference

The Tropical Landscapes Joint Venture, through the James Cook University School of Earth and Environmental Sciences in Cairns, has undertaken an extension of work to cover extra facets requested by the Queensland Department of Main Roads. This research aims to fill knowledge gaps regarding nocturnal traffic noise and its impacts on amphibians.

Aims

1. To examine potential amphibian avoidance of habitat adjacent to the Kuranda Range road in comparison with areas further into the forest, some of which have been identified as 'acoustic refugia';
2. To analyse whether frequency shifts in amphibian calls occurs at the edge of the Kuranda Range road in comparison to calls recorded in the forest interior; and
3. To undertake systematic nocturnal noise recording near Streets and Avondale Creeks on the current road and in identified 'acoustic refugia' along those streams.

Objectives

This project examined nocturnal noise levels in the areas on the current road where threatened stream-dwelling amphibian species have been recorded. Transect assessments along the streams examined avoidance of the road edge by amphibians. Recording of amphibian calls at road edge and further into the forest examined changes in frog calls when a species is subjected to road noise.

Methods

1. Amphibian habitat usage, particularly for species of conservation concern, was observed using transects along Streets Creek and Avondale Creek to determine whether there any pattern in amphibian abundance in relation to proximity to the road was observable.
2. Amphibian calls were recorded opportunistically along the creeks at known distances from traffic noise in the wet season of 2006/2007.
3. Nocturnal traffic noise was measured along these transects and in the acoustic refuges during the dry season using a SVAN noise meter and microphone situated at approximate calling height of frogs.

Executive Summary

Section 1: Nocturnal noise levels in frog habitats and acoustic refugia adjacent to the Kuranda Range Road

Research Objectives

This project was designed to collect nocturnal noise level data in habitats adjacent to streams along the Kuranda Range Road. The research complemented a concurrent study investigating frog population densities and vocalisations in habitats likely to be impacted by the proposed upgrade to the Kuranda Range Road. It quantified traffic-noise impacts in likely anuran habitats adjacent to the existing Kuranda Range Road by data-logging and analysing nocturnal noise levels along streams concurrently surveyed for frog populations.

A secondary objective was to measure noise levels in selected acoustic refugia postulated in sections of the 2007 QDMR report entitled *Noise Disturbance along Highways – Kuranda Range Upgrade Project*¹ (Dawe and Goosem 2007).

- Data covered a suite of acoustic descriptors including third-octave dissemination.
- Noise data was collected at a height of one metre above the forest floor.
- Sample sites along transects that followed upstream and downstream from Streets Creek and Avondale Creek and upstream from Water Point were located at the highway edge, one hundred metres from the edge, and at two hundred metres into the rainforest.
- Data from two acoustic refugia were used for comparison with edge, one-hundred and two-hundred metre sites along transects.

Significant Findings

- The existence of two acoustic refugia designated using topographic criteria was confirmed by noise level measurements, providing confidence in further acoustic refugia designated in a previous report regarding diurnal noise (Dawe and Goosem 2007).
- Nocturnal noise levels at the forest edge and in some interior sites were highly correlated with traffic flows.
- Total noise levels at the 18:30 hrs commuter traffic peak measured between 1.5-2 times higher than at the 02:30 hrs traffic lull (mean of all sites).
- Late night highway edge noise levels were more than four times as loud as occurred in designated acoustic refugia.
- Nocturnal traffic noise penetrated to distances of at least two hundred metres, levels being higher at that distance in the lower and dominant traffic frequency bands than ambients recorded at acoustic refugia.
- Nocturnal noise levels in the 1 kHz band were more than twice as loud two hundred metres along stream transects than at designated acoustic refugia.
- Acoustic spectra were transformed by both traffic flows (time), distance and the presence of flowing water.

¹ Note: This report was published by the Reef and Rainforest Research Centre Ltd in September 2008. View online at http://www.rrrc.org.au/publications/research_reports.html

- Outside commuter traffic peaks, noise from stream flows and rain near streams can obscure traffic noise in the middle and upper frequency bands but does not tend to obscure noise below about 1 kHz.
- The dominant frequency of nocturnal traffic noise on the Kuranda Range was 1 kHz. However, at edge sites, nocturnal traffic noise caused changes to the forest sound frequency spectrum from 31.5 Hz to 2 kHz even when stream noise was present, which demonstrates the potential to blanket areas in which some bird and frog species communicate, particularly at the edge of the forest.

Management implications

Nocturnal noise is affecting forest habitats at the road edge and in some areas to distances of two hundred metres from the road along the current road alignment. However, nocturnal noise from traffic-flows along the current road alignment is not generating a significant effect on the acoustic environment of existing refugia and at some sites two hundred metres along streams there is little impact. This is likely to change if the upgrade proceeds with the current proposed design. The presence of traffic-noise dominating the spectrum is likely to impact on local amphibian and avian populations in some of these areas. This increases the risk of decline in terms of both species loss and reduced populations for these faunal groups.

Although stream noise and rain often blanket traffic noise, particularly at interior sites adjacent to streams, new road alignments and increased commuter peaks may produce traffic-noise levels that supersede these natural noise sources. Local fauna have had evolutionary time scales to develop mechanisms to compensate for the presence of natural noise compared to the relatively short time period they have experienced traffic-noise. Without adequate temporal buffering to adjust to anthropogenic noise perturbations into their habitats, wildlife in the area are at risk of increased stress levels and decreased signalling efficiency; thereby affecting breeding success, predation response, feeding efficiency, and territorial establishment.

Recommendations

- The barriers on bridges 22 and 23 and those on the eastern approaches to Streets Creek as part of the upgrade should be of sufficient height and density to mitigate against noise intrusion into acoustic refugia in the area (a known “hotspot” for the Southern Cassowary), with Streets Creek forming habitat for endangered and rare frog species. Barriers should be high and solid so as to reduce penetration of noise.
- Measures to maintain the nocturnal noise minima that should be considered include the deployment of night-time heavy vehicle noise and usage limits, traffic route planning, driver education and incentive strategies.
- Modelling of noise zones for the Kuranda Range Road upgrade should be modified to cater for changing noise spectra from traffic resulting from the expected increased speeds and structure reverberations.
- In view of the upgraded highway’s generally increased operational speed, noise amelioration instruments should include increased policing and enforcement of maximum noise emission limits particularly from heavy vehicles with regards the deployment of compression braking.
- A structured monitoring program to assess changes to the status of wildlife biodiversity across the Kuranda Range during both the construction and operational phases of the upgrade should be implemented.

Further research

- Evaluation of the effectiveness and suitability of the proposed noise barriers intended for upgraded road should consider nocturnal noise propagation as well as diurnal noise levels.
- Assessment of noise levels below bridges should be undertaken, including propagation of infrasound noise and reverberation effects.

Section 2: Disturbance and edge effects on frog abundance and diversity: Kuranda Range Road upgrade

Research objectives

The objective of this section was to examine potential amphibian avoidance of habitat adjacent to the Kuranda Range road in comparison with areas further into the forest, some of which have been identified as 'acoustic refugia'.

To this end the project aimed to assess whether the Kuranda Range Road impacts on the abundance and diversity of stream frogs.

Five road-side stream transects were monitored 6 times over a 6 week period during the wet season and the data was used to assess the abundance of several species of frog in relation to distance to the road.

Key Findings

- Species diversity *per se* did not appear to be affected by distance from the road, although lower species diversity was observed on Avondale Creek transects in comparison with Streets Creek, probably due to habitat differences.
- A pattern of density change away from the road was detected in two species on the Streets Creek transects.
- On the upstream Streets Creek transect *Litoria rheocola* showed a highly significant increase in density from road edge to forest interior, while on the downstream Streets Creek transect *Austrochaperina pluvialis* also showed a highly significant increase in density away from the road. The density decline in *L. rheocola* was ascribed to road impacts, whereas the cause was unclear for *A. pluvialis*.
- The mechanism for the decline in *L. rheocola* is likely to be the impact of traffic noise, as areas of the transect further from the highway are noticeably quieter, and no other factor explained the pattern.
- For *A. pluvialis*, a terrestrial rather than stream-dwelling species, microhabitat effects, particularly in moisture and habitat structure associated with the rocky substrate may be involved in this edge effect.
- Road mortality was not likely to cause either decline as both species are rare in road kill statistics. The green-eyed tree frog *Litoria genimaculata*, which is more commonly killed on the road showed no decline away from the road ascribable to this mortality.
- The feral cane toad, *Bufo marinus*, was rarely found on the streams in this survey, although it is a very common road victim. This suggests that cane toads use the Kuranda Range road and its verge as a movement corridor but seldom venture into the dense vegetation of the rainforest.

- A tributary of Streets Creek upstream of the road crossing was found to have very low numbers of frogs, although frogs were common on the main Streets Creek branch which runs parallel to the road before branching away.

Recommendations

- Traffic noise amelioration works should be undertaken on high bridges that cross the perennial creeks in the Kuranda Range road upgrade, and particularly at Streets Creek.
- Care should be taken to avoid impacting on current acoustic refuge areas downstream on Streets Creek of the current alignment.
- Care must also be taken to avoid disturbance of the stream habitat upstream of the current alignment at Streets Creek as this is where the majority of endangered stream-dwelling frogs occur.
- Revegetation works along the upgrade and rehabilitated sections of current road should aim for establishment of a dense understorey as well as canopy closure. Limiting open space where weeds can colonise should also aid in restricting cane toads and other frogs of disturbed areas.
- Canopy cover should be maintained as close as possible to the edge of the road to reduce edge effects that might impact on terrestrial microhylid frogs, as well as many other vertebrate groups.
- An investigation of water quality along the other Streets Creek tributary should be undertaken.

Management implications

Certain frog species appear to decline adjacent to the current Kuranda Range road, probably due to traffic disturbance and other edge effects. Alignment of the road should consider this and the design should aim to ameliorate noise adjacent to bridges over permanent creeks, particularly at Streets Creek, and to reduce edge effects by encouraging rainforest canopy and understorey as close as possible to the road edge. Revegetation needs also to consider understorey as well as canopy species to prevent encouragement of movements of the feral cane toad. The lack of frogs in one tributary of Streets Creek above the road crossing should be investigated in terms of water quality, as it is unlikely to be related to road impacts.

Further research

- Examination of the causative mechanism of edge effects for certain amphibian species.
- Assessment of the degree to which cane toads move along the road as compared to into the forest.

Section 3: Impacts of traffic noise on stream frog calling behaviour near the Kuranda Range Road

Research objectives

The objective of this section was to assess whether the Kuranda Range Road impacts on the calling behaviour of stream frogs.

To this end the project aimed to analyse whether frequency shifts in amphibian calls occur at the edge of the Kuranda Range road in comparison to calls recorded in the forest interior.

Calls of an *Endangered* species, the Common Mist Frog *Litoria rheocola*, were recorded along one of the survey transects and traits of the calls were measured and analysed to see if they varied with distance from the road.

Key Findings

- Calls of forty-one male individuals of the endangered species, the Common Mist Frog, *Litoria rheocola* were recorded along a stream transect at Streets Creek between the road edge and 350 metres along the creek (a distance of about one hundred metres perpendicular from the road), examining four call parameters.
- Two call parameters, the rate at which males call and dominant frequency were found to be significantly related to distance from the road.
- The size of the males was highly significantly related to distance, increasing towards the forest interior.
- Smaller males found more often near the road edge called more frequently and at a higher pitch than the larger males found more often further from the road. These changes in vocalisations appear most likely to relate to traffic noise impacts.
- Larger and more dominant males may be selecting for preferable habitat away from the road, leaving the smaller individuals in habitat that is more greatly affected by traffic noise blanketing of calls.
- Alternatively, there may be a genetic overlap zone or road mortality may be removing larger males from the system, but these latter hypotheses appeared less likely as causative factors, although unable to be ignored.

Recommendations

- Noise amelioration works with solid barriers that prevent traffic noise propagation towards ground level should be undertaken on the high bridge and its surrounds adjacent to Streets Creek.

Further research

- Future research should extend the vocalisation research on *Litoria rheocola* and target other species of conservation significance during their peak breeding season.

1. Nocturnal noise levels in frog habitats and acoustic refugia adjacent to the Kuranda Range Road

Gregory Dawe and Miriam Goosem

Summary

We investigated nocturnal noise levels experienced along streams crossed by the current Kuranda Range Road, quantifying current traffic noise impacts in likely amphibian habitats by data-logging and analysing noise levels along streams including Avondale and Streets Creeks concurrently surveyed for frog populations. We also measured noise levels in two acoustic refugia designated using topographic criteria during a previous study. Nocturnal traffic noise followed a similar pattern as demonstrated by diurnal noise in that it decreased with distance from the traffic noise source but was still elevated at distances of at least two hundred metres inside the forest. In forest edge areas and at distances further into the forest unaffected by topographic shielding, nocturnal noise levels were highly correlated with traffic flow, decreasing from a peak at the evening commuter peak until around 02:30 hrs then increasing to the morning commuter traffic peak. Noise levels recorded close to flowing water effectively blanketed some of the impacts of traffic noise in the dominant flowing water frequency band of 2.5 kHz, but not in most lower frequency bands (below about 1 kHz). Amphibian species most likely to be placed at risk by traffic noise propagation through their habitat are therefore expected to be those that communicate in the lower frequencies.

Two of the refugia designated using topographic criteria in the diurnal noise report (Dawe and Goosem 2007) have been verified as providing quiet habitat for fauna that communicate using sound. As similar criteria were used to distinguish all the refugia designated in that report, we feel confident that acoustic refugia occur in the mapped areas. However, it must be recognised that the mapped boundaries provide only an indication of the extent of the refuge, rather than representing measured values.

1.1 Introduction

1.1.1 General acoustics

Sound results from fluctuations in air pressure, with its two main components being amplitude (the extent of the fluctuations) and frequency (the rate of each oscillation). Amplitude is usually described in terms of pressure or intensity (each being commonly expressed as decibels), with pressure being proportional to the square root of intensity (Parris 2006). Frequency, formally described in cycles per second, is now usually expressed in Hertz (Hz).

For human subjects, noise is a perceived evaluation of the degree of sound pressure fluctuations on our eardrums. The loudness level (amplitude) of a particular noise is usually assessed in decibels (dB) which is based on a logarithmic scale, typically A-weighted to emphasize the middle portion of the 20 Hz to 20 kHz auditory range of the human ear. This A-weighting filter is biased towards the frequency range between 500 Hz and 8 kHz (Cavanaugh and Tocci 1991). A noise level of 0 dB is considered the minimum detectable level of sound in adult humans, whereas noise levels in a public library would typically be

around 40 dBA (Egan 1988). In most adults 3 dB is considered the minimum discernible change in loudness, while a 10 dB increase would be perceived as a doubling in loudness. This perceived doubling in noise levels corresponds to only a 6 dBA increase in associated sound pressure due to the decibel scale's logarithmic form (Egan 1988, Parris 2006). Similarly, due to the nonlinear nature of human auditory response, noise increases of 15 dB more closely represent a four-fold increase in loudness than a 20 dB perturbation (Cavanaugh and Tocci 1991).

1.1.2 Roads and traffic-noise impacts

Trombulak and Frissell (2000) describe roads as being “associated with negative effects on biotic integrity on both in both terrestrial and aquatic ecosystems”. They further argue that “roads alter animal behaviour, by causing changes in home ranges, movement, reproductive success, escape responses and physiological state”. Jaeger and others (2005) add that roads and traffic negatively affect both habitat quality and amount, introduce collision mortality, restrict resource access, and fractionalise wildlife populations.

One main contributor to the range of behavioural responses is noise, generated by both the construction and operational phases of road and highway development. Most noise studies have been designed with an anthropogenic focus. Much research into the effects of traffic noise has been undertaken on residential nuisance effects during both daylight and night-time hours. Night-time noise levels have typically been assessed using descriptors such as L_{dn} (day / night noise levels) or L_{den} (day, evening, night) which reflect our increased perception of late night and evening noise by weighting noise between 22:00 hrs and 07:00 hrs upwards by 10 dB (Egan 1988).

1.1.3 Traffic noise effects of amphibians

1.1.3.1 General

Although most studies on the effects of traffic noise on wildlife have focussed on bird species (refer to Sections 3 and 4 in Dawe and Goosem 2007), a few scientific studies have targeted anurans (frogs and toads). The current project concentrates on the effects of traffic-noise on frog populations and vocalisations; however roads also generate microclimate edge-effects such as alterations to wind-speed, relative humidity, temperature and insolation (Pohlman *et al.* 2007) which can also impact on amphibians through increased desiccation (Toral *et al.* 2002).

1.1.3.2 Impact on amphibian vocalisations

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. Studies on neotropical tree-frogs by Schwartz and Wells (1983) found significant behavioural effects on both sexes of *Hyla ebraccata* due to presence of background noise. The largest modification of vocalisations from males of that species occurred when the dominant frequency of the background noise coincided with the frog's dominant vocalisation frequency. However, noise containing frequencies that only partially blanketed calls also triggered some acoustic modifications in that anuran species (Schwartz and Wells 1983).

Ongoing 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 generally call at higher frequencies. That research is also examining frogs' reaction to traffic-noise in relation to vocalisation activity levels, via playback recordings of loud traffic (Catchpole 2004). It follows earlier work on call interference which found that the distance from which female spring peepers (*Pseudacris crucifer*) can identify calls from individual males is significantly reduced in the presence of conspecific chorusing (Parris 2002).

The results of the latter research complement work done by Wollerman (1999) on neotropical tree-frogs *Hyla ebraccata* in Central America which found that continuous background noise elevated acoustic interference to vocalisations and inhibited the detection of calls. Wollerman and Wiley (2002a) later found that even if female frogs could detect male calls amidst moderate background noise levels, the ability to discriminate between each caller was reduced. Later work by the same researchers using discriminant function analysis of pairs of call features suggested that where allospecific anurans coexist, signalling and call recognition errors may be reduced through the evolution of different auditory adaptations between rare and common species (Wollerman and Wiley 2002b). Amphibians appear to rely on combinations of call parameters (e.g. call duration, dominant frequency, fundamental frequency and pulse repetition rate) to identify calls from conspecifics amidst a chorus of calls from a variety of species. Rarer species, with less chance of correctly identifying a conspecific in such a chorus using just those parameters, may evolve calls further toward the periphery of available signal space than calls of those species present in greater numbers. Although this calling is likely to involve the expenditure of greater amounts of energy for an apparently less efficient signal, the uniqueness of the call would reduce the amount of misidentification and consequent wasted energy and risk in wrongly approaching potential mates from another species (Wollerman and Wiley 2002b).

1.1.3.3 Impact on amphibian distribution and densities

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). Recent studies in Australia found that frog movement patterns around ponds in Melbourne were affected by roads and human infrastructure (Parris 2006). Carr and Fahrig (2001) found that although frog populations may decline due to traffic mortality, this decline is likely to be more pronounced in more vagile species.

In Canada, road mortality 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 was 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 through road mortality. In a later study in Canada of a sealed two-lane road crossing Kouchibouguac National Park, Mazerolle (2004) found that traffic volumes were positively correlated with nocturnal road mortality in some amphibian species, and negatively correlated in others such as spring peepers. That study also showed that increased mortality in some species could result from relatively small increases in traffic volume (5-26 vehicles per hour).

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. Therefore the degree that traffic-noise has affected frog densities remains unclear.

1.1.4 Nocturnal noise

Acoustic conditions in tropical regions are significantly influenced by the time of day, with the nocturnal boundary layer aiding long-distance sound propagation (Di and Gilbert 1999). Studies in forests and grasslands of KwaZulu-Natal found a marked difference between the day and night time acoustic environment (Van Stadden and Römer 1997). Daytime transmissions were limited by a shadow zone past fifty metres combined with upward-refracting sound paths, due to the temperature gradient above the surface slowing the speed of sound with increased elevation, causing the sound waves to bend upward. However, night-time signal transmission was enhanced, due to the presence of a downward refracting temperature inversion. This layer trapped sound in a corridor between the ground and the different temperature gradients, providing a transmission conduit with minimal propagation losses (Van Stadden and Römer 1997). These researchers found that this factor resulted in the signal transmission of bladder grasshoppers (*Bullacris membracioides*) increasing from 150 metres in the afternoon to 1.5-1.9 km during the night.

1.1.5 Aims

This project was designed to collect nocturnal noise level data in habitats adjacent to streams along the current Kuranda Range Road. This research complements a concurrent study investigating frog population densities and vocalisations in habitats likely to be impacted by the proposed upgrade to the Kuranda range Road. It quantified traffic noise impacts in likely amphibian habitats adjacent to the existing Kuranda Range Road by data-logging and analysing noise levels along streams concurrently surveyed for frog populations.

A secondary objective was to measure noise levels in selected acoustic refugia postulated in the 2007 report by the QDMR (see Dawe and Goosem 2007).

1.2. Methods

1.2.1 Project design

1.2.1.1 Overview

Between October 2006 and January 2007, nocturnal noise sampling was conducted at six rainforest edge sites, six interior sites (at distances of one or two hundred metres along the stream) and two designated acoustic refugia adjacent to the Kuranda Range Road (Figure 1). Noise was measured at a height of one metre above ground level, representing a height in streamside vegetation that frogs often call. Sampling began each afternoon between 14:25 hrs and 16:26 hrs, and was terminated at between 08:02 hrs and 10:55 hrs the following day, depending on setup time, transect conditions and availability of personnel². Rainforest adjacent to the stream comprised either complex mesophyll vine forest or complex notophyll vine forest (*sensu* Tracey 1982) on metamorphic soils, with some areas dominated by *Acacia celsa* regrowth following past human disturbance. Areas of wait-a-while palm (*Calamus* spp.) and stinging tree (*Dendrocnide moroides*) were common.

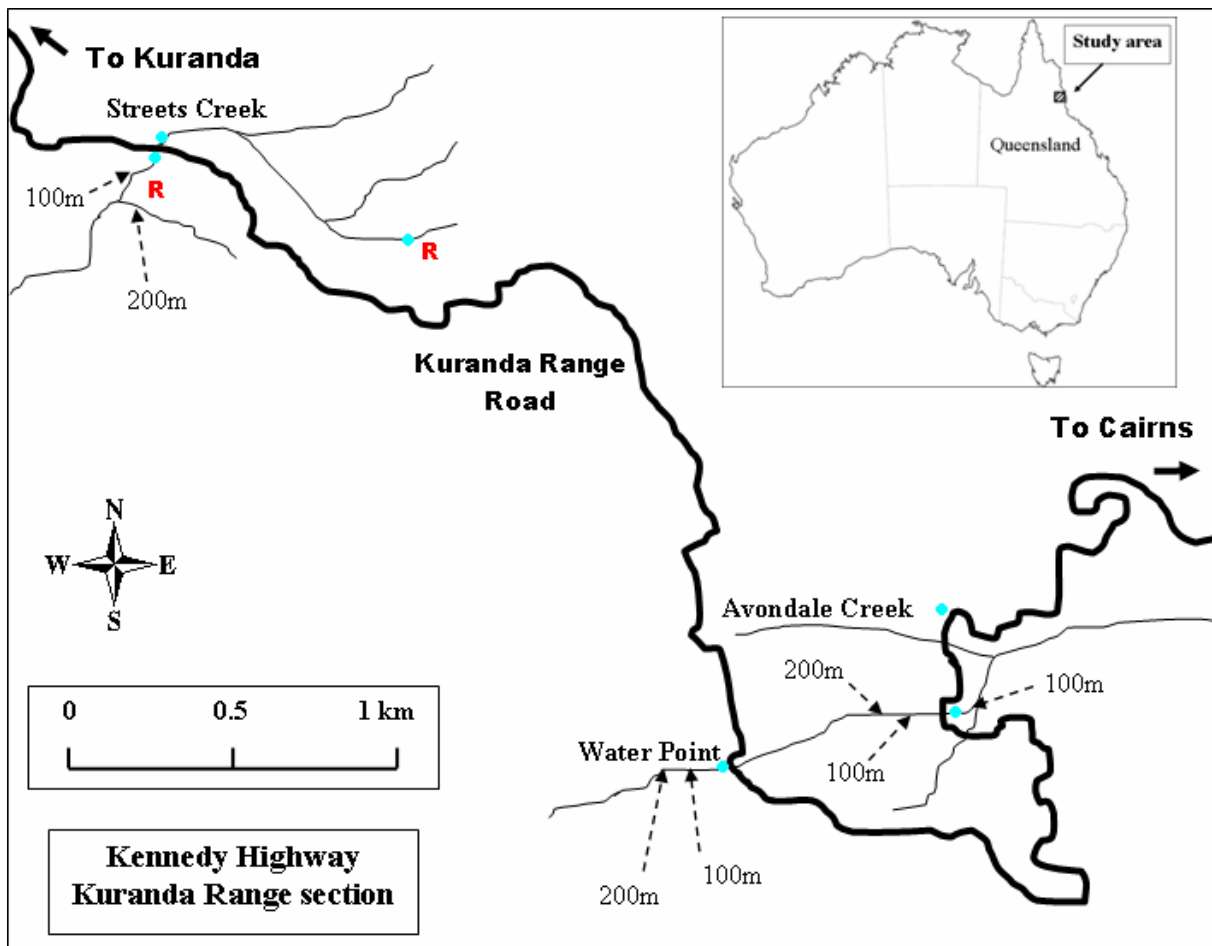


Figure 1: Map of nocturnal noise sampling points, Kuranda Range 2006/2007 (edge sites in blue; refugia in red).

² The refuge at upper Streets Creek about 170 metres along Powerline transect was noise-sampled for 24 hours commencing at 13:00 hours.

1.2.1.2 Site acoustic anomalies

Most amphibians within the Wet Tropics, apart from toads and microhylid species, prefer stream habitats (Hoskin, *pers. comm.*). Noise data sampling was therefore concentrated along perennial streams (Streets and Avondale Creeks) or beside pools where water may be expected to flow during the wet season, in order to provide an accurate representation of typical ambient noise environments for local frog species. Water flows at these locations inevitably produced high and often dominant levels of noise in the mid-range frequency bands concentrated between 1 kHz and 2.5 kHz, particularly when the sound level meter (SLM) was positioned in the vicinity of torrents or ripples.

1.2.1.3 Climatic conditions during project

Most nocturnal noise data was collected during optimum weather conditions, with low wind speeds and only occasional brief rain showers. This factor allowed analysis of the effects of two climatic descriptors: air temperature and relative humidity, on noise levels across the third-octave spectrum, and also frequently enabled the microphone to be deployed without the requirement for a cover for protection against rain. The elimination of this covering helped reduce acoustic blanketing due to the presence of the cover between road sound source and the microphone. Non-availability of a suitable data-logging micro-climate instrument prevented recording of actual *in situ* weather conditions during noise sampling. Therefore climate data was averaged from Bureau of Meteorology records for the study period from the closest recording stations, at Cairns Airport and Mareeba.

1.2.2 Equipment, software and data analysis

1.2.2.1 Equipment and software

Data was recorded at one metre above the ground using a Svantek (Poland) model 949 Type-1 sound level meter (SLM) through an omni-directional BSWA TECH Model SV 22 ½" pre-polarized condenser microphone and pre-amplifier, fitted with a 90 mm diameter foam windscreen (Figure 2). 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. Data from the SVAN 949 meter was downloaded onto a personal computer after each sampling session via the Svantek PC analysis program.

The instrument's statistical analyser also provided a range of L_n loudness levels (L_1 , through to L_{99}). A suite of other noise descriptors including: peak maximum, minimum, Sound Pressure Level (SPL), Sound Exposure Level (SEL), L_{tm3} , L_{tm5} , and L_{den} were also available for each ten-minute linear integration file. The instrument was calibrated before and after each night's sampling using a 1 kHz 94 decibel (dB) 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 for analysis if both readings were within 0.5 decibels of the calibrator's test signal. SLM calibration accuracy during the project was typically within 0.2 dB of reference level.

Start times for the ten-minute L_{eq} noise files from all sites were standardized to the nearest ten minute block within the hour to allow analysis of all replicates (e.g. 08:02 is adjusted to 08:00 and 16:36 advances to 16:40).



Figure 2: Sound level meter setup at one hundred metres upstream from Avondale Creek lower highway crossing.

1.2.2.2 Data analysis

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).

Univariate Analysis of Variance (ANOVA) was conducted on the effects of site location and time of night for noise data where data was found to be normally distributed. Kruskal-Wallis and other non-parametric tests were performed on data which failed to meet the assumptions of normality. Noise distribution across the third-octave spectrum was compared between edge and two hundred metres inside the forest and across time of night using Fisher's Linear Discriminant Function Analysis. The relationship between noise levels and climatic factors were examined by Pearson Product Moment Correlation. Noise levels and traffic flows were also examined using Pearson's correlations.

1.3 Results

1.3.1 Total noise

1.3.1.1 Effect of time

Nocturnal total noise levels displayed a general evening decline irrespective of weighting parameter examined, rising again from about 02:30 hrs to a morning peak after 07:30 hrs (Figure 3). Evening and early morning peaks (more pronounced in the A-weighting filter) were observed at around 18:30 hrs and 05:30 hrs, but plot trends allude to higher peaks in both C-weighted and linear noise levels further into the daylight hours (Figure 3). Noise levels within each of these three parameters were found to vary significantly across the nocturnal period (hours between 16:30 hrs and 07:30 hrs) when investigated using analysis of variance (Table 1).

Table 1: Effect of time on nocturnal total noise levels averaged across all 2006/2007 sites (one-way analysis of variance).

Noise parameter	df	MS	F	Sig.	Power
A-weighted total noise	15	85.904	2.746	0.000	1.000
C-weighted total noise	15	612.340	15.744	0.000	1.000
Linear weighted total noise	15	693.544	19.648	0.000	1.000

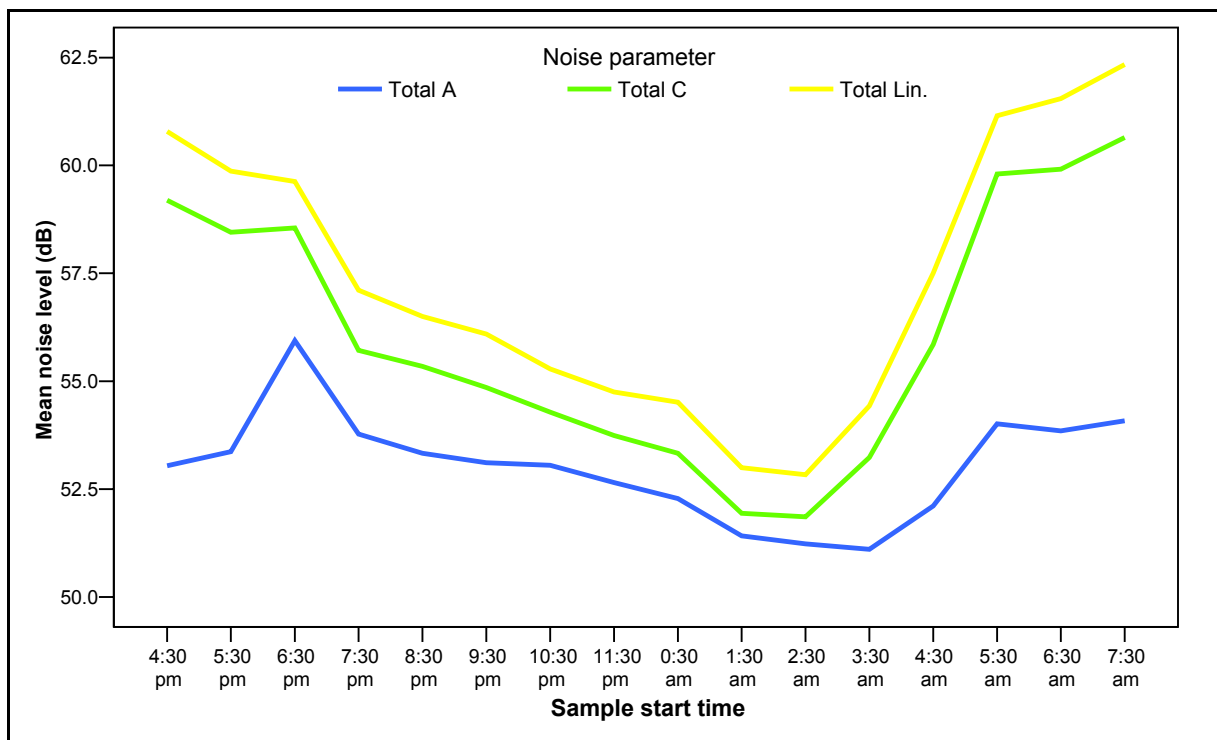


Figure 3: Mean hourly total noise levels at three weightings from all Kuranda Range sites between 16:30 hrs and 07:30 hrs during the 2006/2007 nocturnal noise study.

1.3.1.2 Effects of sampling location

Total noise levels were also found to vary significantly between sites (Table 2), with areas free of water noise (Avondale Creek edge upstream, Streets Creek at two hundred and in both refugia)³ displaying the greatest variance of A-weighted values, particularly in the middle of the night (Figure 4).

An apparent anomaly was observed at the sampling point two hundred metres upstream from the highway “Water Point” sign. Here flows over a small waterfall about fifteen metres from the sound level meter were sufficient to dominate the centre to mid-upper (dominant A-weighted) portion of the acoustic spectrum, even during the evening commuter peak (Figure 5). Noise from this water source with its dominant frequency of 3.15 kHz, although constant, was nevertheless sufficiently quiet (four-hour late-night mean = 38.8 dB) not to override the greater traffic noise contributions from lower frequency bands recognised in the C- and Linear-weighted total-noise statistics, resulting in a much narrower range for the “A” parameter compared to the “C” and linear descriptors (Figure 4). The presence of relatively high water noise levels at most edge sites replicated this feature of narrow-range “A” levels and broader ranges across the other two noise parameters. High-side outliers resulted from the few vehicle passes during this period (Figure 4).

Table 2: Effect of site location on mean total-noise levels between 23:30 hrs and 03:30 hrs.

Noise parameter	df	MS	F	Sig.
A-weighted total noise	13	559.379	112.459	0.000
C-weighted total noise	13	462.046	41.815	0.000
Linear weighted total noise	13	411.975	38.882	0.000

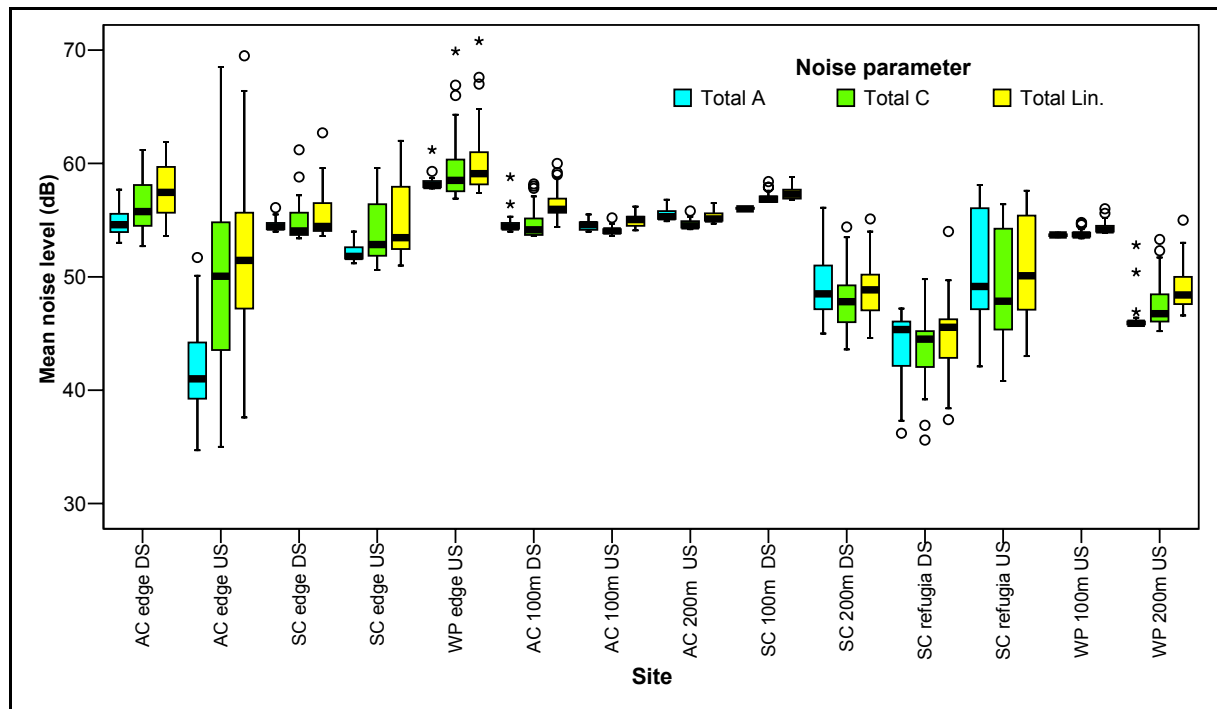


Figure 4: Mean night-time total noise levels for all sites (23:30 hrs to 03:30 hrs). DS = downstream site; US = upstream; AC = Avondale Creek; SC = Streets Creek; WP = Water Point, upper Avondale Creek.

³ The site at Streets Creek two hundred metres from the road lies on the periphery of an identified acoustic refugia, clear of flowing water, at a slightly different location to that used for diurnal noise sampling.

1.3.1.3 Effect of variations in levels of road traffic

Most roadside noise sampling was conducted close to flowing water. Flowing water effectively blanketed any night-time lulls in A-weighted noise levels associated with reduced traffic volumes in late evening / early morning. One edge site adjacent to and upstream of the lower Avondale Creek bridge over the intermittent tributary which feeds in to main lower Avondale Creek stream was monitored when there was no flow to provide a water-noise free reference for the purpose of correlating traffic flows against edge noise levels (Figure 5). At this site total A-weighted noise levels were found to be strongly correlated with adjacent traffic loadings (Pearson product-moment correlation: $r = 0.897$; $P < 0.005$). Noise levels in the 1 kHz dominant frequency band of traffic-noise were found to even more closely correlated at this location ($r = 0.929$; $P < 0.005$).

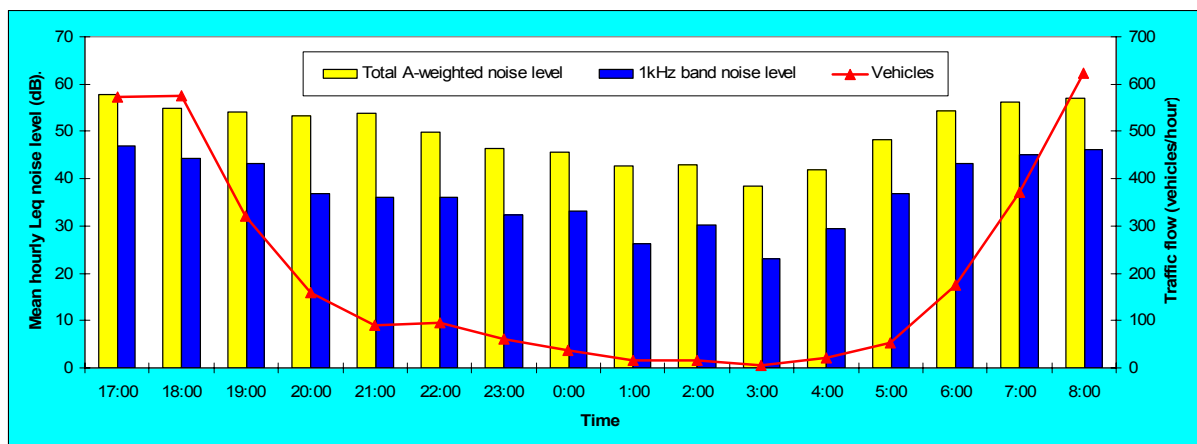


Figure 5: Mean hourly total-A and dominant traffic frequency band (1 kHz) noise levels and corresponding traffic flows at Avondale Creek upstream edge.

1.3.2 Dominant traffic-band noise

Where sampling sites were situated close to flowing streams, even during periods in the early hours of the morning when there was little traffic flow, noise levels remained relatively high in the 1 kHz dominant traffic-noise third-octave band⁴, with values confined to a narrow range. Sites isolated from the effects of water noise displayed lower noise levels with larger variances across the same frequency band (Figure 6). Night-time noise fluctuations in this frequency band were controlled to a large degree by the presence of nearby flowing water which effectively smoothed out much of the diurnal “dip” resulting from reduced traffic noise levels at sites such as Avondale Creek upstream edge (Figures 5 and 9). Noise levels in this frequency band varied significantly between sites during the quiet night-time period between 23:30 hrs and 03:30 hrs (Kruskal-Wallis $\chi^2 = 312.296$; $df = 13$; $P < 0.0005$).

1.3.3 Third-octave spectra noise

A-weighted levels of noise during the 16:30 hrs to 20:30 hrs peak traffic period were elevated above noise levels experienced in the midnight to early morning traffic lull in frequency bands between 30 and 1,250 Hz (Figure 7), whereas noise levels in higher frequency bands were similar throughout the nocturnal period. The exception to this was in the vicinity of the 3.15 kHz band affected by biotic noise. This alteration in the frequency spectrum lower bands was attributed to the noise contribution from traffic, as the majority of traffic noise propagates in the lower frequency bands.

⁴ Refer to Dawe and Goosem 2007.

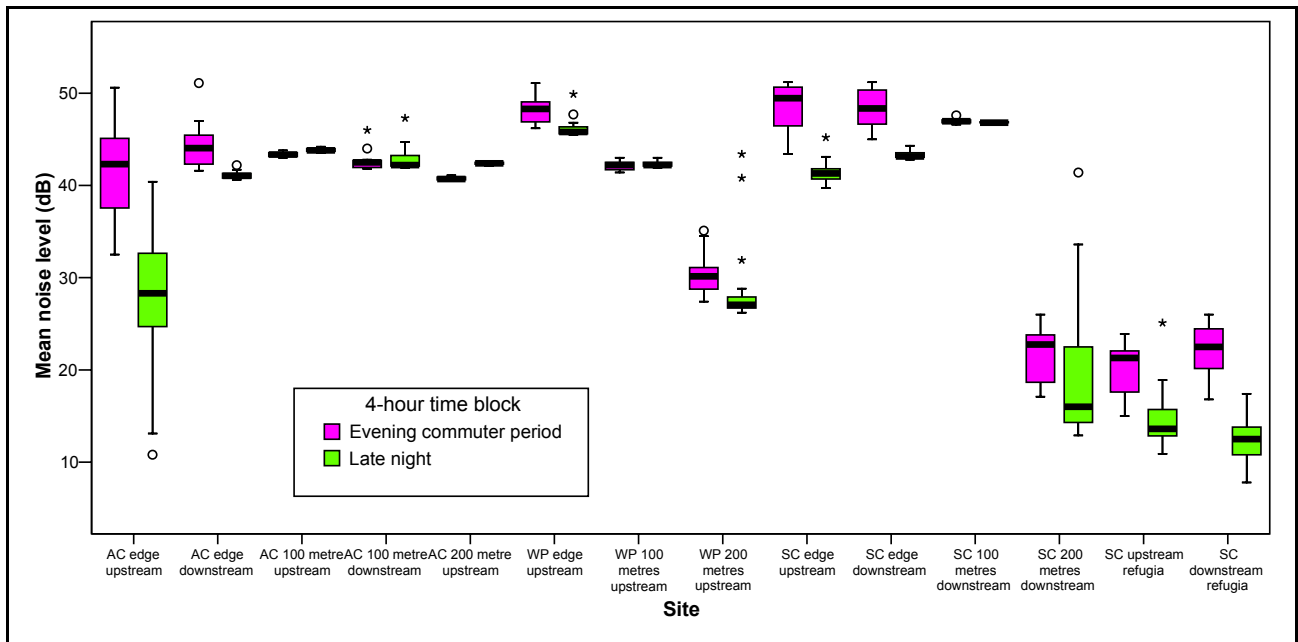


Figure 6: Mean 1 kHz frequency band noise levels for all sites for two four-hour time blocks (16:30 hrs to 20:30 hrs – evening commuter period; 23:30 hrs to 03:30 hrs – late night traffic lull).

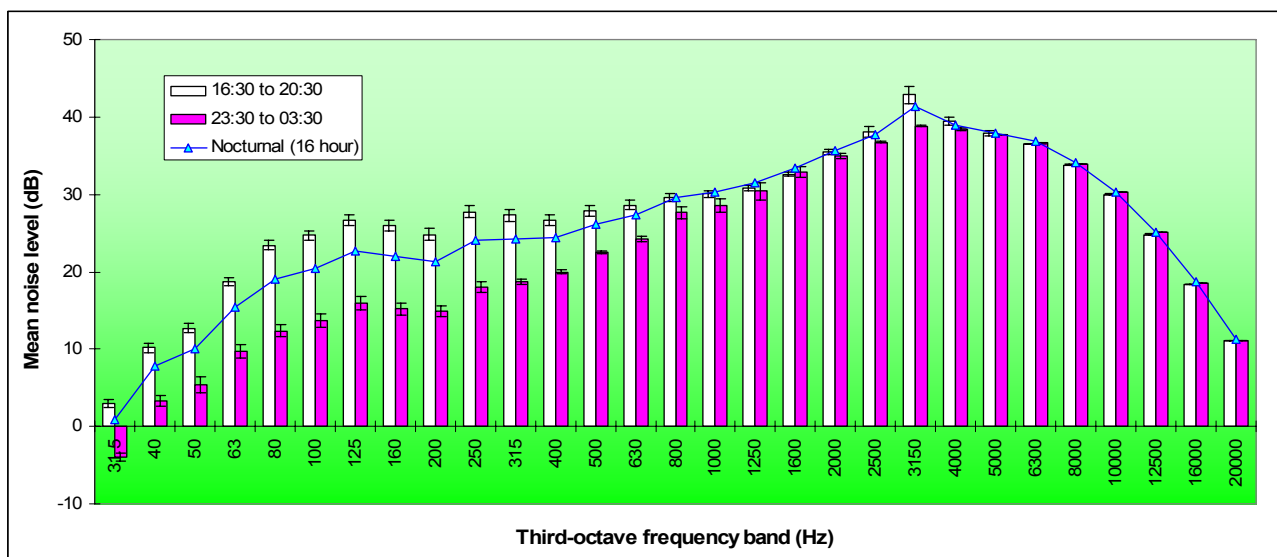


Figure 7: Mean sixteen-hour nocturnal spectrum at Water Point two hundred metres from edge with four-hour periods covering evening commuter peak and late night traffic lull.

1.3.3.1 Effect of distance and topography

Interior sites two hundred metres inside the forest and designated acoustic refugia were generally quieter than locations closer to the highway during late night sampling sessions, particularly in the lower frequency bands (Figure 8). Noise levels in the lower to middle one-third octave bands generally declined relative to distance from the highway. However, noise in frequency bands utilised by avifauna and cicadas (in the vicinity of 3.15 kHz and 4 kHz respectively) was independent of both distance and time (Figures 8 and 9). Late night refugia spectra (including the Streets Creek two hundred metre site) had distinctly different profiles than those of other locations, with a relatively flattened structure in the mid and lower frequency bands and high amplitude levels in the cicada vocalisation bands (Appendix 1).

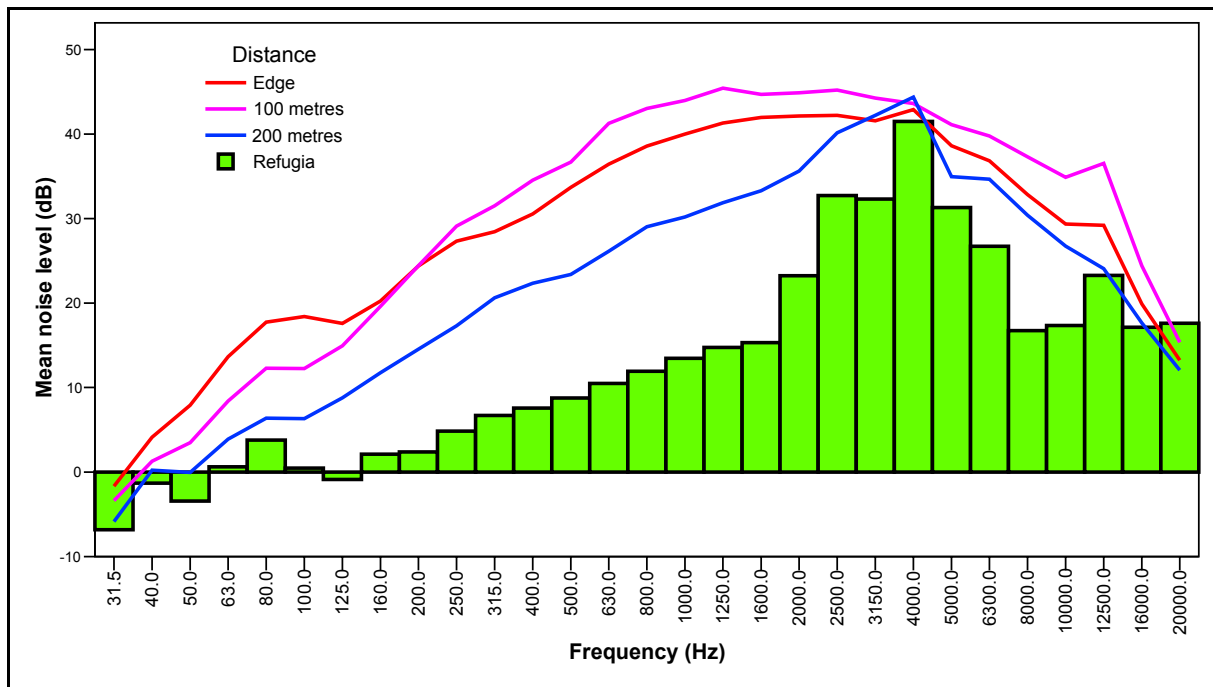


Figure 8: Mean noise levels measured between 23:30 hrs and 03:30 hrs in third-octave frequency spectrum from all sites sampled during 2006 Kuranda Range nocturnal noise project.

At two hundred metres from the roadside in the middle of the night, noise distribution across the 125 Hz to 16 kHz third-octave spectrum was significantly different from that at the edge for frequency bands below 5 kHz, many of which are dominated by traffic noise when it is present (the exception was 2.5 kHz which at many sites was dominated by water noise) (Fisher's linear discriminant function analysis: $\chi^2 = 77.382$; $df = 15$; $P < 0.0005$). When sites were restricted to those close to flowing streams, only those third-octave bands below 1.6 kHz displayed significantly different noise levels between edge and 200 metre distances ($\chi^2 = 102.201$; $df = 13$; $P < 0.0005$), due to acoustic blanketing by flowing water at dominant frequencies upwards of 2.5 kHz. Exceptions relating to cicada activity were also seen at some sites in the 6.3 and 10 kHz bands as these frequencies are sufficiently separated from the dominant water noise band to show detectable differences. Similarly, in comparing night time acoustic refugia with sampling sites one hundred metres from the road beside streams, for frequency bands below 8 kHz a significantly different spectrum was found ($\chi^2 = 175.745$; $df = 19$; $P < 0.0005$), mainly attributable to the presence of flowing water at all 100 m stream sites and its absence at acoustic refugia. The presence of high-frequency cicadas calling uniformly both in stream sites at one hundred metres and acoustic refugia causes non-significance in the 16 kHz band, an area of the spectrum where the water noise has less impact.

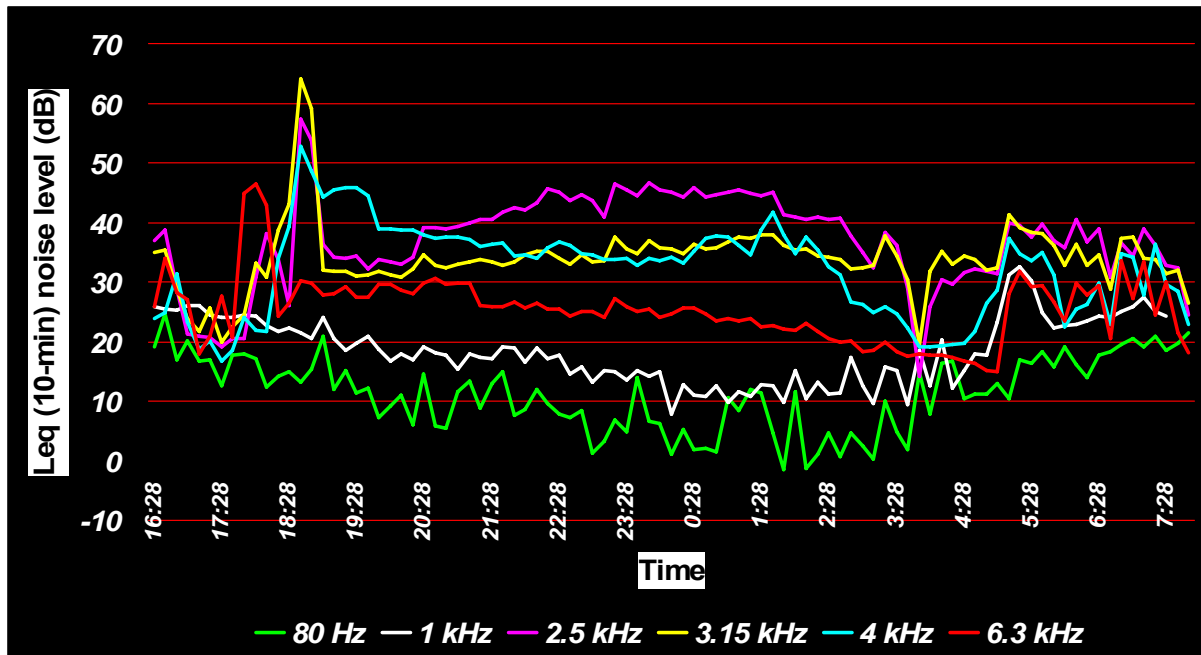


Figure 9: Nocturnal noise levels from six selected third-octave frequency bands at Streets Creek downstream refugia approximately one hundred metres from bridge.

1.3.3.2 Effect of time on spectra noise levels

Evening noise peaks across low to middle frequency bands particularly at edge sites, appeared to correspond with daily commuter traffic peaks. All sample locations experienced a nocturnal lull across a wide portion of the third-octave spectrum, particularly evident at sites clear of water noise perturbations (Figure 10). This lull was more pronounced in the lower frequency bands (Figure 11), but was also distinguishable in the middle and upper spectrum at those sites where water noise and cicada vocalisations were of sufficiently low amplitude.

The acoustic spectrum at the edge had a significantly different profile during the evening commuter peak hour (17:30 hrs to 18:30 hrs) compared with the late night spectrum (01:30 hrs to 02:30 hrs) when analysed across all third-octave bands between 125 Hz and 16 kHz (Fisher's linear discriminant function analysis: $\chi^2 = 124.768$; $df = 22$; $P < 0.0005$). Sites at two hundred metres from the highway together with refugia also presented distinctly different spectral profiles between evening peak traffic flows and the early morning hours when spectra below 16 kHz ($\chi^2 = 109.453$; $df = 21$; $P < 0.0005$).

1.3.3.3 Effect of water flows on noise levels

Water movement at individual sampling points had a significant impact upon ambient noise conditions in mid to upper frequency bands, obscuring any diurnal dips that were observed at other locations isolated from water-noise sources (e.g. Avondale Creek upstream edge, Figure 12). The dominant frequency for noise from these water sources was site specific ranging from 1.25 kHz to 3.15 kHz depending on stream velocity and height of cascades (Table 3).

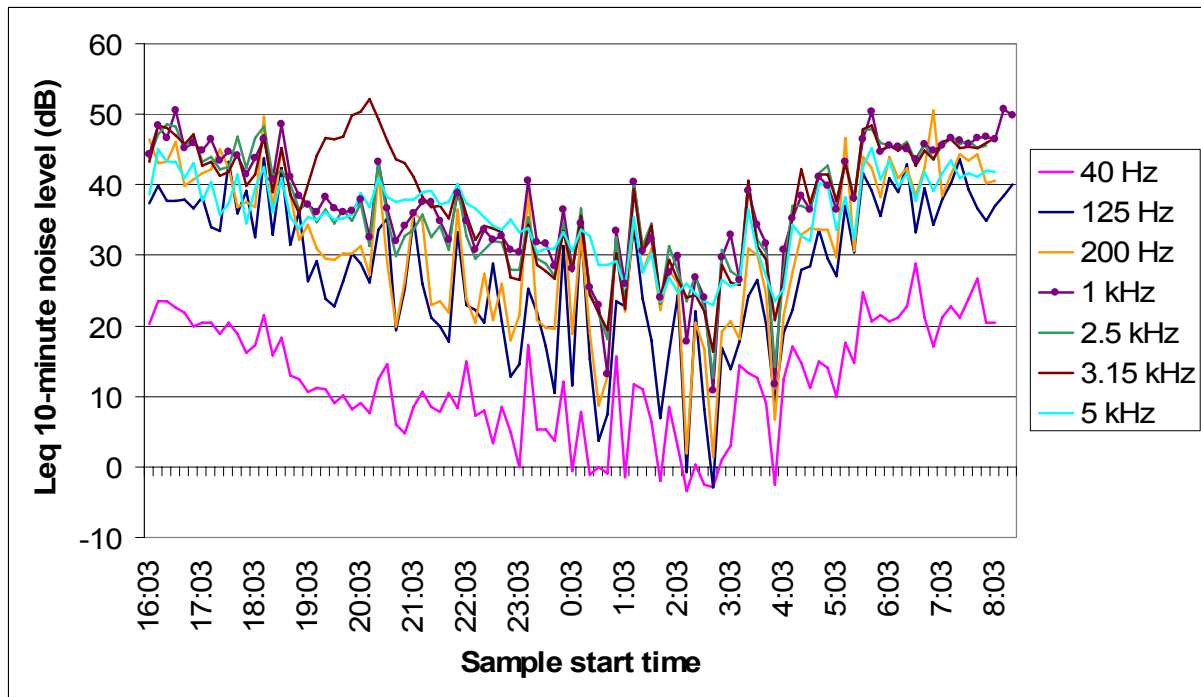


Figure 10: Avondale Creek upstream edge nocturnal noise levels from seven selected third-octave bands.

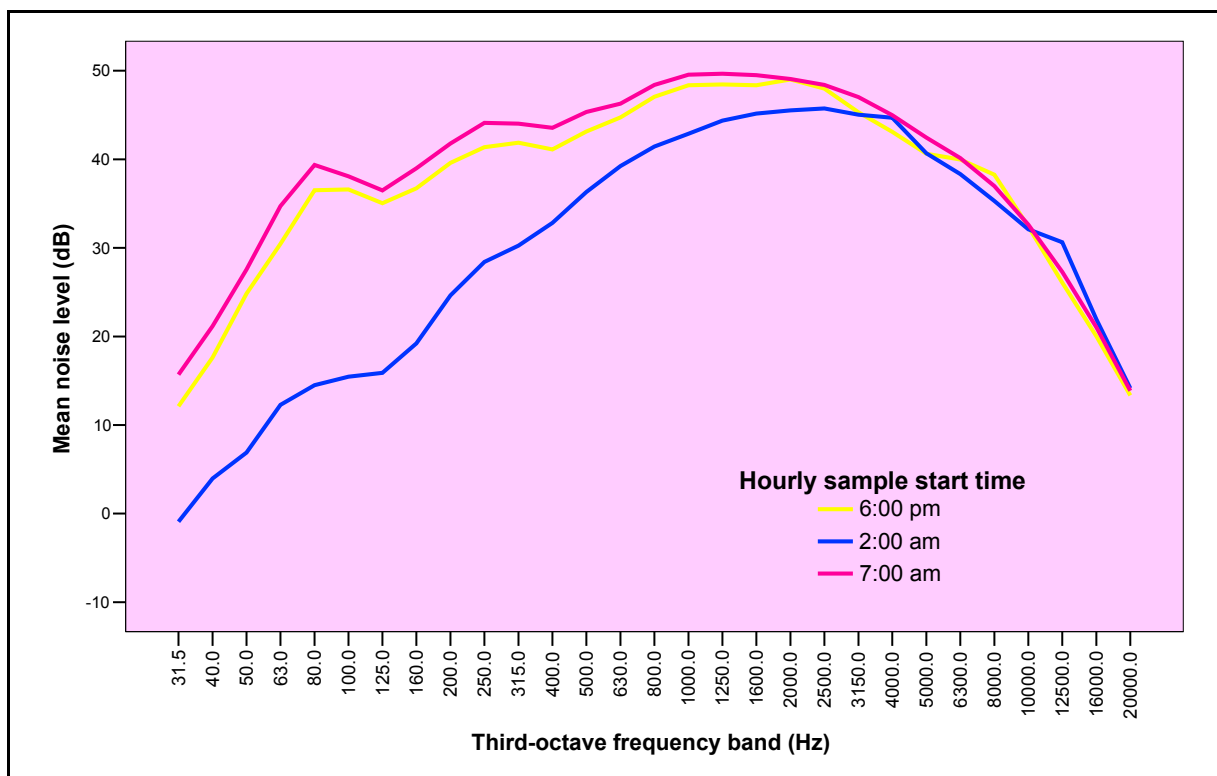


Figure 11: Mean third-octave spectra for edge sites close to flowing water during three separate one-hour periods, two with traffic levels relatively high (18:00 hrs and 07:00 hrs), and one with low traffic levels (02:00 hrs) .

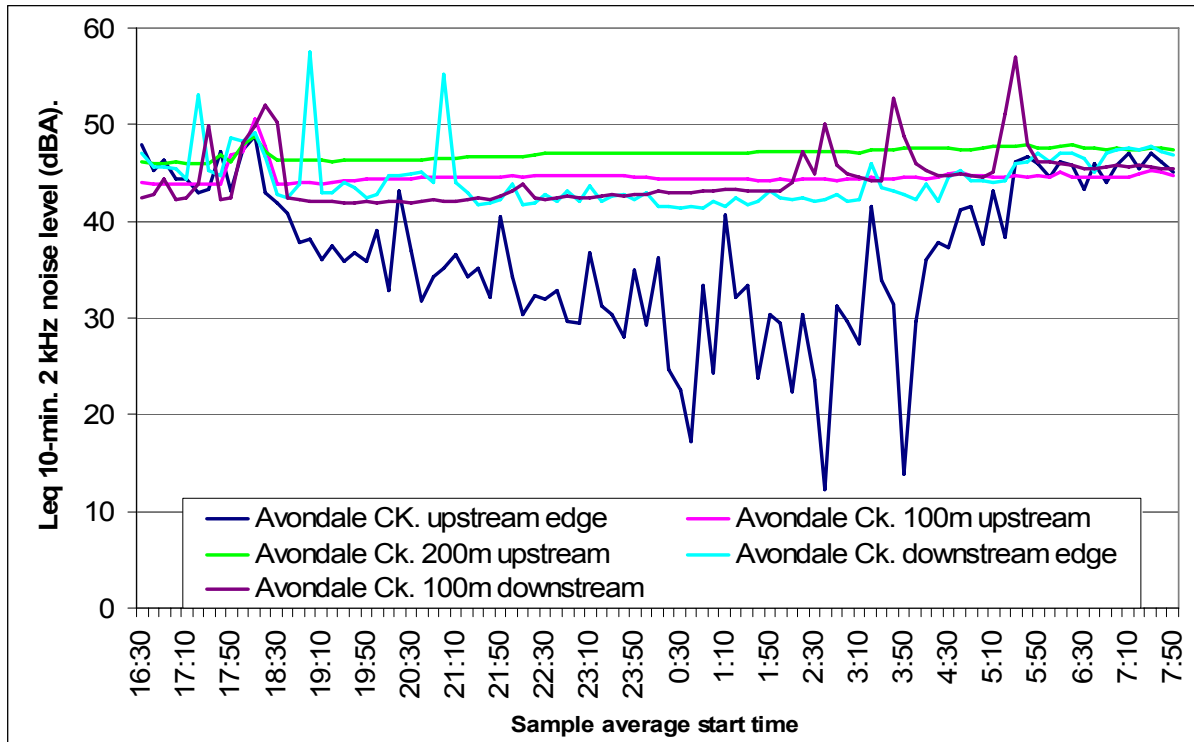


Figure 12: The effect of flowing water or its absence (upstream edge) on 2 kHz band noise levels at edge and interior sites along Avondale Creek. Spikes in noise at one hundred metres downstream edge and one hundred metres downstream are due to rainfall events during the night.

Table 3: Noise levels and dominant frequency (in red) for noise from water sources at all sampling sites located beside flowing streams⁵.

Site	Third-octave frequency band (Hz)					
	1000	1250	1600	2000	2500	3150
Avondale Creek Edge	41.32	42.15	42.31	42.30	42.11	42.51
Avondale Creek 100m Upstream	43.85	45.37	43.46	44.39	45.70	45.23
Avondale Creek 100m Downstream	42.91	44.07	42.93	43.98	44.92	43.93
Avondale Creek 200m Upstream	42.43	44.11	44.82	47.13	46.60	46.28
Water Point Edge Upstream	46.14	47.91	49.63	49.85	50.54	49.93
Water Point 100m Upstream	42.32	45.54	45.18	44.32	44.27	43.65
Water Point 200m Upstream	28.60	30.49	32.88	34.97	36.74	38.76
Streets Creek Edge Upstream	41.39	42.51	42.78	43.43	44.37	42.94
Streets Creek Edge Downstream	43.32	45.39	46.37	46.56	46.06	44.97
Streets Creek 100m Downstream	46.85	46.75	47.28	46.91	45.99	44.19
Mean	41.92	43.43	43.76	44.38	44.73	44.24

Note: Noise levels averaged over four hours (23:30 hrs to 03:30 hrs) to minimise bias due to bird vocalisations.

⁵ The apparent anomaly at site one (Avondale Creek downstream edge) is due to high level of cicada activity dominating the 3.15 kHz band.

1.3.3.4 Effect of biotic activity and vocalisations

Noise from stream flows and rain showers has the potential to mask both faunal vocalisations and traffic noise (Figures 13 and 14). However, by utilising frequency bands towards the upper end of the third-octave spectrum insects and other fauna (for example, bats) can avoid interference from these sources. Some cicada species such as those occurring in the vicinity of Avondale Creek call in the 12.5 kHz band at sufficient amplitude to overcome masking from rain and wind (Figure 14). This species apparently expends most energy in the higher harmonics of its vocalisation, while a harmonic in the 3.15 kHz band with lower energy is prone to acoustic blanketing from rain (Figures 13 and 14).

1.3.3.5 Effect of temperature and relative humidity

Traffic flows (Section 1.3.1.3) may not be the only contributor to the nocturnal dip in noise levels, with the effect of local microclimate a possible influence in lower frequency bands. Relationships between third-octave frequency band noise levels from 31.5 Hz to 315 Hz at the Streets Creek acoustic refuge and selected climate variables were analyzed by Pearson product moment correlation. When tested against temperature, noise levels were found to be moderately correlated in the 100 Hz and 125 Hz bands (Table 4). Noise levels and relative humidity were found to be moderately negatively correlated in frequency bands between 40 Hz and 200 Hz, with only a slight negative correlation in the 1 kHz dominant traffic frequency band (Table 5). This analysis supported the visually observed relationship between nocturnal noise and those climatic variables (Figures 15 and 16). However, it should be noted both that temperature commences to rise and relative humidity starts to fall (06:00 hrs to 07:00 hrs) several hours later in the early morning than noise levels start to rise (03:00 hrs to 04:00 hrs), while noise at dominant traffic frequency of 1 kHz starts to rise from 4:00 to 05:00 hrs in the acoustic refuge. The temperature and relative humidity correlations may possibly simply be correlated with biotic noise and vestigial traffic noise in the acoustic refuge rather than be effecting noise propagation *per se*.

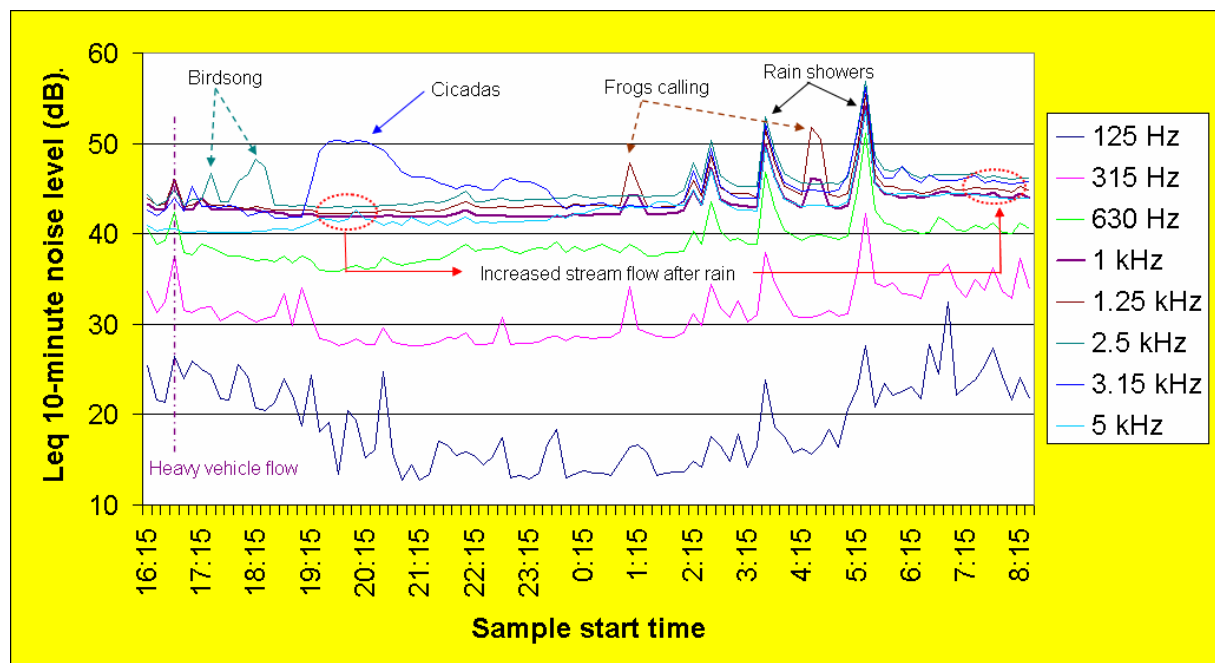


Figure 13: Natural and anthropogenic disturbance to nocturnal ambient noise levels across selected frequency bands one hundred metres downstream from main highway crossing of Avondale Creek, Kuranda Range (22-23 November 2006).

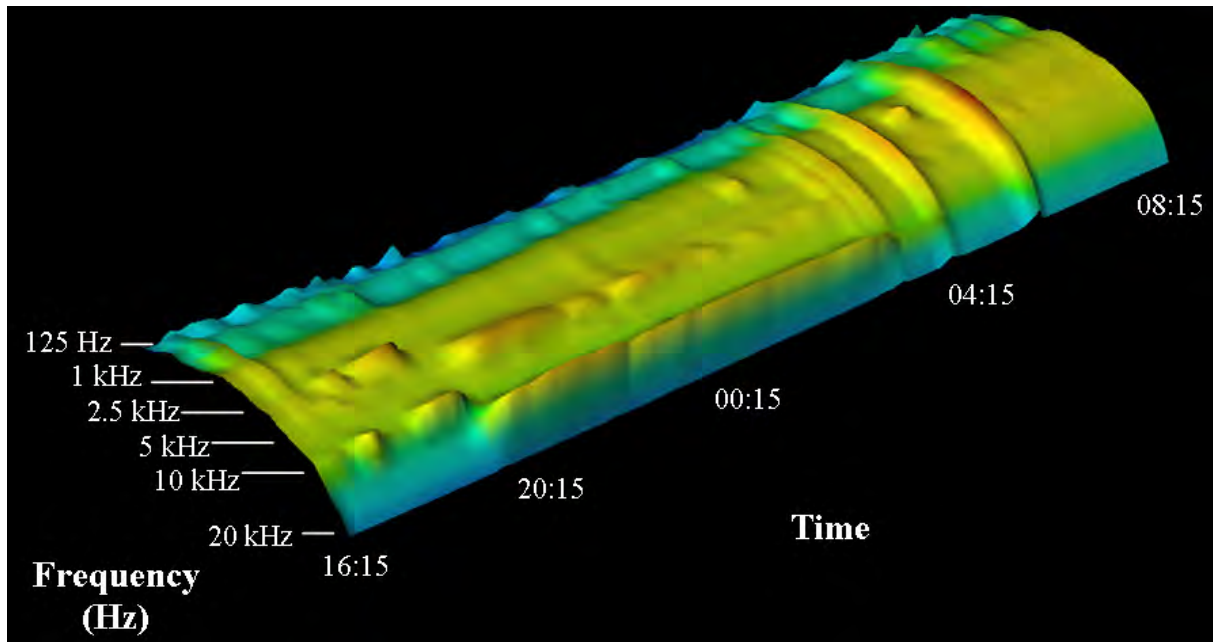


Figure 14: 3-D plot of nocturnal ambient noise levels between 125 Hz and 20 kHz one hundred metres downstream from main highway crossing of Avondale Creek. Note: Colour gradient denotes sound energy level – dark blue is quietest and red is loudest.

Table 4: Significant correlations of temperature and noise levels for low frequency bands between 31.5 and 315 Hz at Streets Creek acoustic refuge.

Hz	100	125
Pearson statistic	0.551	0.541
<i>P</i>	0.033	0.037

Table 5: Significant correlations of relative humidity and noise levels for low frequency bands between 40 and 200 Hz at Streets Creek acoustic refuge.

Hz	40	50	63	80	100	125	160	200	1 kHz
Pearson stat.	-0.525	-0.577	-0.577	-0.575	-0.615	-0.618	-0.545	-0.559	-0.513
<i>P</i>	0.044	0.024	0.024	0.025	0.015	0.016	0.036	0.030	0.050

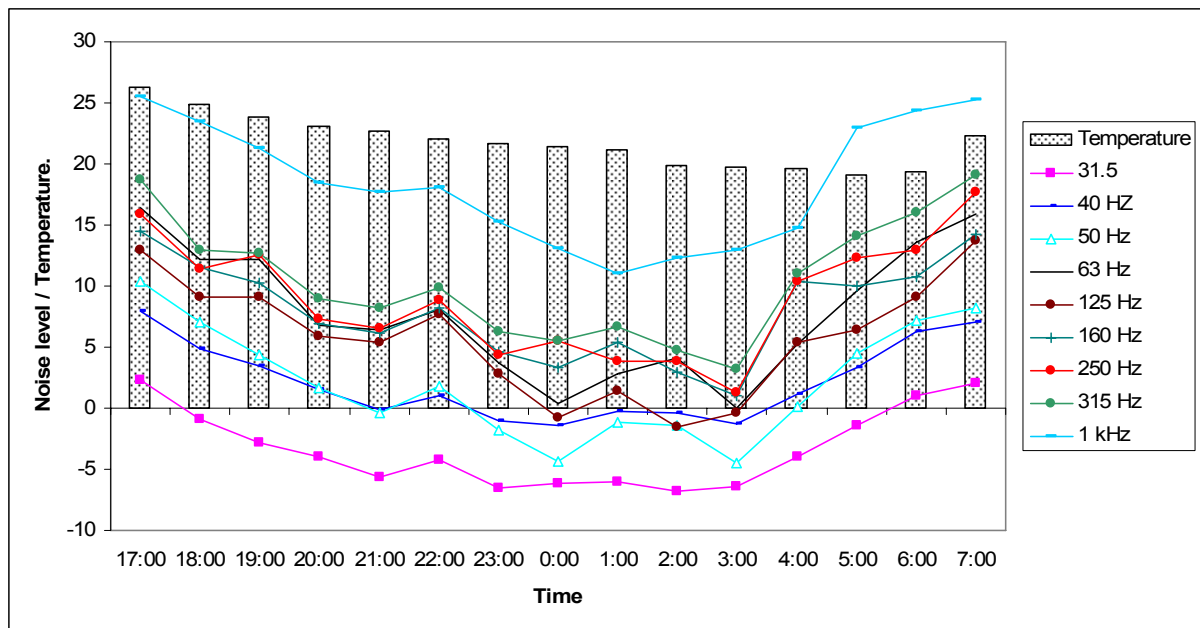


Figure 15: Low frequency and dominant traffic band nocturnal noise levels at Streets Creek downstream acoustic refuge and corresponding ambient temperature.

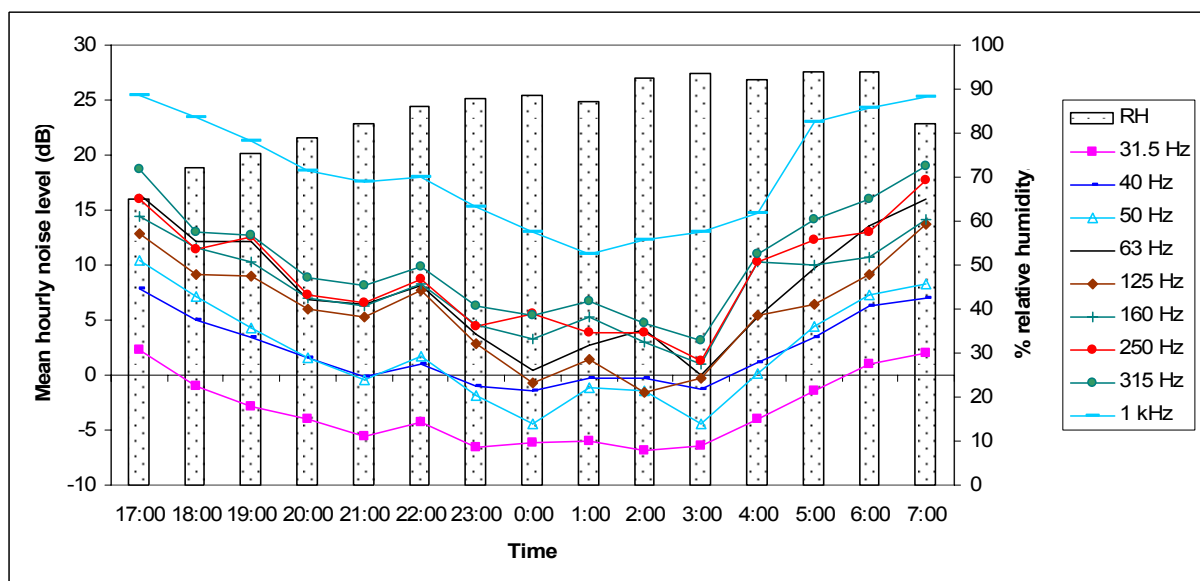


Figure 16: Low frequency and dominant traffic band nocturnal noise levels at Streets Creek downstream acoustic refuge and corresponding relative humidity.

1.3.4 *L_x noise descriptor levels at acoustic refugia compared with stream sites*

1.3.4.1 *L₁ and L₁₀ noise levels*

Total noise statistics based on the level expected to be exceeded for only ten percent of the sampling period (L_{10}) found Streets Creek acoustic refuge noise levels to be about half those at the edge locations⁶. This site however produced high L_1 levels, most likely due to loud intermittent wildlife vocalisations in the area (Table 6).

1.3.4.2 *L₅₀ and L₉₀ noise levels*

As expected, the refugia also produced very low background levels of noise, with the next quietest nocturnal site being at two hundred metres from the road along Streets Creek. An unexpected anomaly occurred at the upstream edge of Avondale Creek which generated the next lowest L_{90} levels (Table 6). Other L_x descriptors also remained low for this site (although L_{10} and L_{50} levels remained well above corresponding refugia levels). This site, which was the only edge site clear of water-noise, had the microphone positioned well below the level of the road surface at one of the slowest curves on the road (at the northern approaches to Avondale Creek before the lower crossing sign). Presumably the lower traffic speeds combined with the absence of water noise to produce these low data.

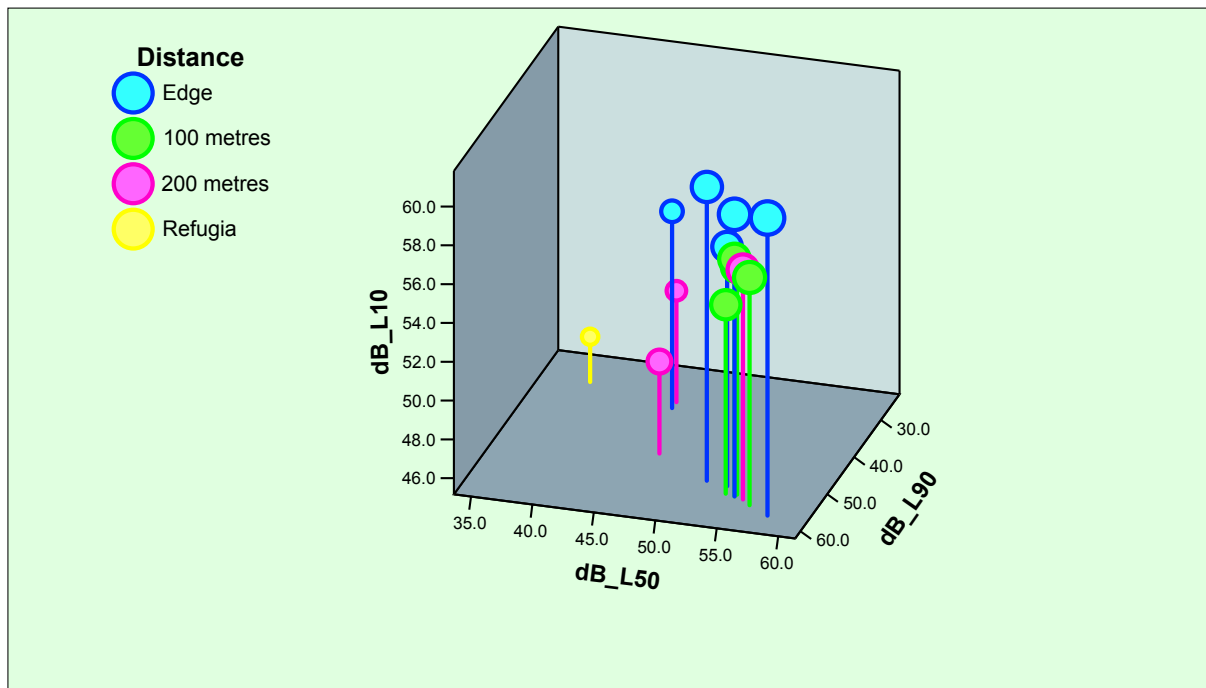
1.3.4.3 *L_x noise level relationships*

The presence of water flows close to all one hundred metre sites combined with the lower levels of traffic noise (producing fewer loud noise events) contributed to the close clustering of the L_x descriptors at this distance (Figure 17). This contrasted strongly with the two hundred metre sites, where the effect of flowing water and faunal vocalisation differed markedly at each site, resulting in a much greater range for the L_x clusters. A similar effect occurred at the edge, although only one site out of four was free from noise from water sources compared to one in three at two hundred metres. As with the background noise levels, the acoustic refuge downstream from the Streets Creek bridge produced the lowest combined data for the three plotted L_x descriptors (Figure 17).

⁶ L_x descriptors were displayed in the buffer of the SLM. The buffer was unavailable for the upper Streets Creek acoustic refuge due to limitations in battery capacity from that site's 24-hour sample.

Table 6: Noise levels across time percentage descriptors.

Sampling location	Noise descriptor			
	L ₁	L ₁₀	L ₅₀	L ₉₀
Streets Creek Refuge Downstream	64.6	47.5	37.7	29.9
Streets Creek Edge Downstream	65.3	59.7	54.6	53.5
Streets Creek Edge Upstream	72.3	60.3	51.7	50.5
Streets Creek 100m Downstream	69.7	56.9	56.2	55.2
Streets Creek 200m Downstream	65.3	50.9	45.2	32.1
Avondale Creek Edge Downstream	65.2	57.5	53.5	51.2
Avondale Creek Edge Upstream	64.5	55.3	45.2	33.7
Avondale Creek 100m Downstream	64.1	56.9	54.7	53.0
Avondale Creek 100m Upstream	60.7	57.4	54.6	53.5
Avondale Creek 200m Upstream	58.7	57.0	55.4	54.0
Water Point Edge Upstream	69.0	60.5	58.1	57.2
Water Point 100m Upstream	61.8	54.9	53.8	53.1
Water Point 200m Upstream	59.3	49.9	46.7	45.3
Mean dB all sites	64.65	55.75	51.34	47.86

**Figure 17:** Nocturnal L₁₀, L₅₀ and L₉₀ noise level relationships over distance for all sites except upper Streets Creek acoustic refuge.

1.4 Discussion

1.4.1 Traffic noise

Nocturnal traffic noise followed a similar pattern as demonstrated by diurnal noise (Dawe and Goosem 2007), in that it decreased with distance from the traffic noise source, with sites at two hundred and one hundred metres inside the forest quieter than those at the highway edge. When compared to areas designated as acoustic refugia, however, sites at two hundred metres from the highway edge had noise levels which were still elevated above ambient, particularly in the lower and dominant traffic noise bands, demonstrating that, similarly to diurnal traffic noise, traffic noise at night penetrates long distances through rainforest at ground level.

At edge locations where traffic noise was not masked by noise from stream flows and cascades, total A-weighted nocturnal noise and noise from the 1 kHz dominant traffic-noise band were both strongly correlated with traffic flow. Much of the apparent “beneficial” masking of traffic-noise at edge sites by water sources is actually a function of the microphone location which was always well below road height, being usually between one and two metres above the surface of the stream, and generally between three and fifteen metres from the highway edge. All the edge noise levels at morning and evening commuter peaks are lower than those recorded during the earlier diurnal study (Dawe and Goosem 2007). This is mainly due to the shielding effect from the edge and bridge sides on the propagation path to the microphone at the stream below together with increased distance from the highway edge to microphone at some sites to ensure that the microphone was placed close to the stream. In this study, placing the microphone close to the stream was important so that recorded noise levels included that generated by flowing water, as would be experienced by stream-dwelling amphibians, the target vertebrate group for this nocturnal noise study.

Mean total noise levels from sites at all distances reached a nocturnal minimum at about 02:30 hrs for both the C- and linear-weightings, which equated to the observed traffic flow minimum, and a minimum about an hour later for the A-weighted noise. Total noise levels from each of the three weighting filters varied significantly over the 16:30 to 07:30 sampling period, suggesting that more attention should be paid to weighting filters other than the anthropocentric A-weighting in future wildlife noise studies, as lower frequency noise may be more relevant to other fauna than it is to humans.

In the mid to low frequency bands of the spectrum, noise levels appeared to correspond with daily commuter traffic peaks, particularly at edge sites, and this correspondence was also detectable and significant at greater distances. This is consistent with the findings of a number of researchers who have shown that vehicle and traffic noise tends to have its greatest effect in the lower portions of the spectrum (Attenborough 1991; Jonasson 2005) and also accords with findings regarding diurnally-generated traffic noise on the Kuranda Range (Dawe and Goosem, 2007). This alteration to the spectrum due to traffic could also be distinguished in mid and upper spectrum frequencies in areas where water noise and cicada calls were not loud. However, the noise generated from flowing water did mask the traffic noise to varying degrees in the mid and upper spectrum.

1.4.2 Acoustic refugia

At the acoustic refugia (including Streets Creek at two hundred metres) in the middle of the night (23:30 hrs to 03:30 hrs), noise levels from the dominant traffic-noise band were less than half those of the next quietest location (Water Point two hundred metres from the road). The quietest edge location during the same period (Avondale Creek upstream edge)

demonstrated noise levels more than three times as loud as the refugia for the same period in the same 1 kHz band. During the evening commuting period, noise in the 1 kHz band was more than four times as loud at the latter site than at corresponding refugia locations (Figure 7).

Therefore, two of the refugia designated using topographic criteria in the diurnal noise report (Dawe and Goosem 2007) have been verified as providing quiet habitat for fauna that communicate using sound. As similar criteria were used to distinguish all the refugia designated in that report, we feel confident that acoustic refugia occur in the mapped areas. However, it must be recognised that the mapped boundaries provide only an indication of the extent of the refuge, rather than representing measured values.

The only correlations between temperature and spectra noise levels occurred in two low frequency bands at acoustic refugia. As amphibian call pulse-rates and repetition rates are temperature dependent (Hoskin, *pers. comm.*), the independence of noise from the nocturnal temperature dip may be important in helping to maintain plasticity of vocalisations within the amphibian community in acoustic refugia. The degree of importance of the low frequency noise / climatic correlations on vocalisations from other fauna remains obscure. However, with deep-pulsed booming of the southern cassowary (*Casuarius casuarius*) recorded from wild birds (albeit in Papua New Guinea) with frequencies as low as 32 Hz (Mack and Jones 2003), such effects may be worthy of future investigation. Any future climatic perturbations within the acoustic refugia, whether from global climate change, increased heat radiation due to greater highway loadings or the new road alignment, could pose a threat to the current noise / climate relationship.

1.4.3 Noise and amphibian habitats

Flowing streams generated noise that was capable of dominating the acoustic spectrum, masking bands utilised by many bird and frog species for communication, as well as bands covering the upper range of traffic-noise. However, as the microphone position was often quite close to water-noise sources relative to sources of traffic-noise, the apparent dominance of the acoustic environment by water sounds rather than traffic-noise is misleading. No relationship was found between the distance between microphone and water source and the sampled noise level, with an apparent combination of site-specific factors such as stream flow rate, height and number of nearby cascades, and relative height of microphone with respect to torrent influencing background noise levels. Distances of the microphone from the adjacent stream surface ranged from approximately three metres to fifteen metres. While one of the closest propagation distances (Water Point edge) did produce the loudest ambient water noise (Table 3), neither of the next two loudest recordings came from either of the next two closest sources. The second and third loudest water noise contributions to the ambient spectrum came from sources at six and ten metres from the microphone.

Rain produced broad-band noise that blanketed noise from all other sources including traffic if the shower was particularly intense. Presumably local frog species have successfully evolved to compete with noise from rain, streams and wind sources through adaptations such as call structure and timing, along with amplitude and frequency adjustment. Studies have shown that males from many frog species space their calls to avoid blanketing calls from neighboring conspecifics, thus retaining the integrity of temporal coding necessary for female attraction (Schwartz 1987). The same technique may well be adopted to help avoid overlap with other natural and anthropogenic noise intrusions provided such intrusions are of minimal duration and relatively infrequent. For example, it appears that frogs at Streets Creek do not call very often during heavy rain showers but commence calling immediately afterwards, thereby avoiding the blanketing of calls by rain (Hoskin, *pers. comm.*). Currently, it may be possible for frogs that call in frequency bands similar to those dominated by traffic

noise to avoid traffic noise blanketing by calling during the relatively quiet traffic flow periods in the middle of the night, even though most species are recognized to prefer to vocalise more often in the first half of the night in their attempts to attract a mate during the night (Hoskin, *pers. comm.*). However, choosing such a later calling time may not be possible if traffic levels during the evening increase, and is probably currently impossible during the early evening commuter peak (the naturally preferred calling time).

Not all of these adaptive measures are likely to prove practical or feasible for frog species. Research on tropical frog species elsewhere suggests that adjustment of dominant frequencies of advertisement vocalisations may face morphological restrictions particularly in relation to body size (Kime *et al.* 2002). This, and the limited evolutionary time for adaptation to traffic-noise may tax the ability of local frog species to co-habit with road transport, particularly where new road alignments result in rapid rises in proximate ambient noise levels.

Amphibian species most likely to be placed at risk by traffic noise propagation through their habitat would be those that communicate in the lower frequencies (between 630 Hz and 2 kHz, Figures 8 and 11). Figure 13 shows frog species calling in the 1 and 1.25 kHz bands. Traffic noise can significantly impede recognition by amphibian females of the male's mating call (Barrass and Cohn 1983) and alter the spacing between conspecific calling males (Barrass and Cohn 1984). Similarly, females may not be able to find the calling male under traffic noise conditions, males may not form chorus groups and therefore reproductive output in the form of eggs can be reduced (Barrass 1986). Low frequency airborne sounds from aeroplane engines suppresses calling in some species (Sun and Narins 2005), and encourages calling in another that generally would wait until there was a natural lull in calling by the first group of species. Several Kuranda Range species fall into a group calling in that range including *Litoria rheocola*, *Litoria genimaculata*, *Mixophyes coggeri* and *Litoria nannotis* (although the latter species has not been recorded recently in the Kuranda Range area, Hoskin, *pers. comm.*). However, those calling in the region of dominant frequencies for flowing water (2.5 kHz) might be expected to already utilise means to avoid the blanketing effect of water, such as calling after water noise from rain events subsides. Such a mechanism might be similarly used to avoid traffic noise, provided the anthropogenic noise was not continuous throughout the night every day. Once traffic reaches a certain level throughout the night, however, such a mechanism cannot be successful.

1.5 Conclusion

Nocturnal traffic noise penetrated the rainforest adjacent to the current Kuranda Range road to distances of at least two hundred metres. Nocturnal noise levels adjacent to the existing Kuranda Range Road are significantly influenced by the rate of traffic flow and the presence or absence of flowing water. Edge noise levels are strongly correlated to traffic-flow rates for both the dominant traffic band and total noise levels. The acoustic spectrum at the highway edge is similarly influenced by both time and the distance between the sampling point and flowing water. This spectrum displays a gradual erosion of noise levels in the bands below 2.5 kHz after the evening commuting peak, reaching a minimum at around 02:30 hrs before building to another peak after dawn.

Nocturnal noise levels in the third-octave spectrum and total noise values are significantly influenced by distance and topography and moderately influenced by some climatic factors, although heavy rain produces a considerable acoustic impact. A number of frog species that call in the frequency bands close to the dominant traffic frequency of 1 kHz may be affected by traffic noise impacts, although some may be able to employ methods used to avoid acoustic blanketing by stream noise to also avoid some of the impacts of traffic noise, at least while there are pauses in traffic noise during the night.

The location of acoustic refugia behind topographic features contributes to both low noise levels in the dominant traffic bands and enhanced nocturnal faunal vocalisation activity in these locations. The existence of two of these acoustic refugia designated in the diurnal noise study using topographic criteria has been confirmed by noise measurements undertaken in the current study. A similar topographic buffering effect (albeit on a much finer scale) occurs at the edge, where the new microphone positioning close to the same elevation as the stream, sees much of the traffic noise passing overhead, avoiding the amphibian habitat. This effect would be likely to improve as bridge heights increase, although the extent of increased vibrations associated with these larger structures and consequential environmental impact remains unclear. The effect of ground transmitted vibration on many taxonomic groups is still poorly understood.

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2. Disturbance and edge effects on frog abundance and diversity: Kuranda Range Road

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Summary

Frogs were surveyed along permanent streams that cross the Kuranda Range road to examine whether species diversity or abundance of any species alter adjacent to the road. Species diversity *per se* did not appear to be affected by distance from the road, although lower species diversity was observed on Avondale Creek transects in comparison with Streets Creek. A pattern of density change away from the road was detected on both the Streets Creek transects. On the upstream Streets Creek transect *Litoria rheocola* showed a highly significant increase in density moving away from the road; while on the downstream Streets Creek transect *Austrochaperina pluvialis* also showed a highly significant increase in density away from the road. The decline in density of *L. rheocola* was ascribed to road impacts. The mechanism for the decline in *L. rheocola* is likely to be the impact of traffic noise, as areas of the transect further from the road are noticeably quieter, and no other factor appeared to be a likely cause. It is more difficult to ascribe a causative factor for the decline in *A. pluvialis* but as a terrestrial species, chance microhabitat effects, particularly in moisture, the position of rocky areas and their slope may be involved in this edge effect. Road mortality was not likely to cause either decline as both species are rare in road kill statistics. *Litoria genimaculata*, a species that is more commonly killed showed no decline away from the road ascribable to this mortality. Interestingly, the feral cane toad, *Bufo marinus*, was rarely found on the streams in this survey, although it is a very common road victim. This suggests that cane toads use the Kuranda Range road and its verge as a movement corridor but seldom venture into the dense vegetation of the rainforest.

2.1 Introduction

2.1.1 Background

Many of the ecological impacts of rainforest roads are now well-recognised (Goosem 2004). They include road mortality, habitat loss from clearing and habitat degradation adjacent to the road caused by edge and disturbance effects and pollution together with invasions of weeds, feral animals and fauna alien to the surrounding rainforest. Together this suite of impacts can combine to create barrier effects where animals will not venture onto or across the road. However there is little information regarding the impacts of roads and highways on rainforest amphibians. The exception is data from road kill monitoring on the Kuranda Range road from the early 1990s which was repeated in 2005/2006 (Goosem 2000a, 2006, Goosem and Weston 2007). A variety of other impacts emanating from roads and highways have the potential to affect amphibians. These include traffic noise and headlight disturbance, water quality reductions caused by pollutants in road runoff, edge effects on microclimate that alter streamside vegetation and stream temperature and light penetration, the presence of weeds and feral amphibians along the road verge with the potential to penetrate the forest proper and linear barrier effects that prevent normal movements through the forest or in the stream.

The current lack of understanding of road impacts on amphibians is caused by the depauperate nature of studies in the scientific literature. Another problem arises from the difficulty of demonstrating cause and effect of an impact. For example, although several studies have found reductions in amphibian populations adjacent to roads, the causative factor was unable to be established due to the potential for a number of road impacts to cause population declines. Road mortality, deaths due to poor water quality caused by pollution or erosion and sedimentation or avoidance of road edge habitat could all cause population declines near roads. Road avoidance itself could be the result of several impacts related to disturbance. These include traffic noise impacting on communication, traffic movement causing a behavioural response, headlights disturbing frogs in habitat near the road or changes to edge habitat in terms of microclimate and consequent vegetation alterations making stream or terrestrial habitat less attractive to rainforest species.

2.1.2 Amphibian population declines near roads

Studies in Switzerland, Canada and the Netherlands have demonstrated population declines near roads. Low densities of European tree frogs (*Hyla arborea*) have been related to traffic nearby and the species was more likely to be missing from breeding ponds close to roads (Pellet *et al.* 2004a, 2004b). Similarly in the Netherlands, Vos and Chardon (1998) found that the likelihood of moor frogs (*Rana arvalis*) to occupy breeding ponds was negatively related to traffic density in the vicinity. Vos and Chardon (1998) not only examined the strength of the chorus but also counted tadpoles, egg clusters, juveniles and adult frogs in ponds and their surrounds to achieve their overall population assessment, assuming sex ratios to be equal. They suggested that road mortality may be the cause of population declines, but could not dismiss other potential factors such as fragmentation of populations by roads or traffic noise or avoidance of vehicle movement.

However, a study in Canada found that road kill of frogs and toads on three paved double-lane roads with traffic volumes varying between five hundred and thirteen thousand vehicles per day was related to traffic volume, as well as day and time (Fahrig *et al.* 1995). As traffic volume increased, density of frogs and toads decreased according to measurements of intensity of calls in the nightly chorus and the number of individuals identified. The authors believed that this decline was due to road mortality, but could not discriminate between loss of animals through road kill and avoidance of traffic noise or failure to breed due to blanketing of breeding calls by traffic noise. Densities of a wide-ranging North American frog have also been found to be negatively correlated with traffic intensity up to distances of 1.5 km from their breeding sites, whereas more sedentary species are not affected (Carr and Fahrig 2001). Therefore it appears that species undertaking long seasonal migrations are those most likely to be affected by mortality on roads (Carr and Fahrig 2001, Ervin *et al.* 2001, Hels and Buchwald 2001).

In Australian urban areas of Melbourne, Parris (2006) has found a decrease in species richness that is associated with increasing density of roads and outweighs other habitat factors such as pond area and habitat quality. In this study, road density increases the degree of isolation of urban pond habitats from other ponds and reduces the probability of recolonisation following local extinction, as animals need to cross more roads to move between breeding sites. Parris (2006) suggested that the probability of multiple successful crossings through a landscape covered densely by roads would be close to zero.

Avoidance of roads with high levels of traffic is also a possibility. For example, in Canada, Mazerolle (2004) found that road kill of some species, including the spring peeper (*Pseudacris crucifer*) increased with decreasing traffic, suggesting avoidance of the road when traffic intensity was high. Another group of ranid frogs suffered greatest road kill at moderate traffic intensities, and may avoid the road when traffic levels are higher. In other species, such as the American toad (*Bufo americanus*), road kill increased with increasing

traffic levels (Mazerolle 2004). Therefore it appears that road or traffic avoidance may occur in some species such as the spring peeper and ranids but not others such as the American toad. Both car noise and headlights caused amphibians to stop moving and therefore become likely road kill victims (Mazerolle *et al.* 2005). However, in this case road mortality did not appear to result in declining populations adjacent to the road (Mazerolle 2004).

Although high traffic noise level is not a factor on forestry roads in North America, salamanders appear to perceive such roads as a barrier to movements (Gibbs 1996, DeMaynardier and Hunter 2000, Marsh *et al.* 2005). In contrast, cane toads (*Bufo marinus*) tend to use roads as a movement conduit and route for dispersal (Seabrook and Dettman 1996, Goosem 2000, 2006, Brown *et al.* 2007).

Amphibian declines adjacent to roads may also be caused by decreased water quality, although sensitivity is variable among species and species groups. Amphibians react to environmental pollutants because of their permeable skin and eggs, their position in the food web as mid-level consumers (which allows bioaccumulation of toxins to some degree), and their potential for prolonged exposure to contaminants of aquatic habitats (Bishop 1992). In particular, polycyclic aromatic hydrocarbons such as those found in tyre leachates can be toxic to tadpoles at extremely low concentrations (Monson *et al.* 1999) and herbicide surfactants are toxic to tadpoles in laboratory experimental doses (Mann and Bidwell 2001). Heavy metals are also toxic to amphibians, particularly tadpoles, but concentrations that have noticeable effects appear high (Birge *et al.* 1977), in comparison with hydrocarbons.

Road maintenance practices and road operation also have the potential to contribute to the movement of frog diseases such as the chytrid fungus in the landscape. When conditions are suitable this pathogen causes catastrophic declines in susceptible amphibian species.

2.1.3 Traffic noise and frogs

As described above, disturbance by traffic noise may be the reason for population declines near roads, although it is difficult to eliminate other factors. However there is evidence that shows that traffic noise can also impact in other ways. For example, acoustic interference from background noise can inhibit detection of frog calls (Wollerman 1999) and discrimination between callers (Wollerman and Wiley 2002). Traffic noise has been demonstrated to have impacts on the breeding behaviour of North American woodland frogs through impeding recognition of male calls by females (Barrass and Cohn 1983), by altering the spacing between males who then fail to form into calling groups (Barrass and Cohn 1984), and by reducing reproductive output as demonstrated by the production of egg masses (Barrass 1986). Although the effect of traffic noise on amphibian community dynamics has not yet been examined, noise from aeroplanes flying by and from motorcycles has been shown to cause a differential effect on the calling rate of a variety of frog species in ponds in Thailand. Three species decreased their calling rate and another increased its calling as it normally calls when there is a lull in the calls of the other three species (Sun and Narins 2005). This is a similar effect to that seen in natural systems when the loud chorus of cicadas (Paez *et al.* 1993) or other frogs (Oldendaal *et al.* 1986, Narins 1992, Matsui *et al.* 1993,) results in certain species avoiding vocalisation or timing their calls to fit in the brief silent periods (Schwartz 1991). Highway traffic noise could be expected to have a similar effect Traffic noise may also cause bird species to call at a higher pitch (Dawe and Goosem 2007). A similar effect may be observed for frogs (see Section 3) (Catchpole 2004, Ainley North 2007).

2.1.4 Aims and research question

This project aimed to assess whether the Kuranda Range road impacts on the abundance and diversity of stream frogs.

We examined frog density in relation to the Kuranda Range road.

Research question:

Did frogs occur at lower density near the road?

Five road-side stream transects were monitored six times over a six-week period during the wet season and the data was used to assess the abundance of several species of frog in relation to distance to the road.

Prediction:

Frogs will be less abundant on stream habitat near the road.

This could be caused by disturbance from traffic noise or from other road impacts such as edge effects or road mortality.

2.2 Methods

2.2.1 Frog survey transects

2.2.1.1 Transect selection

Sections of permanent stream crossed by the Kuranda Range road were chosen for transects starting at the road edge, which followed along the streams for a sufficient distance that the impacts of road noise on frogs was likely to be nil. This distance was initially taken to be around one hundred metres perpendicular straight line distance from the road, but was later thought likely to be significantly less (e.g. fifty metres) given the dominance of stream noise on the transects found in the concurrent nocturnal traffic noise study.

Frogs found on stream transects at night are primarily calling males. These males exhibit limited movement in a night or across nights so their position on transects is likely to indicate a reasonably permanent calling position on the stream.

Five replicate transects were chosen along sections of stream crossed by the Kuranda Range road. All transects were on flowing streams and followed the stream bed path through rainforest, beginning at the forest edge adjacent to the road. Three of the five transects were two hundred metres long, one was 125m long, and one was 325m long. Transects continued until a perpendicular straight line distance of at least one hundred from the road had been achieved. Variation in the overall orientation of the streams meant that this aim was achieved rapidly (125m) in one transect (which ran largely perpendicular to the road with little deviation in course), but over longer stream bed distances (200, 200, 200, 325 metres) on the other four (particularly the 325m transect, where the stream flows parallel to the road for some distance).

Transects were situated on:

1. Avondale Creek, 200m downstream from lower road crossing;
2. Avondale Creek, 200m upstream from lower road crossing;
3. Avondale Creek, 125m upstream from upper road crossing ('water point');
4. Streets Creek, 200m downstream from road crossing; and
5. Streets Creek, 325m upstream from road crossing.

Transects also provided variation in habitat between the replicates. The Avondale Creek transects occur on the drier, steeper eastern slope of the Kuranda Range, whereas the Streets Creek transects are on the wetter, more gently sloping western side of the Kuranda Range. Variation in elevation was also included, with the two lower Avondale Creek transects being approximately one hundred metres above sea level, whereas the upper Avondale Creek transect and the two transects on Streets Creek were at mid elevations (approximately three to four hundred metres above sea level).

2.2.1.2 Transect descriptions

Transects can be described as follows:

The two lower Avondale Creek transects (downstream and upstream) were rocky and reasonably steep, with moderate water flow but plenty of cascades and also some slow pools, and were surrounded by 'drier' rainforest than the other transects.

Upper Avondale Creek transect was rocky and very steep with low water flow, and primarily comprised water flowing over and between rocks, surrounded by 'wet' rainforest.

The two Streets Creek transects were of moderate flow, reasonably flat and meandering, with shallow riffle sections and small cascades separated by slow pools, had gravelly and rocky sections, and were surrounded by well developed 'wet' rainforest.

Characteristics of transects are summarised in Table 7. Variation between transects encompassed most variability in stream frog habitats on the Kuranda section of the MacAlister Range.

All transects started from the edge of the road culvert and were measured by walking up the middle of the stream bed using a hip chain and spooling cotton. A piece of flagging tape was tied to a plant stem every twenty-five metres. The distance was recorded on the tape and a piece of adhesive reflective tape was attached to allow location of the marker at night.

Two methods were later employed to determine the path of the stream transect in relation to the road. Firstly, a GPS position was recorded every twenty-five metres along each transect. However, the thick canopy cover meant a number of the positions could not be determined accurately. The second approach was to measure the orientation and distance of each section of the stream and then plot its path on a map provided by Queensland Department of Main Roads, on which the path of the Kuranda Range Road was already accurately plotted. Using this approach, the perpendicular straight line distance between every ten-metre point along the stream transect and the nearest point on the road was calculated.

Table 7: Characteristics of frog survey transects.

Transect name	Avondale Creek Downstream	Avondale Creek Upstream	Avondale Creek Water Point	Streets Creek Downstream	Streets Creek Upstream
Length (m)	200 m	200 m	125 m	200 m	325 m
Elevation (m)	120 m asl	140 m asl	350 m asl	360 m asl	350 m asl
Start position	16° 50' 37.56" 145° 40' 48.00"	16° 50' 37.68" 145° 40' 46.98"	16° 50' 44.28" 145° 40' 22.32"	16° 49' 39.42" 145° 39' 15.12"	16° 49' 36.54" 145° 39' 15.78"
Finish position	16° 50' 35.04" 145° 40' 52.68"	16° 50' 37.62" 145° 40' 40.80"	16° 50' 47.04" 145° 40' 19.62"	16° 49' 39.96" 145° 39' 11.82"	16° 49' 32.52" 145° 39' 22.74"
Relief	mod. steep	mod. steep	very steep	flat	flat
Substrate	rocky	rocky	Rocky	gravelly/rocky	gravelly/rocky
Flow	moderate	moderate	Low	moderate	moderate
% cascades	52.5	60.0	76.0	17.5	12.3
% riffles	20.0	7.5	20.0	15.0	47.7
% pools	27.5	32.5	4.0	67.5	40.0
Habitat	'drier' rainforest	'drier' rainforest	'wetter' rainforest	'wetter' rainforest	'wetter' rainforest
Frog Diversity	5 spp.	6 spp.	3 spp.	7 spp.	7 spp.
Abundant species			<i>A. pluvialis</i> <i>L. genimaculata</i>	<i>A. pluvialis</i>	<i>A. pluvialis</i> <i>L. rheocola</i>
Moderately common species	<i>L. genimaculata</i>	<i>L. genimaculata</i>	<i>C. ornatus</i>	<i>L. genimaculata</i>	<i>L. genimaculata</i> <i>C. ornatus</i>

2.2.1.3 Habitat descriptions

Habitat data was recorded for every five-metre section along the stream transects. Stream habitat was broken into several broad categories:

- 'Cascades' (rushing flow dropping over or between rocks);
- 'Riffles' (shallow, generally dispersed flow over gravel or small rocks); and
- 'Pools' (deeper sections of stream where flow appears minimal).

The dominant habitat type for each five-metre section of stream was recorded; allowing differences in the stream habitat between transects to be quantified. Figure 18 demonstrates the types of habitats found on the transects.

2.2.2 Frog survey techniques

Transect surveys were conducted between 22/01/07 and 28/02/07. All transects were surveyed six times during this period (once per week) in order to provide replicates incorporating temporal variation in abundance. Conditions during the survey period were ideal for frog breeding activity, with the weather being warm (23-27°C air temperature during surveys), humid, and with periodic heavy rain. Transects were surveyed at night between 19:00 hrs and midnight, the period when frog activity is greatest.

All frogs detected within five metres of the centre of the stream were recorded. Frogs were detected either by hearing the male breeding call or by sighting the frog. Some species were recorded along the streams almost entirely by sound of calls (e.g. *Austrochaperina pluvialis*), others were detected mostly by sight (e.g. *Litoria genimaculata*), while others were recorded

approximately equally by sight and sound (e.g. *L. rheocola*). Almost all frogs detected were males because:

- (i) Only this sex calls; and
- (ii) Females of most frog species lead a cryptic lifestyle amongst vegetation or substrate, often away from the stream. For each frog, the species, sex, and position along each transect (to within five metres) were recorded.

Plates of all species detected are shown in Figure 19.

2.2.3 Data analysis

The objective of the analysis was to determine, for each transect, if any of the common frog species or the combination of all frog species showed a pattern of change in abundance with increasing distance from the road. The analysis assessed patterns within one hundred metres perpendicular straight-line distance from the road as this was determined in advance to be the maximum likely distance of road impacts on frogs. The analysis involved determining perpendicular straight-line distances to the road for all frog records. Records were then grouped into suitable distance categories for analysis and then, for each transect, calculating a density measure (frogs per metre) for common species and all frog species combined. The final step was to perform linear regressions of this data against distance to the road.

The six replicate data-sets for each stream survey were analysed as separate replicates (rather than being averaged) so as to incorporate diurnal variation in the analyses. The count data for each survey was summed into five-metre stream transect sections for each species. This data was then converted to perpendicular straight-line distances to the road (also calculated to the nearest five metres). The count data was then grouped by twenty-metre distances from the road (i.e. 1-20, 21-40, 41-60 m, etc. from the road). Twenty-metre distance groups were used to incorporate fine-scale variation in habitat and frog positioning along the streams and to ensure sufficient data for statistical analysis, given the low overall abundance of frogs. Grouping the data into twenty-metre distances from the road was considered the best scale for analysis because it overcame vagaries of habitat variation and allowed enough individuals to be incorporated into each group to give accurate estimates of density change with distance.

A frog density measure was then calculated that incorporated the length of stream available to frogs within each twenty-metre distance group. This calculation was required because the data were collected from stream transects that were not perfectly perpendicular to the road but rather travelled away from the road, then parallel to the road, then away again, etc. Therefore, if there was a high count for frogs within a twenty-metre distance group it may either reflect high abundance at that distance from the road or alternatively may be due to a greater length of stream transect at that distance from the road. To avoid this potential confounding issue, standardised abundance measures were calculated by dividing the count for each twenty-metre distance group by the length of stream transect available to the frogs in that distance group. This gave a measure of standardized frog abundance which was then tested for normality before being analysed against distance to the road in linear regressions. The stream transects were all analysed independently because the large discrepancy in overall frog abundance and abundance of individual species between transects meant it was not possible to pool all five transects into a single analysis.

Figure 18: Photographs of transects and stream habitats (all photos were taken on the transects by Conrad Hoskin).



Plate 1: Avondale Creek, rocky section with pools.



Plate 2: Avondale Creek, cascade.



Plate 3: Southern Cassowary, Avondale Creek.



Plate 4: Avondale Creek, steep rocky section at 'water point'.



Plate 5: Streets Creek, shallow gravelly riffles.



Plate 6: Streets Creek, shallow rocky riffles.



Plate 7: Streets Creek, stream pool.

Figure 19: Photographs of main frog species recorded at sampling sites (all photographs taken by Conrad Hoskin).



Plate 1: Tapping Green-eyed Tree frog (*Litoria genimaculata*) (male).



Plate 2: Common Mist frog (*Litoria rheocola*), calling (male).



Plate 3: Northern Stony-creek frog (*Litoria jungguy*) (female).



Plate 4: Rain Whistling frog (*Austrochaperina pluvialis*) (male).



Plate 5: Mottled Barred frog (*Mixophyes coggeri*) (male).

Table 8: Summary of data from nocturnal stream transect surveys. All transects were replicated six times. Table shows total number of records for each species across all transects. For each transect, the number of records on that transect, the average number of individuals encountered per transect visit, and the number of individuals per one hundred metres (a standardised measure of abundance) are shown. Grey shading shows species recorded at an abundance of one to five individuals per hundred metres, black shading shows abundance of more than five individuals per hundred metres. The EPBC status categories included here are E (Endangered) and LC (Least Concern). Two species are newly described and have no EPBC status (shown as asterisk). These two species are common and should be considered LC.

Common name	Species name	EPBC status	Total No.	Avondale Ck downstream (200 m)			Avondale Ck upstream (200 m)			Avondale Ck 'water point' (125 m)			Streets Ck downstream (200 m)			Streets Ck upstream (325 m)		
				No.	No. / visit	No. / 100 m	No.	No. / visit	No. / 100 m	No.	No. / visit	No. / 100 m	No.	No. / visit	No. / 100 m	No.	No. / visit	No. / 100 m
Treefrogs																		
Tapping Green-eyed Treefrog	Litoria genimaculata	LC	295	17	2.8	1.4	37	6.2	3.1	112	18.7	14.9	40	6.7	3.3	89	14.8	4.6
Common Mistfrog	Litoria rheocola	E	189	0	0	0	0	0	0	0	0	0	2	0.3	0.2	187	31.2	9.6
Northern Stoney-creek Frog	Litoria jungguy	*	13	2	0.3	0.2	1	0.2	0.1	0	0	0	8	1.3	0.7	2	0.3	0.1
White-lipped Treefrog	Litoria infrafronata	LC	2	1	0.2	0.1	1	0.2	0.1	0	0	0	0	0	0	0	0	0
Northern Orange-eyed Treefrog	Litoria xanthomera	LC	1	0	0	0	1	0.2	0.1	0	0	0	0	0	0	0	0	0
Southern Frogs																		
Mottled Barred Frog	Mixophyes coggeri	*	9	0	0	0	0	0	0	0	0	0	2	0.3	0.2	7	1.2	0.4
Narrow-mouthed Frogs																		
Rain Whistling-frog	Austrochaperina pluvialis	LC	485	2	0.3	0.2	1	0.2	0.1	74	12.3	9.9	188	31.3	15.7	220	36.7	11.3
Ornate Nursery-frog	Cophixalus ornatus	LC	54	0	0	0	0	0	0	10	1.7	1.3	9	1.5	0.8	35	5.8	1.8
Toads																		
Cane Toad	Bufo marinus	LC	8	4	0.7	0.3	2	0.3	0.2	0	0	0	1	0.2	0.1	1	0.2	0.1
Dragons																		
Eastern Water Dragon	Physignathus lesueurii	LC	33	4	0.7	0.3	2	0.3	0.2	0	0	0	9	1.5	0.8	18	3.0	0.9
Boyd's Forest Dragon	Hypsilurus boydii	LC	2	0	0	0	0	0	0	1	0.2	0.1	1	0.2	0.1	0	0	0
Geckos																		
Northern Leaf-tail Gecko	Saltuarius cornutus	LC	3	0	0	0	0	0	0	3	0.5	0.4	0	0	0	0	0	0
gecko (no common name)	Nactus cheverti	LC	2	2	0.3	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Skinks																		
Shade Skink sp.	Saproscincus basiliscus	LC	2	0	0	0	0	0	0	2	0.3	0.3	0	0	0	0	0	0
Mammals																		
Eastern Tube-nosed Bat	Nyctimene robinsoni	LC	19	0	0	0	4	0.7	0.3	3	0.5	0.4	1	0.2	0.1	11	1.8	0.6
Fawn-footed Melomys	Melomys cervinipes	LC	6	0	0	0	3	0.5	0.3	2	0.3	0.3	1	0.2	0.1	0	0	0
Bush Rat	Rattus fuscipes	LC	6	4	0.7	0.3	1	0.2	0.1	1	0.2	0.1	0	0	0	0	0	0
Birds																		
Lesser Sooty Owl	Tyto multipunctata	LC	5	0	0	0	0	0	0	2	0.3	0.3	0	0	0	3	0.5	0.2
Pale Yellow Robin	Tregellasia capito	LC	4	0	0	0	0	0	0	0	0	0	1	0.2	0.1	3	0.5	0.2
Southern Cassowary	Casuarius casuarius	E	3	0	0	0	1	0.2	0.1	0	0	0	0	0	0	2	0.3	0.1
Azure Kingfisher	Alcedo pusilla	LC	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2	0.1

2.3 Results

2.3.1 Frog species diversity and broad patterns of abundance

A total of 1,146 vertebrate records were obtained from the six replicate surveys of the five transects, of which 1,056 (92%) were frogs. Table 8 provides a summary of the species recorded during the nocturnal surveys of the stream transects, and estimates of abundance of these species. A total of nine amphibian species, five reptile species, three mammal species, and four bird species were recorded.

Frog species diversity recorded in the vicinity of the Kuranda Range road as a whole in these surveys was high. This diversity comprised four amphibian families, Hylidae (five species), Myobatrachidae (one species), Microhylidae (two species), and Bufonidae (one species). The Bufonid species, the Cane Toad (*Bufo marinus*), was recorded on four of the five transects but very rarely and never breeding. This was the only introduced animal species recorded during the surveys. Large numbers of three frog species were recorded (*Austrochaperina pluvialis*, *Litoria genimaculata* and *L. rheocola*), one species was moderately common (*Cophixalus ornatus*), while the remaining species (*L. jungguy*, *L. infrafrenata*, *L. xanthomera*, *Mixophyes coggeri* and *B. marinus*) were rarely recorded on the stream transects. *A. pluvialis*, *L. genimaculata*, *L. rheocola*, *C. ornatus* and *M. coggeri* were all calling and breeding on the streams during the survey period, whereas only foraging individuals of *L. jungguy*, *L. infrafrenata*, *L. xanthomera* and *B. marinus* were recorded on the transects and no breeding activity was observed.

Frog species diversity varied across transects, and was generally lower on the Avondale Creek transects (downstream, five spp.; upstream, six spp.; 'water point', three spp.) than the Streets Creek transects (both 7 spp.). Frog abundance was noticeably low on the two lower Avondale Creek transects compared to the 'water point' transect on Avondale Creek and the two Streets Creek transects. There were some clear differences in species composition across the transects (Figure 20), the most noticeable being the abundance of the endangered species *Litoria rheocola* on the upstream Streets Creek transect (approximately ten individuals per hundred metres) compared to its absence or rarity on all other transects, including the adjoining downstream Streets Creek transect. *Litoria rheocola* was very rare on the downstream Streets Creek transect (0.2 individuals per hundred metres) and was not recorded on any of the Avondale Creek transects. Also of interest was the high abundance of *A. pluvialis* on the higher altitude transects ('water point' and the two Streets Creek transects) where it was recorded at approximately ten to fifteen individuals per hundred metres, compared to its almost complete absence from the lower Avondale Creek transects (0.1-0.2 individuals per hundred metres). The other microhylid frog species recorded in the Kuranda Range road area, *C. ornatus*, exhibited a similar pattern of abundance across the transects, but at considerably lower abundances. *Litoria genimaculata* was the only species recorded at more than one individual per hundred metres across all transects. The species was recorded at a density of one to five individuals per hundred metres on all transects except the 'water point' transect on Avondale Creek, where it was abundant (approximately fifteen individuals per hundred metres).

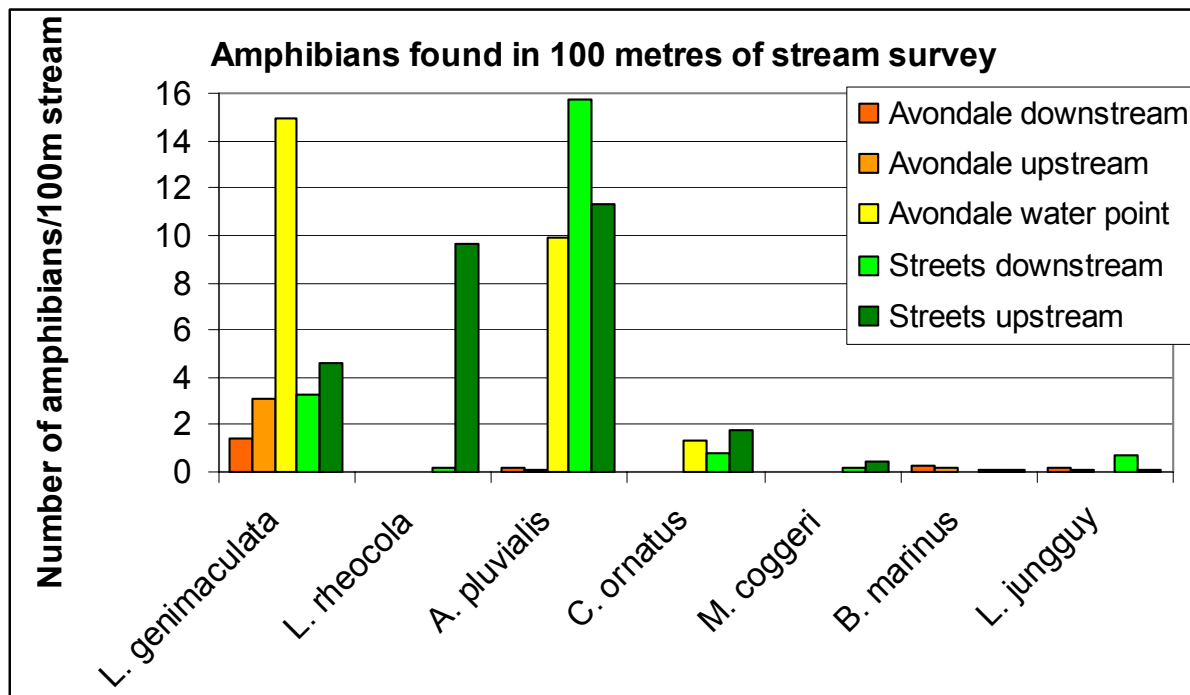


Figure 20: Abundance relative to length of stream of the more common amphibian species found in frog surveys at each transect.

2.3.2 Amphibian diversity and abundance and stream habitats available

The five stream transects can be broadly characterised as shown in Table 8. The two lower Avondale Creek transects are of reasonably high species diversity but low frog abundance, with only *L. genimaculata* breeding at low-moderate density. The 'water point' transect on Avondale Creek is of low frog diversity but two of those three species, *L. genimaculata* and *A. pluvialis*, breed at high density. The Streets Creek transects are similar to each other in being of high species diversity (the same species were recorded on both) and having moderate abundance of *L. genimaculata* and *C. ornatus* and high abundance of *A. pluvialis*. They differ, however, in that *L. rheocola* is abundant on the upstream transect but very rare on the downstream transect.

Quantification of stream habitat along transects revealed noticeable differences between them (Table 8, Figure 21). Cascade habitat was common along the Avondale Creek transects (more than fifty percent of the transect length on all), whereas it was rare on the Streets Creek transects (less than eighteen percent on both). Cascade habitat was particularly common on the upper Avondale Creek ('water point') transect (76%). Riffle habitat was generally uncommon on the transects, comprising twenty percent or less of their length, except on the upstream Streets Creek transect, of which nearly half was riffle habitat. The Streets Creek transects had more pool habitat (particularly downstream Streets Creek) than the Avondale Creek transects. The steep, rocky Avondale Creek water point transect had almost no pool habitat along its entire length. This variability was incorporated in the twenty-metre distance grouping used for data analysis to encompass such fine-scale habitat differences. In general, there was no obvious habitat compositional differences close to the road on each of the transects compared to distances further from the road on that transect, habitat types being relatively evenly distributed over twenty metre distances on each transect.

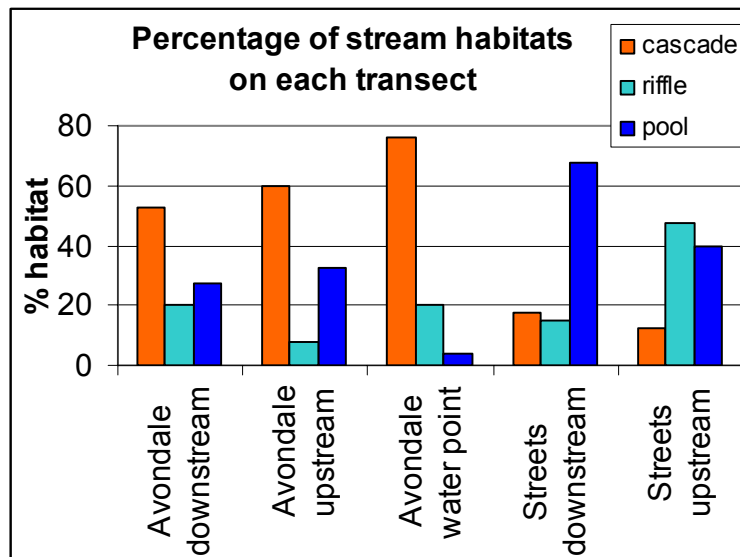


Figure 21: Percentage of stream habitat types found on each transect.

2.3.3 Incidental faunal observations

All vertebrate fauna that could be accurately identified on the stream transects at night was recorded. This resulted in a number of reptile, mammal and bird records across transects, either individuals of nocturnal species encountered foraging or diurnal species found sleeping near the streams. Fish and insectivorous bats were observed frequently but were not recorded due to difficulty in identification. Water dragons, *Physignathus lesueurii*, were frequently observed sleeping on vegetation overhanging the stream. Other reptiles occasionally observed sleeping along the stream transects were Boyd's Forest Dragon, *Hypsilurus boydii*, and a species of Shade Skink, *Saproscincus basiliscus*. Two species of gecko were observed foraging on vegetation and rocks along two of the stream transects, the Northern Leaf-tail Gecko, *Saltuarius cornutus*, and the gecko, *Nactus cheverti*. Three species of mammal were observed on most transects, a fruit eating bat, the Eastern Tube-nosed Bat, *Nyctimene robinsoni*, and two native rodents, the Fawn-footed Melomys, *Melomys cervinipes*, and a *Rattus* sp. (most likely the Cape York rat, *Rattus leucopus*, but could also be the Bush Rat, *Rattus fuscipes*). One nocturnal species of bird, the Lesser Sooty Owl, *Tyto multipunctata*, was recorded active on the 'water point' and upstream Streets Creek transects. Several diurnal bird species were recorded sleeping along the stream transects (particularly upstream Streets Creek), the Pale Yellow Robin, Southern Cassowary and Azure Kingfisher. Of particular interest is the endangered Southern Cassowary, *Casuarius casuarius johnsoni*, which was recorded sleeping on the upstream Avondale Creek transect once and the upstream Streets Creek transect twice. This species was also detected on several occasions on both Streets Creek transects during diurnal work (e.g. when setting out the transect markers).

2.3.4 Impact of the Kuranda Range Road on frog abundance

2.3.4.1 Lower Avondale – downstream transect

Frog density on this transect was too low to analyse density relationships against distance to the road. *Litoria genimaculata* was the only species recorded in each of the six replicate surveys but only an average of 2.3 individuals were recorded within one hundred metres of the road on each replicate visit.

2.3.4.2 Lower Avondale – upstream transect

Frog density on this transect was too low to analyse density relationships against distance to the road. *Litoria genimaculata* was the only species recorded on each of the six replicate surveys but only an average of 2.8 individuals were recorded within one hundred metres of the road on each replicate visit.

2.3.4.3 Avondale – ‘water point’ transect

Two species, *A. pluvialis* and *L. genimaculata*, were sufficiently common to be analysed separately for density relationships with the road. An analysis of the density of all frogs in relation to distance to the road was also performed. The *L. genimaculata* data was normalised with a square-root transformation. Linear regressions revealed no significant relationship between the density of *A. pluvialis* ($\beta = -0.013$, $F_{1,28} = 0.01$, $P = 0.944$), *L. genimaculata* ($\beta = 0.097$, $F_{1,28} = 0.26$, $P = 0.612$) or all frogs combined ($\beta = -0.335$, $F_{1,28} = 3.55$, $P = 0.070$) and distance to the road.

2.3.4.4 Streets Creek – downstream transect

Three regressions were performed against distance to road, *A. pluvialis*, *L. genimaculata* and all frogs combined. A large data-set was obtained for *A. pluvialis* but *L. genimaculata* were probably too rare on this transect for accurate analysis of road impacts on this species. The total frog data-set consisted of data from seven species but it is heavily influenced by *A. pluvialis* given the abundance of this species compared to the rarity of the others. There was a highly significant positive relationship between *A. pluvialis* density and distance to the road ($\beta = 0.512$, $F_{1,28} = 9.96$, $P = 0.004$) (Figure 22), and also between the density of all frogs (mostly *A. pluvialis*) and distance to the road ($\beta = 0.504$, $F_{1,28} = 9.55$, $P = 0.004$). There was no significant relationship between density of *L. genimaculata* and distance to the road ($\beta = 0.158$, $F_{1,28} = 0.72$, $P = 0.404$).

2.3.4.5 Streets Creek – upstream transect

Sufficient data were available for three species to be analysed separately (*L. rheocola*, *L. genimaculata* and *A. pluvialis*). These three species were also pooled with other frog species recorded on the transect for an analysis of total frog abundance versus distance to the road. The *A. pluvialis* data was normalised by log transformation. There was a highly significant positive relationship between *L. rheocola* density and distance to the road ($\beta = 0.621$, $F_{1,28} = 17.54$, $P < 0.001$) (Figure 23). In contrast, there was no significant relationship between the density of *L. genimaculata* ($\beta = 0.051$, $F_{1,28} = 0.072$, $P = 0.791$), *A. pluvialis* ($\beta = -0.116$, $F_{1,28} = 0.383$, $P = 0.541$) and all frogs ($\beta = 0.321$, $F_{1,28} = 3.23$, $P = 0.083$) and distance to the road, although the combined frog data approached significance due to the strong *L. rheocola* pattern with distance from the road.

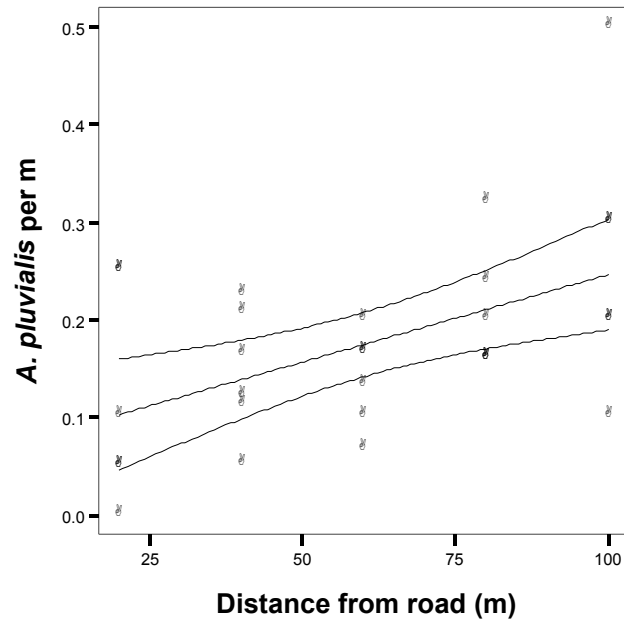


Figure 22: The relationship between the density of *Austrochaperina pluvialis* on the Streets Creek downstream transect and perpendicular straight-line distance from the Kuranda Range Road.

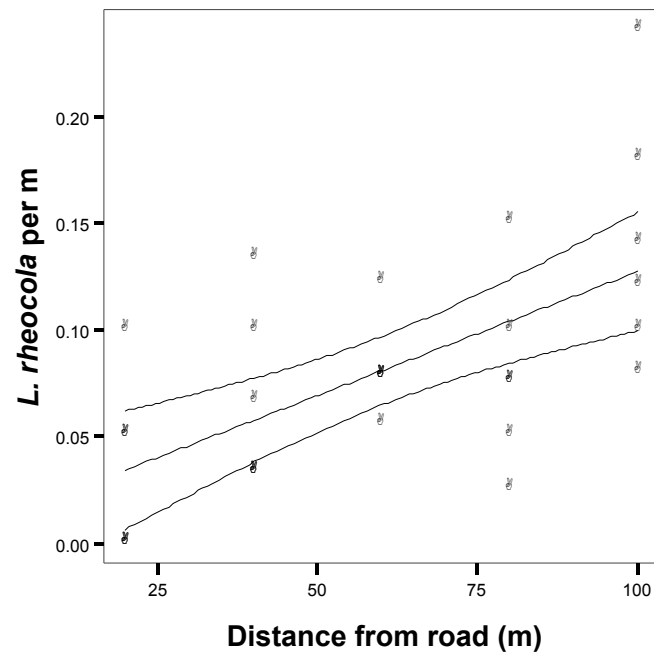


Figure 23: The relationship between the density of *Litoria rheocola* on the Streets Creek upstream transect and perpendicular straight-line distance from the Kuranda Range Road.

2.4 Discussion

2.4.1 Frog species diversity and broad patterns of abundance

The transect surveys revealed high frog species diversity in the vicinity of the Kuranda Range Road. Frogs were rare on the lower Avondale Creek transects but several frog species were common to abundant on the upper Avondale Creek transect (water point) and on the Streets Creek transects. *Austrochaperina pluvialis* and *Litoria genimaculata* were common on these three transects and the endangered species *Litoria rheocola* was common on one of these transects (Streets Creek upstream).

A pattern of density change away from the road was detected on both the Streets Creek transects. On the upstream Streets Creek transect *L. rheocola* showed a highly significant increase in density from the road edge towards the forest interior; while on the downstream Streets Creek transect *A. pluvialis* also showed a highly significant increase in density away from the road. Frog density of all species combined also increased significantly away from the road on the Streets Creek downstream transect but this reflected the abundance of *A. pluvialis* in the data-set. No significant relationship was found between density and distance to the road for any of the other species or frogs overall on any of the other transects.

In the case of *L. rheocola*, the significant results in the above analyses are highly suggestive of road impacts. The significant relationship occurred in the predicted direction of change that would be expected if frogs were avoiding the edge of the forest near the road (i.e. increasing abundance away from the road) or declining in density near the road. No other factor easily explains this result. Habitat suitability for the frog species varied along the stream transects but generally on a fine-scale. The broad groupings of twenty metres perpendicular distance from the road were used in this analysis specifically to incorporate this habitat variability by giving density estimates that averaged over habitat variability. Additionally, the regression analysis incorporated a series of distance points, so localised density changes related to habitat variability would not be expected to produce a significantly linear pattern of relationship.

If proximity to the road is affecting the density of *L. rheocola* upstream of Streets Creek, then what is the cause? It appears extremely unlikely that reductions in water quality due to pollutants in road runoff could be a causative factor, as this pattern of density decline near the road was observed on a transect upstream of the Streets Creek road crossing. Therefore, road runoff should not have reached the creek on that transect. Unfortunately, it appears likely that water quality in another tributary of Streets Creek may be affected by an unknown factor again unrelated to the road. Very few frogs were found on this tributary which joins the main creek a few metres upstream of the road crossing and therefore also cannot have been affected by road runoff. Water quality in this tributary was visibly worse – the stream was continually murky in comparison with the clear water in the main stream and the temperature was noticeably warmer (*pers. obs.*). The decision to select the upstream transect along the major clear stream, rather than the tributary, was a response to the lack of stream-dwelling frogs and poor water quality of the tributary. It should also be noted that very few individuals of the stream-dwelling frog common on the upstream transect were found downstream of the road crossing after this tributary had entered the main stream, although another species occurred in similar densities on either side of the road.

Two possible causative factors that would explain the density declines, both of *L. rheocola* upstream of Streets Creek and *Austrochaperina pluvialis* downstream of Streets Creek, are road mortality and edge effects, possibly mediated through traffic noise disturbance. Firstly, male frogs may generally avoid calling and breeding near the road due to the disruption of their mating signal caused by traffic noise as seen in North American species (Barrass and

Cohn 1983, 1984, Barrass, 1986). The potential for other traffic noise effects on frog calls is examined further in Section 3 of this report. Alternatively, if traffic noise is not the factor impacting on the frog species, frogs may attempt to utilise habitat near the road. In this scenario, however, a proportion of the population near the road is continually being indiscriminately removed from the population when killed on the road. The chance of a frog being killed on the road is likely to be directly related to how close it lives to the road, therefore potentially producing the linear patterns detected in this study. However, there are two reasons why road-kill may not adequately explain the patterns observed. The first is that *L. rheocola* males appear to be very closely associated with the stream and are therefore likely to utilise the stream culvert where the road crosses Streets Ck, rather than be killed on the road. Evidence that corroborates this hypothesis is that in more than four years of road mortality surveys, only two individuals of *L. rheocola* have been found as road victims (Goosem 2000a, Goosem 2006). Secondly, the terrestrial species that shows a decline, *A. pluvialis*, is very small and is unlikely to travel the sort of distances required to generate a density relationship with the road over a distance of one hundred metres.

However, it should be noted that decreasing abundance in the vicinity of the road edge is not always consistent for *A. pluvialis* – the pattern did not occur at the Avondale Creek ‘water point’ transect nor upstream on Streets Creek. *Austrochaperina pluvialis* is a tiny, terrestrial, litter-dwelling, rather than stream-dwelling frog species. Therefore it is possible that other variables in the terrestrial habitat and microtopography of the landscape adjacent to the road may be affecting these results. Such influences might include the presence of high banks to climb before reaching the road surface on the Streets Creek upstream transect, potentially reducing loss due to road mortality of this small species with low mobility, or protecting the edge habitat from microclimate effects. Other terrestrial amphibians (salamanders) find steep roadside verges an impediment to movement across roads, increasing the road barrier effect observed (Marsh *et al.* 2005). The significant decline near the road downstream of Streets Creek for *A. pluvialis* may represent fine-scale habitat changes along this transect in terms of moisture and position of rocky areas for this terrestrial species that did not occur on the other two transects where sufficient individuals were recorded for analysis. *A. pluvialis* has a high frequency call, so the lower dominant frequency of traffic noise is less likely to cause avoidance of the road edge than in certain of the hylid species. However low numbers in the road mortality statistics (Goosem 2000a, 2006), also suggest that the species may avoid the open spaces of the road itself, although varying microhabitat conditions might not always cause avoidance of the forest edge adjacent to the road.

Road mortality is one of the factors postulated to cause density declines near roads in temperate zones (Fahrig *et al.* 1995, Vos and Chardon 1998, Carr and Fahrig 2001, Hels and Buchwald 2001, Parris 2006). However, in this study, it does not appear to be the main factor causing these density declines. The two species which demonstrate this pattern are not subject to high levels of road mortality on the Kuranda Range Road, while another species which did not demonstrate density dependence with distance from the road, *Litoria genimaculata*, is killed regularly in the vicinity of Streets Creek and Avondale Creek water point (Goosem 2000a, 2006).

Therefore it appears that edge effects or disturbance from traffic noise could be the major factor causing density declines near the highway at Streets Creek for *Litoria rheocola*. Changes in microhabitats in the stream with respect to distance from the road are not obvious upstream from the Streets Creek road crossing. The remaining possibility is traffic noise, which appears to be the most likely impacting factor for this species. Noise levels along the upstream Streets Creek transect decrease with distance from the road (see Section 1), eventually reaching an acoustic refuge about two hundred metres along the transect which protects calling frogs from traffic noise. The increased population density in this area suggests that traffic noise may be a factor. The situation for *Austrochaperina pluvialis* downstream of the Streets Creek bridge is not as clear. There is a marked drop in

traffic noise at two hundred metres along that transect compared with the edge and one hundred metres which could explain the increase in population seen at the greatest distance (see Section 1), but this is also the case on the upstream side where a similar distance dependence was not observed.

2.4.2 Frog species of conservation significance

As the green-eyed tree frog, *Litoria genimaculata* occurred in sufficient numbers to allow data analysis on one transect where it did not appear to suffer road avoidance, with a similar result on two other transects, where data were relatively rare, it appears most likely that this species does not suffer edge effects or traffic disturbance. As this is a stream-dwelling species, the lack of edge impacts may relate to the current state of the two streams investigated, where the rainforest canopy and understorey is maintained along the stream to the road edge. Lack of road avoidance accords with the high levels of road kill of this species observed during road mortality surveys along the Kuranda Range Road (Goosem 2000a, 2006). The locations in which it was commonly found also accord with the road mortality data: road kill was very common in the vicinity of Streets Creek and near the tributaries of upper Avondale Creek near the 'water point', while never being found near lower Avondale Creek in 2005/2006 and very occasionally found between 1989 and 1992. *Litoria genimaculata* is recognised with conservation status as a *Rare* species under the Queensland Nature Conservation (Wildlife) Regulation, 1994, (as updated in reprint 3c, Dec 2005) and the species is believed to be endemic to the Wet Tropics, although this taxonomic status is yet to be published. The species' seeming lack of avoidance of roads and high road mortality rate suggests that the major road impact likely to affect the species is road mortality. However, the data obtained along the surveyed transects for this species remains equivocal, as it was abundant on one transect and generally rare on the others. It is not possible to be certain that road effects would not occur at intermediate frog densities for these species. One factor that must certainly reduce road impacts for this species in the form of road kill comprises the retention or restoration of vegetation along stream banks below high bridge crossings, as this removes the need for road crossing on the bitumen surface.

In contrast, the *Endangered* endemic species, *Litoria rheocola* showed a significant effect of distance from the road on the one transect where it occurred in sufficient numbers for analysis. It is very rarely a road kill victim but appears to suffer both from water quality impacts, although these were not road-related, and probably traffic noise impacts. Therefore careful design of traffic noise amelioration measures should form part of the mitigation strategies for the Kuranda Range road upgrade. The water quality of the Streets Creek tributary which had unexpectedly low populations of the species should also be investigated. Maintenance of stream connectivity and stream bank vegetation connectivity by the incorporation of high bridges into the road upgrade design can only benefit this species by maintaining habitat connectivity, stream water temperatures and reducing potential movement impediments caused by culverts.

Austrochaperina pluvialis is endemic to the Wet Tropics bioregion and showed density declines close to the road at one transect which did not translate to two other transects with sufficient data. It is very rarely killed on the Kuranda Range (Goosem 2000a, 2006) but may suffer road edge effects which need to be further investigated in terms of open space avoidance, microclimate and vegetation edge effects, microtopography and traffic noise disturbance. A similar effect has been seen for other terrestrial amphibians. Salamanders suffer edge effects adjacent to roads (DeMaynardier and Hunter 2000, Marsh and Beckman 2004, Marsh 2007), although in one study frogs were less susceptible than salamanders (DeMaynardier and Hunter 2000). It would be expected, however, that microclimatic edge effects particularly in temperature, wind speed and relative humidity could cause greater impact on terrestrial amphibians which have semi-permeable skins than those edge effects

previously demonstrated for rainforest mammals and birds (Goosem 2001, Laurance 2004, Dawe and Goosem 2007).

Other species which are endemic to the Wet Tropics bioregion were not recorded in high population numbers during these surveys, including *Mixophyes coggeri*, *Litoria xanthomera*, *Litoria jungguy* and *Cophixalus ornatus*. Unfortunately this survey did not provide sufficient data to comment on causative road impacts on these species. It is already known that *L. jungguy* and *L. xanthomera* suffer high road mortality on the Kuranda Range road. Seasonality was probably a factor in their relatively low numbers in this survey as *L. xanthomera* road mortality rate is related to extreme rainfall events, the timing of which is variable (December 2005, March and May 1991, February 1992) and major roadkill of *L. jungguy* occurs between October and December in most years (Goosem 2000a, 2006).

The lack of the feral cane toad (*Bufo marinus*) in surveys was an interesting result. Cane toad road mortality peaked in January during 2005/2006 (170), while in most other years January has high numbers of road-killed frogs (98, 39, 9). It appears that, as previously suspected, the vast majority of cane toads remain either in the altered habitat of the road verge or on the road surface itself. The pattern seen with greater numbers of toads near the base of the range closer to open and agricultural and urban habitats, with numbers declining as the road climbs the range (Goosem 2000a, 2006) suggests that the highway acts as a conduit for this species. The lack of individuals observed at distance in these surveys corroborates this idea and agrees with similar results observed in northern New South Wales (Seabrook and Dettman 1996) and the Northern Territory (Brown *et al.* 2007). The results suggest that cane toads do not prefer to disperse through dense vegetation such as rainforest understorey, even though they are occasionally found deep in the forest interior (*pers. obs.*). However they have been observed to prefer the relatively open understorey of areas revegetated with rainforest trees that have yet to develop a dense understorey (Larsson 2003). Therefore revegetation works undertaken subsequent to road upgrade should aim to create a dense understorey as well as create canopy closure as quickly as possible.

2.5 Conclusion

Population declines adjacent to the Kuranda Range road have been confirmed for one species. For a second declines appear to occur in some situations. For those species for which sufficient data were obtained, road mortality appears unlikely to be causing these population declines. Traffic noise impacts may be implicated in the density decline of the endangered *Litoria rheocola* and noise mitigation should be considered for the Streets Creek bridge area of the new upgrade. The alignment of the upgrade away from the edge of Streets Creek should enhance the traffic noise amelioration for the upstream population of this species. However, care should be taken to avoid impacting on current acoustic refuge areas downstream of the current alignment which may harbour elevated bird densities in comparison to surrounding noise-affected areas (Dawe and Goosem 2007). For the terrestrial *A. pluvialis*, edge effects, possibly in microclimate or substrate are a potential cause but targeted investigations would be required to elucidate causative factors. The feral cane toad was not common in surveys, suggesting that the road and its verge functions mainly as a movement conduit. Frogs were very uncommon on one tributary of Streets Creek upstream of the road crossing, although they were common on the main Streets Creek branch upstream of the crossing, suggesting that the observed poor water quality in that tributary was a likely cause of frog absence but that the reduction in water quality was unrelated to road runoff because it occurred upstream of the road crossing.

2.6 Recommendations

- Traffic noise amelioration works should be undertaken on high bridges that cross the perennial creeks in the Kuranda Range road upgrade, and particularly at Streets Creek.
- Stream bank vegetation should be retained on the creeks below these bridges to encourage stream frogs to move along the stream and not venture towards the road surface.
- Care should be taken to avoid impacting on current acoustic refuge areas downstream on Streets Creek of the current alignment, to maintain faunal habitat.
- Creek habitat should be left undisturbed during construction and sedimentation and erosion runoff into creeks curtailed completely by sediment control measures, as the impact of poor water quality on frogs has been demonstrated by the lack of the endangered species along the Streets Creek tributary.
- Revegetation works along the upgrade and rehabilitated sections of current road should aim for establishment of a dense understorey as well as canopy closure to maintain habitat integrity and reduce potential for intrusions by cane toads.
- Canopy cover should be maintained as close as possible to the edge of the road to reduce edge effects that might impact on terrestrial microhylid frogs, as well as many other vertebrate groups.
- An investigation of water quality along the other Streets Creek tributary should be undertaken.

2.7 Further research

This project has suggested further research questions:

1. Examination of the causative mechanism of edge effects for certain amphibian species; and
2. Assessment of the degree to which cane toads move along the road as compared to into the forest.

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3. Impact of traffic noise disturbance on stream frog calling behaviour near Kuranda Range Road

Conrad Hoskin and Miriam Goosem

Summary

We investigated the impacts of roads on the calling behaviour of an endangered species, the Common Mist frog, *Litoria rheocola* along a stream transect at Streets Creek on the Kuranda Range road by recording calls of all calling male individuals found between the road edge and 350 metres along the creek (a distance of about one hundred metres perpendicular from the road). Four call parameters were analysed: call duration, call dominant frequency (the frequency at which the call is at greatest intensity), call pulse rate and call rate (how often an individual calls). Forty-one separate calls were analysed, believed to be mostly from different individuals. The rate at which males call was found to decline significantly from the road edge towards the forest interior, both over fifty-five metres and one hundred metres distance. The dominant frequency of the call also declined with distance to fifty-five metres from the road edge. The size of the males was highly significantly related to distance, increasing towards the forest interior. There was no relationship between distance from the road and call duration or pulse rate. Smaller males found more often near the road called more frequently and at a higher pitch than the larger males found more often further from the road. These changes in vocalisations appear highly suggestive of traffic noise impacts. Larger and more dominant males may be selecting for preferable habitat away from the road, leaving the smaller individuals in habitat that is more greatly affected by traffic noise blanketing of calls. Alternatively, there may be a genetic overlap zone, a potential causative factor unable to be rejected until further genetic studies are complete. These results suggest that amelioration of traffic noise impacts using noise barriers on the bridge and road near the Streets Creek crossing is very important. As *L. rheocola* calls at a relatively high frequency, several other species of conservation significance that have lower-pitched calls should be investigated for traffic noise impacts at their peak breeding seasons.

3.1 Introduction

3.1.1 Background

A variety of impacts of roads and highways on rainforest vegetation and fauna have been recognised (see Section 2). One of these relates to wildlife disturbance adjacent to a road arising from its operation, i.e. due to vehicles moving along the road surface. Several emissions from vehicles have the potential to cause disturbance to wildlife. These include pollutants from vehicle exhausts, tyre and break wear, and disturbance from traffic noise and headlights (Forman *et al.* 2003, Goosem 2004). Traffic noise has been shown to penetrate the rainforest from the Kuranda Range road to distances of at least two hundred metres during the day (Dawe and Goosem 2007) and to similar distances during the night, although the degree of traffic noise penetrating the forest is dependent on traffic volume, which is at its minimum during the late evening and early morning hours (see Section 1). Vehicle noise tends to penetrate further at subcanopy levels than at ground level (Dawe 2005). Headlights penetrate to distances of fifty to seventy metres through the forest at ground level, and much further above the canopy on downhill sections of road (Wilson and Goosem 2007). The

penetration of both these energy emissions can be reduced, particularly in the forest understorey, by the presence of microtopographical features that prevent noise and/or light penetration by reflection or absorption of those energy wavelengths (Dawe and Goosem 2007, Wilson and Goosem 2007).

3.1.2 Acoustic communication

To communicate successfully, the sound produced must be able to propagate through the natural environment between the signal sender (individual calling) and the receiver (individual hearing). Therefore sounds that transmit effectively through rainforest habitat would be selected for by rainforest wildlife (Patricelli and Blickley 2006). Ambient noise is one environmental factor that exerts selection pressure on the type of sound emitted (Ryan and Brenowitz 1985). For the receiving individual to respond, the sound must be detectable in the background noise, meaning that many species have evolved communication signals specific to the habitat in which they live (Brumm and Slabbekoorn 2005). Four of the most important features of animal sounds are the frequency structure, timing of modulations, notes and syllables within vocalisations, and timing of delivery (e.g. rates of repetition, diurnal patterns). All are used to detect relevant sounds from background noise. Traffic noise may blanket these communications and a variety of adjustments might be made to vocalisations to overcome this acoustic interference. If this proves impossible for a species or individual, avoidance of the habitat containing the anthropogenic noise may be the only alternative.

3.1.3 Impacts of traffic noise on wildlife

Impacts of the penetration of traffic noise can be serious for wildlife. For example, birds have been shown to avoid the edge of roads (Rheindt 2003). The study found declines in bird diversity and abundance in forest one hundred metres away from a busy German motorway carrying fifty thousand vehicles per day in comparison with an area 750 metres from traffic noise sources. The change in abundance was independent of the size of the species, but species with higher dominant song frequencies occurred in greater abundance closer to the motorway than those species with lower-pitched songs closer to the dominant frequency of the traffic noise (Rheindt 2003). Similarly other studies on forest birds have suggested that traffic noise is the primary cause of density declines adjacent to roads (Reijnen *et al.* 1995, Weiserbs and Jacob 2003). The alternative to avoidance of habitat near roads that is affected by traffic noise that can be used by some bird species is adjustment of vocalisations, but this is dependent on the morphology, vocalisation development and behaviour of the species (Patricelli and Blickley 2006). Some species may increase the loudness of their calls, but this may be limited by body size (Rabin and Greene 2002). Others increase repetition and duration (Warren *et al.* 2006). In locations subject to infrequent traffic, it may be possible to avoid calling when vehicles pass close by and only call during quiet periods, a similar response to interspecies song spacing (Ficken *et al.* 1974). But all of these strategies have energetic cost consequences. Others, such as some passerines have greater vocal plasticity and can adjust the dominant frequency of their call (Wood and Yezerinac 2006, Dawe and Goosem 2007), although this is also expected to come at an energetic cost and perhaps cause a reduction in transmission and detectability by other individuals of the species.

3.1.4 Impacts of traffic noise on amphibians

Traffic noise has been shown to have an impact on breeding behaviour of some North American frog species, impeding male call recognition by females and altering spacing between individuals (Barrass and Cohn 1983, 1984, Barrass 1986). Anthropogenic noise in the form of aircraft and motorcycles also causes alterations to choruses of frogs, causing some species to decrease their calling rate and therefore potentially reduce their attractiveness to females and likely reproductive output while others increase their normal

calling rate with consequent energetic costs (Sun and Narins 2005). Highway traffic noise may have similar effects.

It is possible for at least some frog species to modify their calls in response to background noise. Modifications of vocalisations in an American tree frog species were elicited by background noise, alterations being greatest when the dominant frequency of the background noise coincided with the dominant frequency of the frog's call (Schwartz and Wells 1983). However, changes also occurred when there was only partial blanketing of calls by the background noise. Wollerman (1999) found that continuous background noise increased acoustic interference to the calls of neotropical tree frogs, inhibiting their detection. Female frogs might detect the calls of the males, but, if so, their ability to discriminate between each calling male was reduced (Wollerman and Wiley 2002a). Amphibians rely on four call parameters to identify calls from individuals of their own species (Wollerman and Wiley 2002b). These include call duration, dominant frequency, and fundamental frequency and pulse repetition rate. Recent and current research in Victoria has suggested that some Australian frog species may also be able to call at a higher pitch (Catchpole 2004, Ainley North 2007). This research also examines whether larger frogs with consequent lower frequency calls (a result of larger size) are more likely have their calls blanketed by traffic noise and therefore be more seriously affected than smaller species or individuals, or whether species with low ability to detect calls could be more severely affected. Males with higher frequency calls adapted to areas with traffic noise may also be less attractive to females as deeper calls generally mean more mature males and greater likelihood of breeding success (Ainley North 2007).

3.1.5 Aims and research question

This project aimed to assess whether the Kuranda Range road impacts on the calling behaviour of stream frogs.

Research question:

Do frog call characteristics change with proximity to the road?

Calls of an *Endangered* species, the Common Mist frog *Litoria rheocola*, were recorded along one of the survey transects and traits of the calls were measured and analysed to see if they varied with distance from the road.

Prediction:

- 1) *Frogs will call at higher frequency near the road to minimise acoustic competition with low frequency traffic noise.*

This could occur either by frogs changing their call or, if males are unable to change the frequency of their call, those with higher frequency calls using habitat closer to the road.

- 2) *Frog call rate will be greater near the road.*

This was based on the expectation that frogs near the road would call more frequently to make up for calls that are 'drowned out' by the noise of passing traffic.

3.2 Methods

3.2.1 Frog call recording

Sufficient numbers of recordings were obtained for *Litoria rheocola* on the upstream Streets Creek transect for analysis. Male *L. rheocola* are not particularly shy when calling making it possible to record at a close distance and get clear recordings over the background stream noise. Additionally, because males call at high density along the length of this transect and because the transect moves away at a gradual angle from the road; it was possible to obtain good numbers of recordings across a range of distances from the road.

The other abundant species could not be effectively recorded for the purposes of this project. *Austrochaperina pluvialis* called too sporadically during the survey period and generally called during periods unsuitable for recording (during or immediately following rain when the falling drops interfere with recording and can damage the equipment). Additionally, this species is not a stream breeder (the tadpoles live within eggs laid in leaf-litter) and the call is of such a high frequency (3.1 kHz) that it is unlikely to be affected by road noise. *Litoria genimaculata* was common on the upper Avondale Creek 'water point' transect but recording was not possible with the available equipment because the species is very shy when calling and has a very soft call relative to the background stream noise. Additionally, this transect was oriented essentially perpendicular to the road making it difficult to obtain enough recordings at various distances from the road to statistically assess road noise impacts. Eight *L. genimaculata* were recorded on the upstream Streets Creek transect several years ago but these were not analysed as distances to the road were not recorded. The average dominant frequency of these calls was 1.57 kHz (range 1.27-1.88), which, together with the quiet call, suggests the potential for traffic noise effects on the species. Three *Mixophyes coggeri* were recorded on the upstream Streets Creek transect, too few to analyse in detail. The average dominant frequency was 562 Hz (range 520-580 Hz), a level of interest in relation to traffic noise.

The mating call of *L. rheocola* males was recorded on the upstream Streets Creek transect using a Marantz digital recorder and a Sennheiser microphone. The microphone was placed approximately one metre from the male and an approximately one minute string of consecutive calls was recorded. The male was then captured in a freezer bag, body length (snout-vent-length, SVL) was measured using calipers, and the frog was released at the point of capture. Position of the frog on the transect was recorded and air temperature was taken.

3.2.2 Frog call measurements

The call files were downloaded onto a computer and analysed using the Canary ver. 1.2.1 software.

Four consecutive replicate calls were measured for each individual to give average call characteristics for that male. The following call traits were measured:

- Call duration (length from the beginning of the first pulse to end of the last pulse of a single call);
- Pulse rate (number of pulses per second across the entire call);
- Dominant frequency (the frequency at which the call is of greatest intensity); and
- Call rate (the duration between consecutive calls).

These call traits have previously been shown to be suitable for characterising call variation (e.g. Gerhardt and Huber 2002, Hoskin 2004, Hoskin *et al.* 2005).

Dominant frequency was the call trait of greatest importance for this project but it also was the most difficult to measure consistently in *L. rheocola*. Generally frog calls display a consistent dominant frequency throughout a call but in *L. rheocola* there are often two peak frequencies in a call due to a frequency shift during the call. A number of different methods were used to try find a single consistent frequency measure, including the highest frequency peak across the whole call, the dominant frequency through the middle half of the call, separate measurement of the frequency peaks of the first and second half of the call, the difference in frequency peaks between the two halves of the call, and finally, the dominant frequency of the middle pulse of the call. The latter measurement was deemed the most appropriate as it was consistently unambiguous to score and provided a clear indicator of the dominant frequency of a consistent component of the call. This measure was therefore the only dominant frequency measure used in the analysis.

3.2.3 Frog call data analysis

The analysis aimed to test whether any of the call traits (duration, pulse rate, dominant frequency, and call rate) showed a pattern of variation related to distance from the road. The prediction for dominant frequency was that frogs nearer the road would have higher frequency calls than those further from the road. This prediction was based on the idea that the higher the call frequency the less the frog is competing with the low frequency road noise. Frog call rate was also predicted to be elevated near the road, based on the expectation that frogs near the road would call more frequently to make up for calls that were 'blanketed' by the noise of passing traffic. No specific prediction could be made about the type of alteration that road noise would be expected to cause in the other call traits.

Data manipulation was performed in Microsoft Excel and all analyses were performed in SPSS ver. 15.0. Linear regression was used to test the relationship between each call trait and perpendicular straight-line distance to the nearest point of the road. Air temperature has been shown to impact structural components of frog calls (e.g. Gerhardt and Huber 2002, Hoskin *et al.* 2005); however, in this case the very limited variation in air temperature during recording (1°C) meant this was not an issue. All characters were tested for normality using both Kolmogorov-Smirnov and Shapiro-Wilk tests. Where required, a log transformation was applied to data to normalize the distribution.

The first analysis examined data from across the full range of distances from the road (15-180m). Secondly, only the data for males within 55m straight-line distance from the road were examined because:

- a) Approximately fifty metres was deemed in advance to be the likely distance that road noise would impact frog calling behaviour given the level of stream noise; and
- b) A large number of males (22) were recorded within 55 m of the road and there was a natural break in the data to the next male at 78 m.

Finally, the relationship between frog size and call traits was analysed by performing a regression of the data for each call trait against male size (SVL – snout-vent length).

3.3 Results

3.3.1 Frog calls recorded

Call data were obtained for forty-one *L. rheocola* males, recorded across a wide range of distances from the road. Some call traits could not be measured for some males due to poor recording quality. At least seventeen males were known to be different individuals because they were recorded on the first night. The majority of the remainder, recorded over the following two nights, were also likely to be different males as they were recorded from different sections of the creek and, given that male frogs generally show high calling site fidelity (e.g. Duellman and Trueb 1994), the *L. rheocola* males were unlikely to have moved far on consecutive nights. Some males on the stream had calls that sounded unusual in comparison to the majority of individuals. These unusual males were observed calling from the same perch on consecutive nights during the recording period, contributing to the belief that calling male *L. rheocola* did not move a large amount over the recording period and therefore most of the recorded males were different individuals.

3.3.2 Call variation across entire transect

The data used in this analysis (distance to road, call duration, pulse rate, dominant frequency, call rate and SVL) were examined for normality. The data were normally distributed except for the distance to road and call rate data, which were significantly skewed. A log transformation was applied to normalize the distribution of these data.

There was no significant relationship between dominant frequency ($\beta = -0.219$, $F_{1,38} = 1.917$, $P = 0.174$), call duration ($\beta = 0.273$, $F_{1,36} = 2.907$, $P = 0.097$) and pulse rate ($\beta = -0.256$, $F_{1,36} = 2.514$, $P = 0.122$) in regressions against distance to the road. There was however a significant negative relationship between call rate and distance to the road ($\beta = -0.366$, $F_{1,36} = 5.573$, $P = 0.024$), with frogs near the road calling more frequently than those further from the road (Figure 24). There was also a highly significant positive relationship between male size and distance to the road ($\beta = 0.515$, $F_{1,37} = 13.36$, $P = 0.001$), with males near the road being smaller than those further from the road (Figure 25).

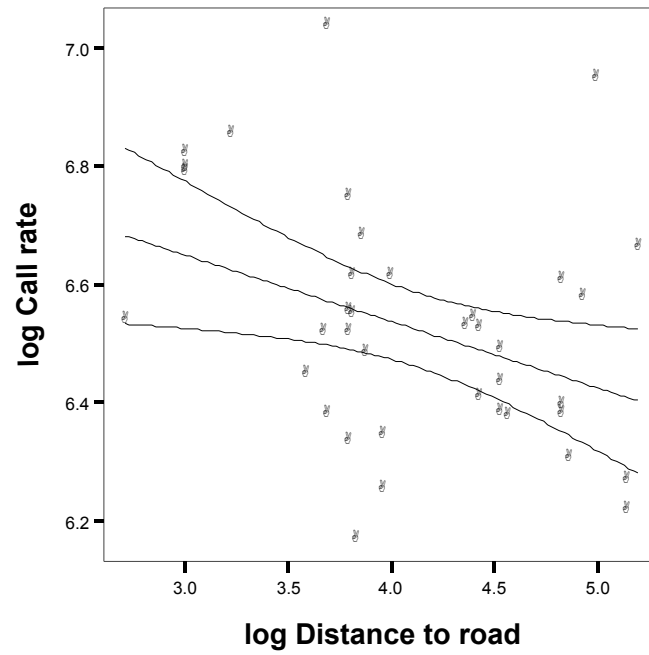


Figure 24: The relationship between call rate and distance from the road; showing the regression line with upper and lower 95% confidence limits. The x-axis shows the log of distance from the road; the range of the data is 15-180m from the road.

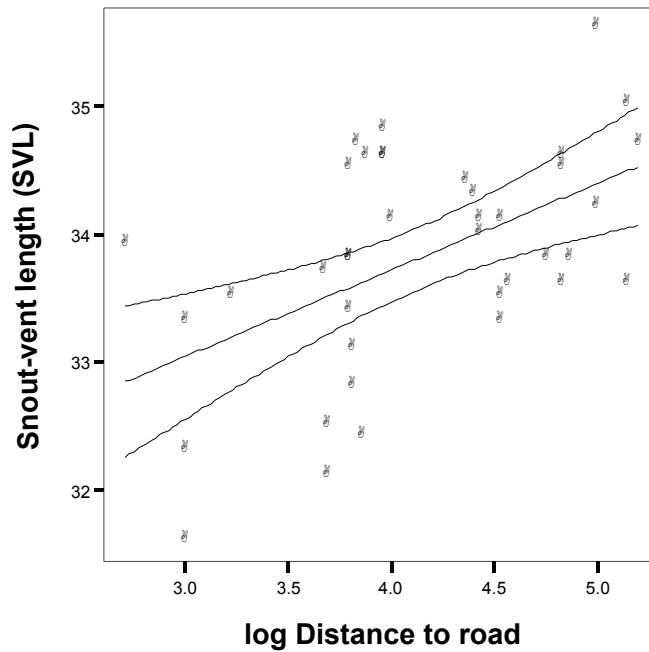


Figure 25: The relationship between male size and distance from the road; showing the regression line with upper and lower 95% confidence limits. The x-axis shows the log of distance from the road; the range of the data is 15-180m from the road.

3.3.3 Call variation within 55m of the road

The call and SVL data within a fifty-five metre straight-line distance to the road were used for this analysis. This included data for 22 males. The reduced data for each variable were analysed for normality. The call variables and the SVL data were normally distributed but the data for distance to the road was significantly left skewed. A cube transformation was applied to normalize the distribution of the distance to road data.

Three of the measured traits showed a significant relationship with distance to the road. Dominant frequency showed a significant negative relationship with distance from the road ($\beta = -0.446$, $F_{1,20} = 4.96$, $P = 0.038$), with males closer to the road having higher pitched calls than those further from the road (Figure 26). Call rate showed a similar relationship ($\beta = -0.500$, $F_{1,19} = 6.35$, $P = 0.021$), with males closer to the road calling more frequently than those further from the road (Figure 27). Male size showed a highly significant positive relationship with distance from the road ($\beta = 0.573$, $F_{1,19} = 9.27$, $P = 0.007$), with males being larger the further you move from the road (Figure 28). No significant relationship with distance to the road was found for call duration ($\beta = 0.372$, $F_{1,19} = 3.06$, $P = 0.097$) and pulse rate ($\beta = -0.278$, $F_{1,19} = 1.59$, $P = 0.223$).

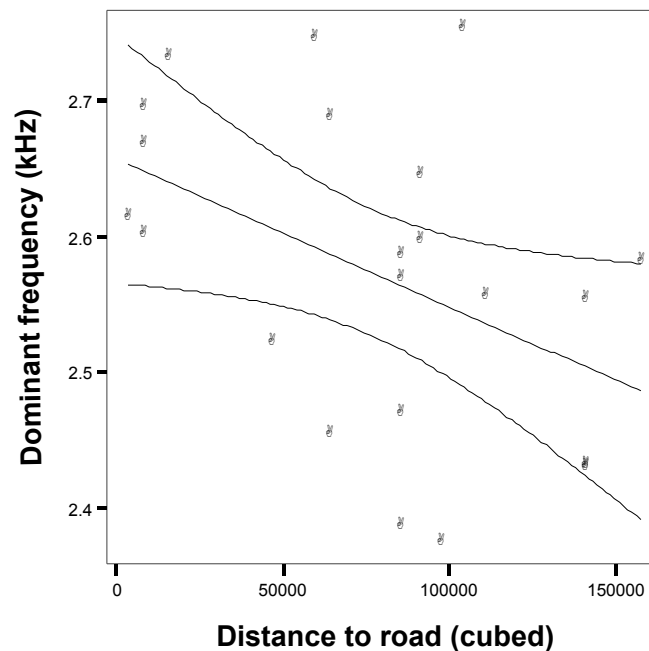


Figure 26: The relationship between dominant frequency and distance from the road (within 55m of the road); showing the regression line with upper and lower 95% confidence limits. The x-axis shows the cube of the distance from the road; the range of the data is 15-54m from the road.

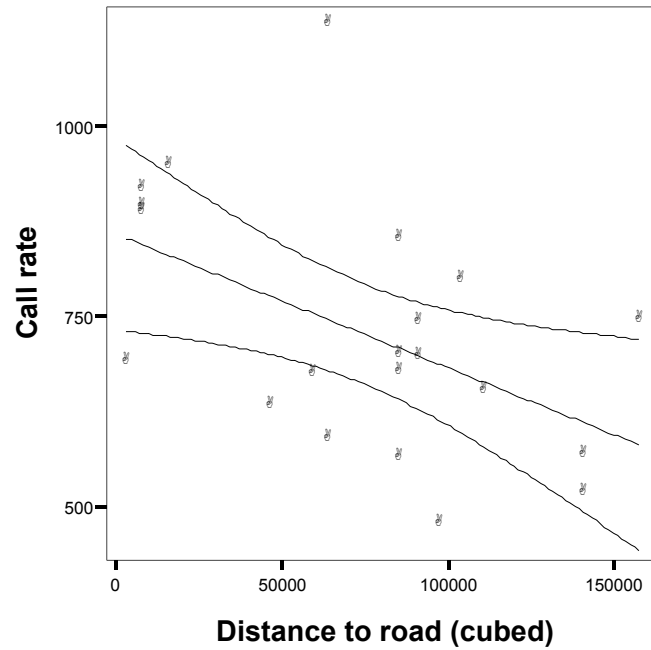


Figure 27: The relationship between call rate and distance from the road (within 55m of the road); showing the regression line with upper and lower 95% confidence limits. The x-axis shows the cube of the distance from the road; the range of the data is 15-54m from the road.

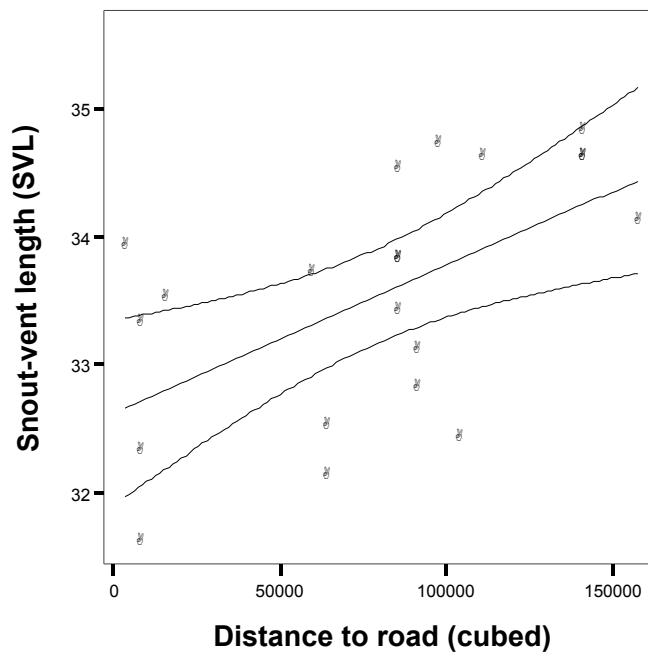


Figure 28: The relationship between male size and distance from the road (within 55m of the road); showing the regression line with upper and lower 95% confidence limits. The x-axis shows the cube of the distance from the road; the range of the data is 15-54m from the road.

3.3.4 Are call traits dependent on male body size?

A regression of dominant frequency against SVL (body length) for all recorded males revealed a significant negative relationship ($\beta = -0.322$, $F_{1,36} = 4.18$, $P = 0.048$) between call pitch and male size. The smaller the male the higher pitched was his call (Figure 29). Similarly, a regression of call rate against body length revealed a significant negative relationship ($\beta = -0.383$, $F_{1,34} = 5.86$, $P = 0.021$), with smaller males calling more frequently than larger males (Figure 30). The other two call traits did not show a significant relationship with male body size (duration $\beta = 0.177$, $F_{1,34} = 1.10$, $P = 0.301$; pulse rate $\beta = -0.066$, $F_{1,34} = 0.148$, $P = 0.703$).

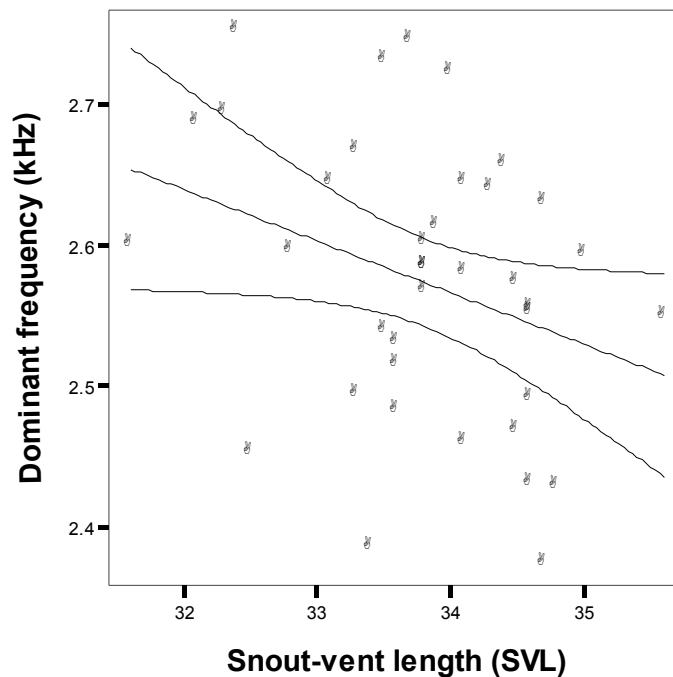


Figure 29: The relationship between call pitch and male body size; showing the regression line with upper and lower 95% confidence limits.

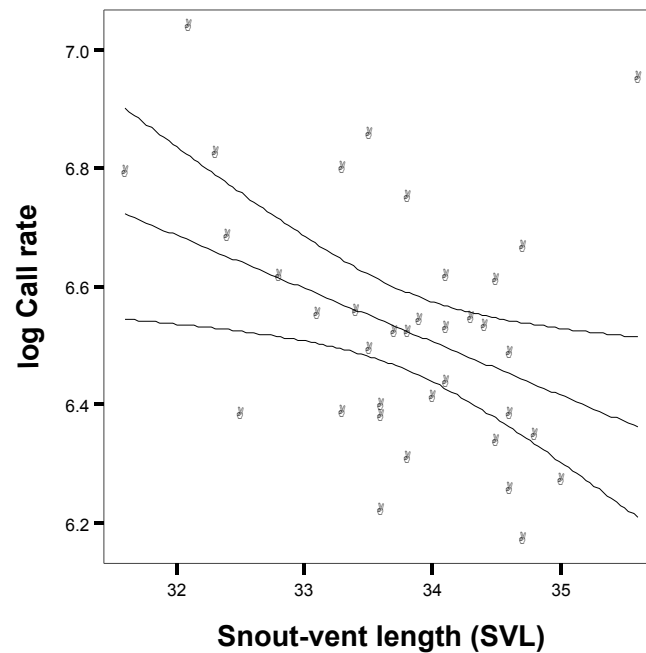


Figure 30: The relationship between call rate (log of the interval between consecutive calls) and male body size; showing the regression line with upper and lower 95% confidence limits.

3.4 Discussion

3.4.1 Impact of the Kuranda Range Road on frog calling behaviour

The analysis of the *Litoria rheocola* calls on the upstream Streets Creek transect revealed significant relationships between some call traits and the distance to the road. Both the analysis of all recorded individuals and the analysis of just those individuals recorded within fifty-five metres of the road revealed that males closer to the road call more frequently. Additionally, the analysis of the recordings within fifty-five metres of the road showed that males closer to the road generally have higher pitched calls than those further from the road.

The call analysis is, however, complicated by links between call traits and male body size. Some components of a frog's call, particularly spectral traits such as dominant frequency, are well documented to be linked to the body size of the male, due to factors such as the thickness of the laryngeal fibres (Gerhardt and Huber 2002). In this case the data shows a strong relationship between male body size and the two call traits (dominant frequency and call rate) that were significantly related to the distance from the road. To further complicate matters, in both the complete call dataset and in the fifty-five metre dataset, male body size shows a highly significant relationship with distance from the road, with males generally being smaller towards the road edge.

3.4.2 Mechanisms for alteration in calling behaviour

To summarise the results, from the forest interior towards the road edge, male *L. rheocola* became generally smaller and their call was uttered more frequently and at a higher pitch. Does this reflect road impacts? Here we outline three possible explanations for the pattern:

1. Road noise impacts have produced the change in two call traits (which is secondarily reflected in male size);
2. The road or some other factor has produced the change in male size near the road (which is secondarily reflected in call traits); and
3. The change in call traits and size reflects overlap between two genetic lineages.

The first theory is that road noise has changed frog calling behaviour. This is supported by the significant change in two call traits with distance from the road. It appears unlikely that this could happen randomly within two different call traits but much more likely that the same impact is operating on both. This is further supported by the observation that these call traits change in the direction that would be predicted by road noise impacts – higher pitched calls near the road would overlap less with low frequency road noise, and calling more frequently may overcome the ‘blanketing’ of the calls of frogs near the road by traffic noise. The fact that the change in call is strongly linked to a change in male body size rules out the possibility that males near the road are simply choosing to call at a higher pitch or more frequently. Rather the pattern may reflect:

- a) A localised change in male call near the road (i.e. road noise selecting for males that utter higher pitched calls and/or call more frequently); or
- b) Positioning of males on the stream depending on their call (i.e. males with deeper calls move away from the road leaving the higher pitched males breeding near the road).

In this hypothesis, the fact that male body size increased away from the road is simply a by-product of its physical link to the call traits - whatever impacts the call traits, indirectly impacts male size. It should be pointed out that only one of the call traits needs to be impacted because both are highly correlated (Pearson Correlation = 0.534, $P = 0.001$), although there is no known reason that would necessarily link call rate to dominant frequency – they are thought to be unrelated call parameters.

A second, alternative, theory is that road noise does not impact on calling behaviour but rather a factor has produced the pattern of increasing male size away from the road and the two call traits change away from the road because they are dependent on male size. Male size shows a highly significant relationship with distance to the road in both analyses whereas the two call traits show weaker relationships with distance to the road. This is suggestive (but not conclusive) evidence that male size is the primary trait producing the pattern and the change in call traits is a linked secondary pattern. If this hypothesis is correct what is the reason for the increase in male size as you move away from the road? One possibility is that if stream habitat is of higher quality away from the road (e.g. due to lower road noise disturbance or an ecological factor unrelated to the road) then this habitat may be preferred and dominated by larger males, with the smaller males moving downstream to utilise less favourable habitat near the road. Could the increase in male size away from the road reflect road-kills near the road? Assuming that frogs increase in size as they get older and that they have a constant chance of being killed on the road, then you would expect a deficit of larger frogs near the road whereas away from the road all size classes should be represented. However, this is not the pattern seen here. There was a deficit of large frogs near the road but there was also a deficit of smaller frogs away from the road, indicating that other factors are responsible for the body size pattern. Additionally, this species has only

been found twice as a road kill victim (Goosem 2000, 2006), so road mortality is unlikely to be removing a large number of larger individuals from the population.

The third theory is that the change in call traits and body size reflects overlap between two genetic lineages of *L. rheocola*. *Litoria rheocola* is composed of several genetically divergent lineages in the Wet Tropics (Schneider *et al.* 1998), two of which are known to meet in the Kuranda area (C. Moritz, *pers. comm.*). These lineages are not known to differ in morphology or call, but this has not been studied in detail. An area where genetic lineages overlap is called a 'contact zone' or a 'hybrid zone'. If the genetic lineages within a species differ in morphology, calls or other traits, these differences will be evident in areas where the lineages overlap, and the differences could potentially be misinterpreted as being due to other factors (e.g. road impacts). Differences in morphology and call have been shown in the Kuranda area where two lineages of the Green-eyed Tree frog (*Litoria genimaculata*) overlap (Hoskin *et al.* 2005), but no morphological differences have been found at a nearby contact zone between two lineages of the skink *Carlia rubrigularis* (Phillips *et al.* 2004). Additionally, little if any differences in morphology have been found between genetic lineages within several other Wet Tropics reptiles (Schneider and Moritz 1999). A hybrid zone can occur anywhere along a stream and can be abrupt. However, it is less likely, although possible, that such an overlap zone would occur on such a very short section of stream. Whether the patterns of *L. rheocola* size and/or call change away from the road represent differences between two overlapping genetic lineages or road impacts is not possible to determine from this data. Genetic analysis coupled with morphological and call analyses would be required to resolve this.

Ultimately the data shows that there is potentially an impact of noise from the Kuranda Range Road on *L. rheocola* calling behaviour. However, this cannot be determined with complete confidence because the pattern of call change with distance from the road is complicated by links to morphology and, potentially, other factors. It is not possible from this dataset to determine which of the above theories is most likely. The possibility that the call and morphological variation is due to two genetic lineages of *L. rheocola* can be tested with genetic, morphology and call data, whereas the other two theories are very hard to disentangle without manipulative experiments and other data.

3.4.3 Traffic noise as a mechanism

If traffic noise is the impact causing the decline in larger males near the road and replacement by smaller males that call at a higher frequency, what is the mechanism? It could be a result of greater blanketing of larger males' lower-pitched calls by traffic noise. Blanketing of calls has been observed for North American frog species (Barrass and Cohn 1983, 1984, Barrass 1986). Such blanketing would make the area adjacent to the road less than optimal habitat for the species and may cause the larger, more dominant males to select calling habitat further from the road.

The call of this species is at a relatively high pitch (2.4-2.7 kHz), while the dominant traffic noise frequency is about 1 kHz, whereas flowing water appears to dominate in the 2-2.5 kHz bands (see Section 1). Thus traffic noise may be expected to be less important for this stream-dwelling species which already often must deal with noise from water flow. Measurements demonstrated that water flow noise was not prominent at the 100 metre distance along the stream (see Section 1) and absent at the two hundred metre area which bordered on an acoustic refuge. Traffic noise may thus be dominating the species' dominant calling frequency at the one hundred metre distance by overlapping with that band when water flow is not present. This overlap would be expected to be especially important closest to the noise source near the road edge, resulting in the decline near the road.

It is known that background noise can affect the calls of amphibians. Studies on neotropical tree frogs by Schwartz and Wells (1983) found significant behavioural effects on both sexes of *Hyla ebraccata* due to the presence of background noise. The largest modification to vocalisations in that species occurred when the dominant frequency of the noise coincided with the dominant frequency of the frog's call. However, noise with frequencies that only partially blanketed calls, similar to traffic noise and calls of *L. rheocola*, also triggered some acoustic modifications (Schwartz and Wells 1983).

Although the work has yet to be published, Parris and Velik-Lord may have found evidence that frogs in Melbourne urban areas with high levels of traffic noise are compensating for the noise by adjusting the pitch of their calls to a higher frequency (Catchpole 2004, Ainley North 2007). The southern brown tree frog calls at a higher frequency in noisy sites compared with quiet areas. The researchers believe that this decreases the reproductive capacity of the male that has adjusted its vocalisations because females still prefer a lower-pitched call and may ignore the male calling at a higher pitch because he sounds like a smaller individual. For *L. rheocola* the pattern appears different, in that the males appear to be aligning their home ranges along the stream in terms of call pitch which itself depends on body size, so that smaller males with higher-pitched calls that might suffer less interference from traffic noise occur closest to the source of the noise.

3.4.4 Management implications

Litoria rheocola is an endangered species that appears to be affected by traffic noise. Therefore noise amelioration near the habitat of this species at Streets Creek is of great importance during the Kuranda Range road upgrade. The alignment of the road so it does not follow Streets Creek so closely should be an advantage to the species. This species calls at a relatively high frequency, while several other rare and endemic species found on the Kuranda Range call at lower frequencies that might be expected to show greater effects of traffic noise due to blanketing of calls. Some of these other species (e.g. *Mixophyes schevilli*, *Litoria genimaculata*) should be targeted at their peak breeding season in similar studies to examine whether they also may be affected by traffic noise, either in terms of alteration of vocalisations or road edge avoidance or both impacts.

3.5 Conclusion

This study has found conclusive evidence that the calling rate of males of *L. rheocola* increases near the road and that the dominant frequency of their calls also increases from fifty-five metres inside the forest to the forest edge. This is related to the size of males – smaller males are found closer to the road. Larger and possibly more dominant males may be selecting for preferable habitat away from the road, leaving the smaller individuals in habitat that is more greatly affected by traffic noise blanketing of calls. Alternatively, there may be a genetic overlap zone or road mortality may be removing larger males from the system. The second of these latter hypotheses appears unlikely from road mortality surveys. The genetic overlap zone hypothesis cannot currently be eliminated as a cause of the changes in vocalisations. However, it appears likely that traffic noise may cause hitherto unknown impacts on amphibians, resulting in declines in some species (Section 2) and changes in vocalisations of at least one species (Section 3).

3.6 Recommendations and future research

Noise amelioration works with solid barriers that prevent traffic noise propagation towards ground level should be undertaken on the high bridge and its surrounds adjacent to Streets Creek.

Future research should extend the vocalisation research on the species and target other species of conservation significance during their peak breeding season.

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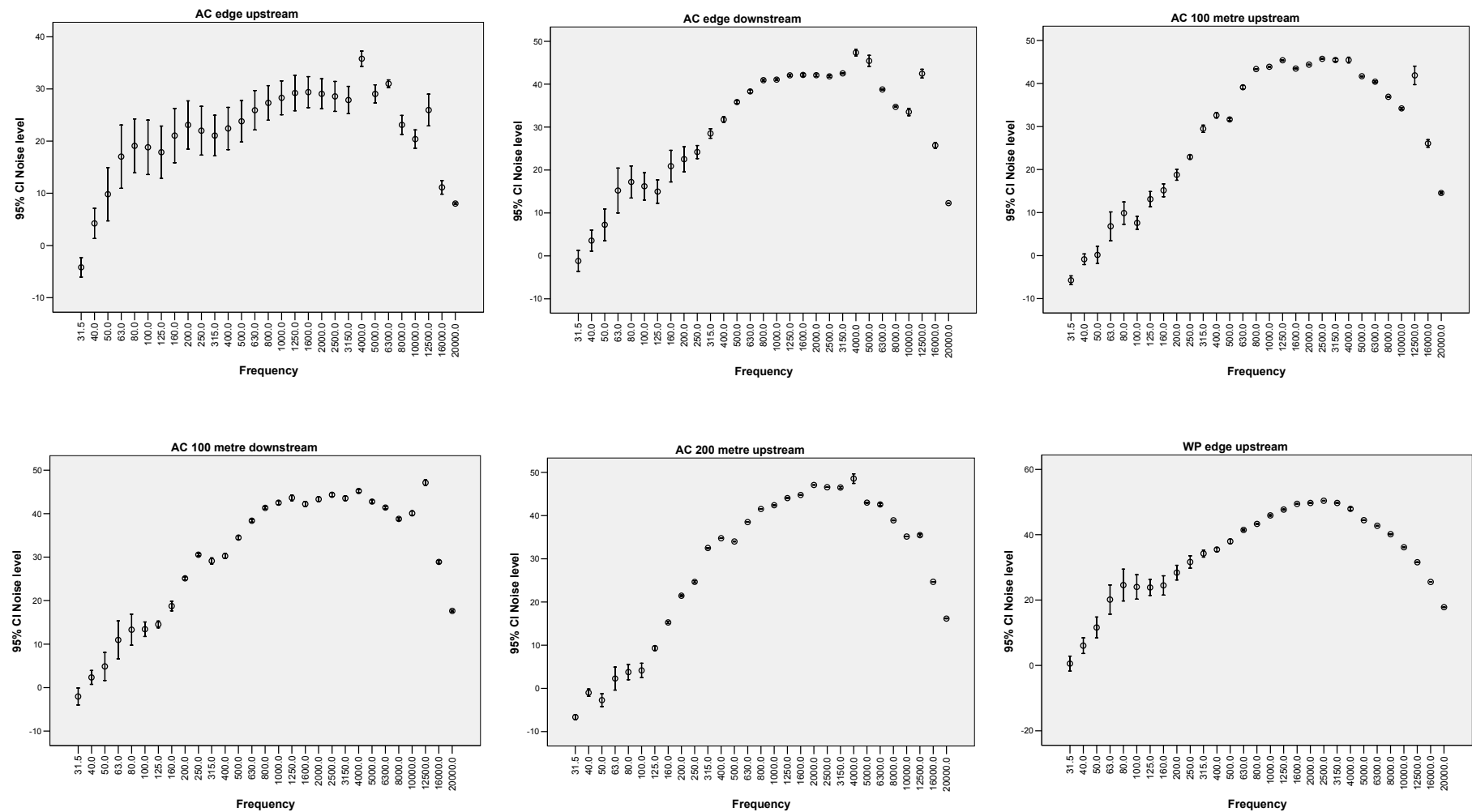
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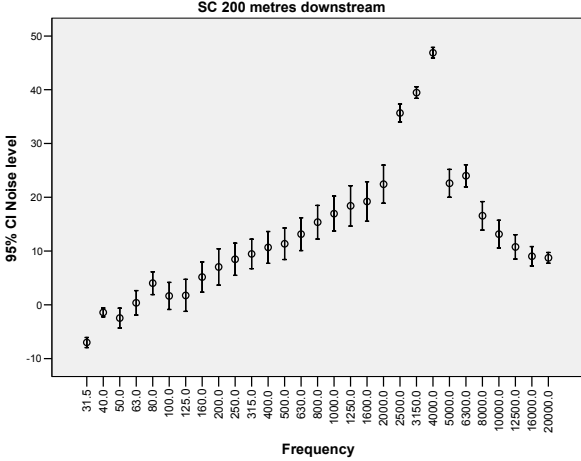
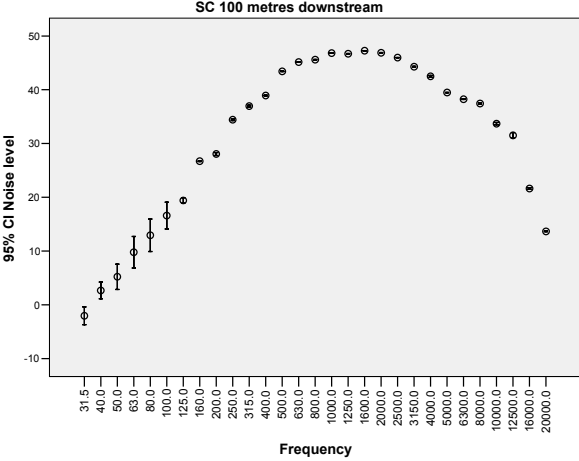
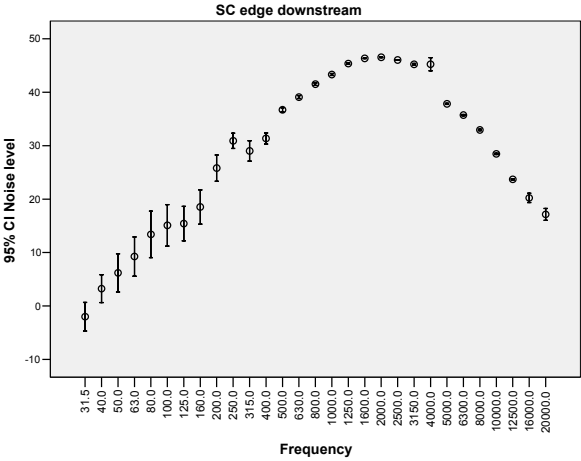
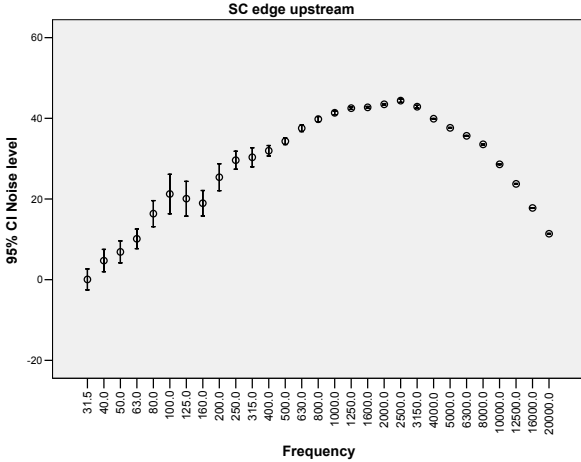
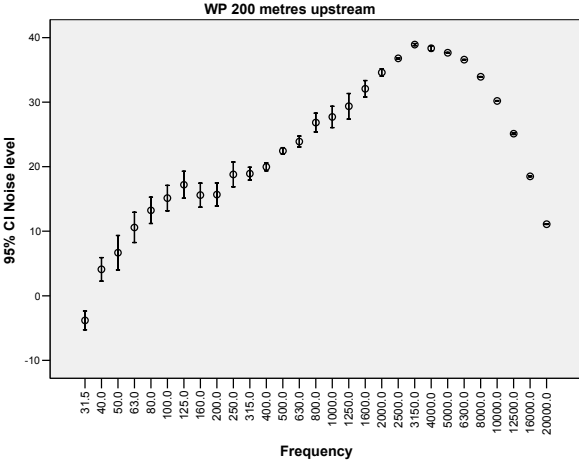
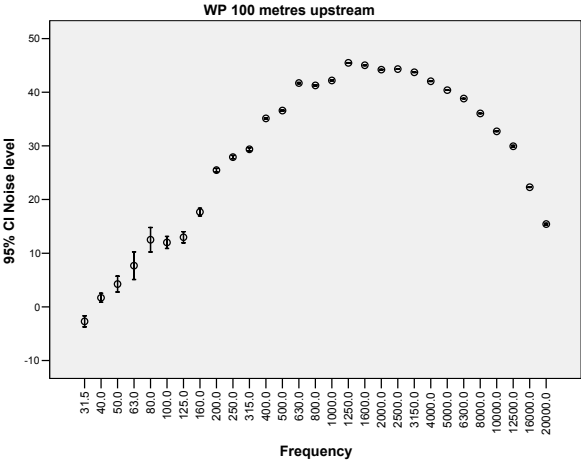
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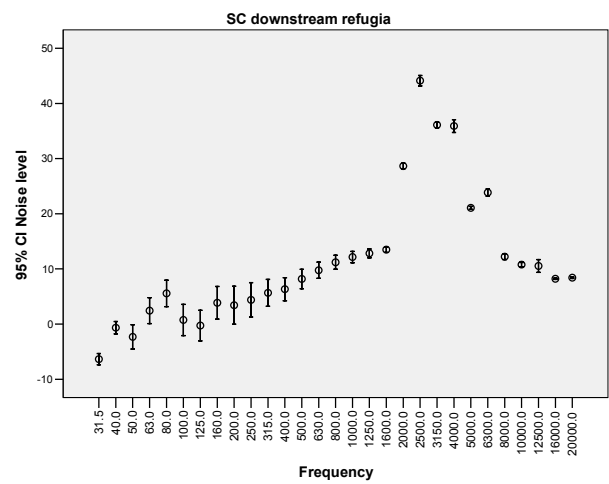
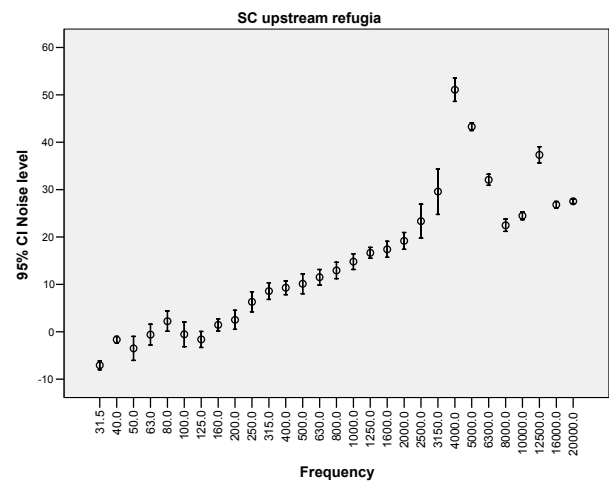
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Appendix 1 – Late night third-octave spectra at each site







Appendix 2 – Photographs of nocturnal noise sampling points



Figure 1: Sound level meter setup at upper Streets Creek acoustic refuge, 170m from highway along Powerline transect.



Figure 2: Nocturnal noise sampling setup at Avondale Creek, two hundred metres upstream from lower highway crossing.

Further information

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