



Lincoln University Digital Thesis

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- you will use the copy only for the purposes of research or private study
- you will recognise the author's right to be identified as the author of the thesis and due acknowledgement will be made to the author where appropriate
- you will obtain the author's permission before publishing any material from the thesis.

**Ecology of long-tailed bats *Chalinolobus tuberculatus*
(Forster, 1844) in the Waitakere Ranges: implications
for monitoring**

Jane Alexander
2001

**A thesis submitted in partial fulfilment of the requirements for the degree of
Master of Applied Science at Lincoln University**

Acknowledgments

Special thanks to my husband Simon Chapman for sharing my love of the Waitakere Ranges and for encouraging me. I couldn't have done it without your help. Thanks also to my parents who provided enormous support and encouragement. Many thanks to all the volunteers who sacrificed themselves to mosquitoes and enthusiastically helped with this project. Thank you to Greg Wittmer who rediscovered long-tailed bats at Cascade Kauri Park and shared his extensive local knowledge and enormous enthusiasm for bats with me.

Thank you to Colin O'Donnell for commenting on an early chapter draft and to all the National Bat Monitoring Team for training, equipment and for helping with the study. Thanks to Vern Smith and Pam Robinson for weather data. Thank you to the Department of Conservation for equipment and help with surveys. Thanks to the Auckland Regional Council for funding and equipment. Special thanks to Auckland Regional Council parks staff at Arataki, for all their interest in the project, help with surveys, and for sharing their own observations of bats with me. Thanks also to Watercare Services Limited for providing access into reservoir areas and to Watercare staff for interest in the project.

Last but not least, thank you to my supervisor, Kerry-Jayne Wilson and associate supervisor, Sue Worner, for their constructive criticism and help with editing.

But now ask the beasts, and let them teach you;
and the birds of the heavens, and let them tell you.
Or speak to the earth, and let it teach you;
who among all these does not know
that the hand of the Lord has done this,
in whose hand is the life of every living thing,
and the breath of all mankind?

Job 12: 7-10

Abstract of a thesis submitted in partial fulfilment of the requirements for the
Degree of Master of Applied Science

**Ecology of long-tailed bats *Chalinolobus tuberculatus* (Forster, 1844) in the
Waitakere Ranges: implications for monitoring**

by Jane Alexander

The long-tailed bat (*Chalinolobus tuberculatus*) is a threatened species endemic to New Zealand. Historical anecdotes indicate that long-tailed bat populations have declined. However, it is unknown if all populations have declined and if declines are historical or ongoing. Thus, the development and implementation of a national network of long-tailed bat monitoring sites is a priority of the Department of Conservation's Bat Recovery Plan. Potentially, information gained from a national monitoring programme would assist conservation managers to target resources towards those areas where bat populations are declining and provide baseline information to assist managers to gauge the impact of management techniques on bat populations. Of critical importance is that unless it can be demonstrated that long-tailed bat populations have declined and that, that decline is real, management will not be initiated.

The aim of this research was to investigate aspects of the ecology of long-tailed bats that would influence the development of a monitoring programme. The distribution, roost selection, habitat use, and activity patterns of a long-tailed bat population that persisted in the Waitakere Ranges, Auckland, were investigated. A study of the Waitakere Ranges long-tailed bat population was significant because (1) the Waitakere Ranges is the northern most location at which long-tailed bats have been researched; (2) the study was the first to be conducted on a long-tailed bat population that persisted in kauri *Agathis australis* dominated forest remnants; (3) the long-tailed bat population in the Waitakere Ranges is the only known extant population in close proximity to a major urban area; and (4) the factors that are attributed to long-tailed bat population declines (i.e., forest clearance, predation and urbanisation; O'Donnell, 2000) are likely to be ongoing and intensified in the Waitakere Ranges.

Twenty roosts were located. Most roosts (85%) were in kauri, 2 were in mature rimu (*Dacrydium cupressinum*) and 1 was in a kahikatea (*Dacrycarpus dacrydioides*). All roosts were in large, live, emergent trees. Mean height of roost trees was 38.4 ± 1.3 m and average DBH was 186 ± 12 cm. The entrances of six roost cavities were identified all were located in minor lateral branches in the crown of the tree and were primarily near the tip of branches. Roosts were a mean height of 24.6 ± 3.7 m above ground level. It was argued that roosts in the crowns of kauri were inaccessible to terrestrial mammalian predators.

Twenty-eight roost watches were conducted. The average number of bats counted leaving roosts was 10.0 ± 1.5 (maximum = 24). Roosts were occupied by radio-tagged bats for an average of 2.0 ± 0.4 days, and 11 (55 %) were occupied for only one day. Roost size was the lowest reported for long-tailed bats. Roost switching also appeared higher than in other populations that have been studied. It was argued that morepork predation may have a significant impact on the population viability of the population.

As in other studies long-tailed bats were found to forage over modified habitats including over farmland, dwellings, orchards and along streams and roads with little vehicular traffic. Long-tailed bats foraged throughout the Waitakere Ranges and their foothills. Bat activity was highly variable. Of the environmental variables analysed, temperature was found to have the greatest influence on bat activity. There were seasonal and habitat influences on bat activity. The relationship between sample sizes, variation in bat detection rates and desired statistical power using automatic bat detectors to monitor populations of bats was explored. A power analysis on activity data collected with automatic bat detectors indicated that declines in bat populations would need to be reflected in declines of greater than fifty percent in bat activity before monitoring programmes would have sufficient power to detect declines in activity. It was recommended that monitoring programmes should concentrate on intensive presence – absence surveys rather than long-term studies at a few sites.

Contents	Page
Acknowledgments	2
Abstract	3
List of Figures	6
List of Tables	9
Chapter one:	
General Introduction	10
Chapter two:	
The distribution and roosts of long-tailed bats in the Waitakere Ranges, West Auckland, New Zealand	22
Chapter three:	
Nocturnal activity of long-tailed bats in the Waitakere Ranges, West Auckland, New Zealand	48
Chapter four:	
Can bat detectors be used to detect changes in long-tailed bat populations?	69
Chapter five:	
General discussion	89

List of Figures

Figure		Page
Chapter one:		
Figure 1	Location of the Waitakere Ranges	17
Chapter two:		
Figure 1	Location of catchments and names mentioned in the text	30
Figure 2	Distribution of long-tailed bats in the Waitakere Range	31
Figure 3	Dominant land classes in the Waitakere Ranges, and the distribution of long-tailed bats and their roost sites	32
Figure 4	The number of sites that long-tailed bats in the Waitakere Ranges were detected on the 1 st , 2 nd , 3 rd , 4 th nights of recording	34
Figure 5	Survey efforts at sites where long-tailed bats were not detected in the Waitakere Ranges	34
Figure 6	Proportion of sites where bats were and were not recorded in each habitat type	35
Chapter three:		
Figure 1	Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during spring in three habitats	53
Figure 2	Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during summer in three habitats	54
Figure 3	Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during autumn in two habitats	54
Figure 4	Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during winter in two habitats	55
Figure 5	Percentage of bat passes containing feeding buzzes in three different habitats (all seasons combined)	55
Figure 6	Mean number of bat passes (all seasons combined) through the night in three habitat types	56

List of Figures

Figure		Page
Chapter three (continued):		
Figure 7	Bat activity levels during different minimum overnight temperature categories	58
Figure 8	Patterns of bat activity throughout the night at Cascades during lactation and pregnancy	59
Figure 9	Patterns of bat activity throughout the night at Huia during lactation and pregnancy	60
Figure 10	Comparison of bat activity between pregnancy and lactation at Huia and Cascades	60
Chapter four:		
Figure 1	Influence of variability in count data (CV%) on power to detect a decline with a single future survey	77
Figure 2	Power to detect changes in bat activity at Huia during winter with annual surveys	80
Figure 3	Power to detect changes in bat activity at Cascades with annual surveys during summer and only including monitoring data when overnight minimum temperatures are between 15-20°C	80
Figure 4	Power to detect a 5 % annual decline in bat activity during summer at Cascades	81
Figure 5	Power to detect declines in bat activity at Cascades monitoring for 20 nights	81
Figure 6	Power to detect annual declines in the proportion of sites with and without bats, comparing results from this study with a single future presence/absence survey	82
Figure 7	Power to detect changes in the proportion of sites with and without bats, comparing results from this study with a single future survey	82

List of Tables

Table		Page
Chapter two:		
Table 1	Summary of bat sightings in the Waitakere Ranges	28
Table 2	Frequency of occurrence of bats at automatic bat detector sites	33
Table 3	Roost tree characteristics	37
Table 4	Cavity entrance characteristics	38
Chapter three:		
Table 1	Association of bat activity with environmental variables	58
Chapter four:		
Table 1	Summary of seasonal bat activity	75
Table 2	Variability in bat activity	76
Table 3	Percentage of random subsamples from Huia	78
Table 4	Percentage of random subsamples from Cascades during summer	79
Table 5	Percentage of random subsamples from Cascades during spring	79

Chapter 1: Introduction

Introduction to New Zealand bats

Bats are New Zealand's only native terrestrial mammals. Three species, all endemic to New Zealand, are known: the long-tailed bat (*Chalinolobus tuberculatus* Forster, 1844), the lesser short-tailed bat (*Mystacina tuberculata* Gray, 1843) and the greater short-tailed bat (*M. robusta* Dwyer, 1962). The greater short-tailed bat became extinct during 1967 (Daniel, 1990). Both extant species are classified as threatened (Molloy, 1995). The short-tailed bat is listed by the Department of Conservation in category A (species of highest conservation priority) and the long-tailed bat in category B (second priority species for conservation action) (Molloy and Davis, 1994). Species in category B are considered to be at risk of extinction in the medium term if population trends continue (Molloy and Davis, 1994; O'Donnell, 2000a).

Taxonomy

The long-tailed bat belongs to an almost cosmopolitan family, Vespertilionidae. The genus *Chalinolobus* contains five other species distributed among Australia, New Guinea and New Caledonia (Hill and Smith, 1984). Three of the six *Chalinolobus* species are described as threatened (G. C. Richards pers. comm. cited in O'Donnell, 1999a). No subspecies of the long-tailed bat are formally recognised. However, there is geographic variation in echolocation calls (Parsons, 1997), morphology (Daniel, 1990), and there are genetic differences among populations. The level of genetic distinctiveness between the North and South Island populations is similar to that found between the recognised short-tailed bat subspecies (Winnington, 1999). Winnington (1999) recommended that North and South Island long-tailed bat populations should be treated as separate conservation management units.

Distribution and population declines

Since European settlement, anecdotal evidence suggests a steady decline in the number and size of long-tailed bat populations (O'Donnell, 2000a). Prior to the mid-1800s long-tailed bats were common and widely distributed throughout New Zealand (O'Donnell, 2000a). Buller (1892) and Cheeseman (1893) reported roosts containing hundreds or thousands of bats. By the 1930s naturalists had begun noting declines in long-tailed bat populations. For example, Stead (1936) recalled that 'It is, unfortunately, no longer correct perhaps, to refer to the long-tailed bat as a

common species, for it is quite gone from most districts, and is rapidly becoming scarcer in those where it still remains’.

O’Donnell (2000a) reviewed published distribution maps for long-tailed bats (Dwyer, 1960, 1962; Daniel and Williams, 1984; Molloy, 1995). The maps were based on presence or absence in each square of the 10 000 yard national grid. While the maps showed sightings made during different periods (pre-1930, 1930-1960, 1961-1983 and 1980-1995), they were inadequate for examining population trends and status (O’Donnell, 2000a). The maps were large-scale and contained errors. For example, Molloy (1995) attributed sightings to long-tailed bats when the bat species was not known (O’Donnell, 2000a). While bats were recorded in a grid square no data was given on the number of sightings, the number of bats present, or measures of survey effort (O’Donnell, 2000a).

Despite very limited data, some authors have reached conclusions on the status, population trends, and causes of decline of long-tailed bats. For example, Dwyer (1960, 1962) found that although long-tailed bats were widespread throughout New Zealand their distribution had significantly contracted since European settlement. He suggested there was no evidence that long-tailed bat populations had declined in areas of unmodified forest and attributed the reduction in long-tailed bat distribution to the clearance of indigenous forest cover and increasing urbanisation. Daniel and Williams (1984) considered that long-tailed bats had a secure conservation status. Daniel (1990) concurred, suggesting long-tailed bats were common and widely distributed throughout New Zealand.

During the 1990s, survey effort mostly in the South Island found that long-tailed bats were absent from some areas where they had previously been observed. Where they persisted, with the exception of the Eglinton and Dart Valleys, they were uncommon or rare (O’Donnell, 2000a). At Banks Peninsula and South Westland the declines have occurred during the last thirty years and while some population declines have occurred in very modified and fragmented habitats (e.g., Arahura and Geraldine) others have declined despite the retention of large areas of indigenous forest (e.g., Northern Nelson, South Westland) (O’Donnell, 2000a). In Eglinton Valley, where

bats are considered common (O'Donnell, 2000a), the average colony was small, averaging 35 bats (O'Donnell and Sedgely, 1999).

Similar surveys were not undertaken in the North Island therefore it is unclear whether a similar population decline has occurred there (O'Donnell, 2000a). In some North Island populations, there has been a reduction in the number of bats reported. For example, as early as the 1930s concern was expressed that long-tailed bats had declined in Waikato and there is anecdotal evidence that declines have continued (Borkin, 1999). Demographic studies undertaken at Balls Clearing, Hawkes Bay (Gillingham, 1996) and at Grand Canyon Cave near Te Kuiti (Ryan, 1999) paint a different picture. Both populations appear to be healthy with relatively high numbers of reproductive females and juveniles (Gillingham, 1996; Ryan, 1999). In fact, Gillingham (1996) reported communal tree roosts with an average of 86 occupants, and up to 200 bats in a roost, the most reported during the 20th century.

Other than circumstantial evidence, there is little information on the causes of long-tailed bat population declines. Forest clearance, predation and competition from introduced species, and disturbance at roost sites may all contribute to declines in long-tailed bat populations (O'Donnell, 2000a). Bats have been killed by cats (*Felis catus*) and moreporks (*Ninox novaeseelandiae*), and when trees containing roosts were felled (Daniel and Williams, 1984). Introduced species have been reported making nests in long-tailed bat roosts (starlings *Sturnus vulgaris* and ship rats *Rattus rattus*; Sedgely and O'Donnell, 1999a) and in cavities that appeared to be suitable for bat roosts (wasps *Vespula* spp., sparrows *Passer domesticus* and feral pigeons *Columbia livia*; Griffiths, 1996). However, the relative impact of these factors on long-term population viability has not been assessed (O'Donnell, 2000a).

Long-tailed bat ecology

Habitat use and movements

Long-tailed bats are largely associated with indigenous forest (Daniel, 1990), though roosts have been found in limestone cliffs, caves, buildings and exotic trees such as willows (*Salix fragilis*), macrocarpas (*Cupressus macrocarpa*) (Griffiths, 1996) and radiata pine *Pinus radiata*, (Daniel and Williams, 1984). Foraging long-tailed bats frequent forest edges (O'Donnell and Sedgely,

1994), regenerating *Kunzea ericoides* and *Leptospermum scoparium* forest (O'Donnell, 2001b) and utilise linear landscape features such as streams and roads (Griffiths, 1996; O'Donnell, 2001a; G. Moore pers. comm). They also forage over farmland and open water (Molloy, 1995; Griffiths, 1996; Borkin, 1999).

Patterns of activity vary during the night, through the year and between habitats (e.g., Griffiths, 1996; O'Donnell, 2001a). In the Eglinton Valley, activity was constant through the night along roads and within the forest but peaked along the forest edge and grassland during the two hours following sunset (O'Donnell, 2000b). Foraging over *K. ericoides* and *L. scoparium* was greatest post-lactation (late summer/autumn) (O'Donnell, 2001a). Different temporal patterns of bat activity are probably closely correlated with the availability of invertebrates in the different habitats (O'Donnell, 2000b). In contrast to overseas studies, there were single peaks in activity at dusk rather than bimodal peaks at both dusk and dawn which coincide with invertebrate activity. O'Donnell (2000b) suggested that the all night foraging may be necessary if food was limited and bats could not satisfy their hunger through shorter feeding bouts.

The home range sizes of long-tailed bats are amongst the largest of the Microchiroptera (O'Donnell, 2001b). The maximum home range of long-tailed bats in Eglinton Valley was 5629 ha and the maximum range length was 19 km (O'Donnell, 2001b). In Geraldine, the maximum home range size was 642 ha and maximum range lengths only 4.4 km (Griffiths, 1996). At least two explanations have been proposed to explain the reported differences. Griffiths (1996) suggested that because habitats in Eglinton Valley are homogenous compared with Geraldine, bats there would need to travel further to utilise alternative habitats. However, O'Donnell (2001b) hypothesised that food resources may be limited in Eglinton Valley and bats need to travel further to obtain enough adequate food. Despite variability in home range sizes, different long-tailed bat populations exhibit similar movement patterns each night, returning to optimal foraging areas most nights (Griffiths, 1996; O'Donnell, 2001a).

Roost site selection and use

Tree cavities used by long-tailed bats are not a random selection of those available. Roost trees in forested habitat are generally close to the forest edge. In Eglinton Valley, 95% of roosts were

within 500 m of the forest edge (Sedgeley and O'Donnell, 1999a) and at Hawkes Bay, all roosts were within 280 m of the forest edge (Gillingham, 1996). Sedgeley and O'Donnell (1999a) found that while long-tailed bats selected particular tree species (including standing dead trees) for roosts. Analysis indicated that rather than discriminating between tree species, trees were selected on the basis of functional characteristics associated with those trees (i.e. availability of cavities, greater trunk surface area and relatively low canopy cover). Generally, long-tailed bats select the largest mature trees with cavities (Gillingham, 1996; Griffiths, 1996; Sedgeley and O'Donnell, 1999a). They select cavities that are relatively high from the ground. For example, the average height of cavities was 15.9 m in Balls Clearing, Hawkes Bay (Gillingham, 1996) and 17 m in Eglinton Valley (Sedgeley and O'Donnell, 1999b). In Eglinton Valley, compared with random available cavities, roost cavities were all located in knot hole cavities that were dry and had little surrounding vegetation (Sedgeley and O'Donnell, 1999b). Bats used a higher proportion of cavities which had medium sized entrances and internal cavities with thick cavity walls (Sedgeley and O'Donnell, 1999b).

Long-tailed bats roost in solitary and colonial roosts. Females are more likely than males to roost in colonies (Gillingham, 1996; O'Donnell and Sedgeley, 1999). Roost-site lability is exceptionally high compared to other microchiroptera (O'Donnell and Sedgeley, 1999). For example, in Eglinton Valley the mean number of days that bats would use a roost for was 1.7 days and rates of reuse were very low, with 300 new roosts found over three years (O'Donnell and Sedgeley, 1999). In Geraldine, while the mean was 1.6 days/roost (Griffiths, 1996), the same roosts were revisited during the study period by different bats, suggesting that roosts may be limited.

Nocturnal activity patterns

Habitat, season, time of night, dusk temperature, minimum overnight temperature, and invertebrate activity all influence long-tailed bat activity (O'Donnell, 2000) as does moon phase (Griffiths, 1996), cloud cover, moonlight and maximum daily temperature (Gillingham, 1996). Factors that are correlated with bat activity differ among studies and may be area specific (Hayes, 1997). An effective monitoring program that aimed to detect population trends of long-tailed bats would need to account for both temporal and spatial variation in bat populations

(O'Donnell, 2000b). Otherwise valid comparisons between successive counts and other populations could not be made (O'Donnell, 2000b) and researchers may have little ability to detect small differences, which may be biologically significant (Hayes, 1997). It is important to design monitoring programmes that can adequately account for this variation or be effective despite it.

Current management of long-tailed bat populations

The Department of Conservation bat recovery plan suggested that the development of survey and monitoring techniques for long-tailed bats was a priority (Molloy, 1995). A number of Department of Conservation conservancies have undertaken broad scale surveys with automatic bat detectors (O'Donnell and Sedgeley, 1994). Critically, other than very limited presence/absence surveys there has been no research into kauri (*Agathis australis*) forest dwelling long-tailed bat populations (S. McManus, pers. comm.). The Department has established long-term monitoring of bat populations at four sites (C. O'Donnell, pers. comm.). Three of the sites are in the South Island: Dart Valley and Eglinton Valley, Fiordland and Geraldine, South Canterbury. The only site in the North island is at Te Kuiti in the King Country, a cave dwelling population.

Monitoring

Monitoring is an integral part of conservation management (Noss, 1990). Potentially, information gained from a national bat monitoring programme would assist conservation managers to effectively target resources towards areas where bat populations are declining and provide baseline information to assist managers to gauge the effect of management techniques on bat populations. Understanding population trends of a variety of long-tailed bat populations may also assist researchers to identify factors limiting populations (O'Donnell, 2000a).

Monitoring requires considerable planning, statistical evaluation (Zielinski and Stauffer, 1996) and an understanding of the ecology of the species that is being monitored (Norton, 1996). Monitoring can be very expensive (Norton, 1996). Sample size and the magnitude of the real change all affect the likelihood of a monitoring program being powerful enough to detect a trend (Cohen, 1988). Unless the probability of detecting a decline is known managers may rely on

monitoring programs that are not capable of detecting a decline before it is too late to prevent local extinctions (Taylor and Gerrodette, 1993). For example, in the case of the northern spotted owl (*Strix occidentalis caurina*) a monitoring programme indicated that the population was stable. However, on closer examination it was found that the monitoring programme had little power to determine whether the population was declining (Taylor and Gerrodette, 1993). Misguided mitigation techniques may waste valuable resources and future conservation efforts may be compromised (Blaustein, Wake and Sousa, 1994).

Monitoring bat populations overseas has primarily involved counting active or hibernating bats in roosting aggregations (e.g., in hollow trees, the foliage of vegetation, house attics, caves and mineshafts) and counting bats as they leave large maternity roosts, or by conducting demographic studies (Thomas and La Val, 1988; Gannon and Willig, 1998). Long-tailed bats move to new roosts almost every day, not all colony members share the same roost (O'Donnell and Sedgeley, 1999), they do not hibernate for long periods (O'Donnell, 2000b), and they may be susceptible to disturbance at their roosts (O'Donnell, 2000a). Therefore, most monitoring methods used overseas either cannot be applied to long-tailed bats, or would be impractical, too expensive, or would involve unacceptable levels of disturbance at roosts.

Low-cost bat detectors are now used extensively to monitor bat populations (Hayes, 1997). While they can be used to confirm the presence of bats and provide estimates of bat activity, there is no clear and consistent relationship between activity levels and the number of bats present (Hayes, 1997; O'Donnell and Sedgeley 1994). Knowledge of activity patterns can be used to guide the design of surveys and assess the relative importance of different habitats (Hayes, 1997). Attempts are being made to understand the relationship between levels of bat activity and actual population size. This is being tested by comparing index counts (primarily obtained through automatic bat detectors (O'Donnell and Sedgeley, 1994) and standardized road transects (Walsh and Harris, 1996)) with a range of known population sizes and productivity (O'Donnell, 1999). This has led to the development of draft monitoring guidelines for long-tailed bats (C. O'Donnell pers. comm.).

Study area

This research was undertaken in the Waitakere Ranges, Auckland, New Zealand (36° 57'S, 174° 32'E; Figure 1). The Waitakere Ranges were selected as a study site because:

1. They are 15 km west of Auckland City, New Zealand's largest city and home to one in four New Zealanders (Denyer *et al.*, 1993). A predominant feature of the Waitakere Ranges is the Auckland Centennial Memorial Park, comprising 14 899 ha of protected land, managed primarily by the Auckland Regional Council as part of the regional park network (Denyer *et al.*, 1993). There are between 1.7 and 2.5 million annual visits to the Waitakere Ranges parkland (Waitakere City Council, 2000). Therefore the Waitakere Ranges are an area where many New Zealanders experience nature. The long-tailed bat population in the Ranges, is thus a key population for advocacy and provides opportunities for public involvement in bat conservation.
2. The Waitakere Ranges have a long and intensive history of human induced change and these changes are ongoing (Denyer *et al.*, 1993). They are likely to intensify given the unparalleled pressure for development around the periphery of the park (Denyer *et al.*, 1993). No where else in New Zealand has development occurred within such a forested area (Denyer *et al.*, 1993). Therefore, it may be expected that factors that have been implicated in the decline of long-tailed bats elsewhere are heightened in the Waitakere Ranges. Given that other long-tailed bat populations near urban areas have become extinct and those populations that have persisted in highly modified environments are declining (e.g., O'Donnell, 2000a), it is likely that the Waitakere bat population is under threat. Thus, obtaining baseline data on this population is essential.

The Ranges are an uplifted dissected plateau and one of the two largest remaining areas of continuous indigenous vegetation in the Auckland region. Altitude ranges from 474 m down to sea level along the western and southern boundaries, where the Ranges give way to the Tasman Sea and Manukau Harbour respectively. The northern boundary is delineated by Mokoroa stream catchment and the eastern slopes merge with the western suburbs of Auckland where the boundary is indistinct. The northern Waitakere Ranges are relatively undulating, the southern Waitakere Ranges are extremely rugged with a deeply dissected topography (Denyer *et al.*, 1993). Annual rainfall averages 1569 mm (Grace, 1992) and average daily minimum and

maximum temperatures are between 5°C in July to 24°C in February respectively (New Zealand Meteorological Service, 1980).

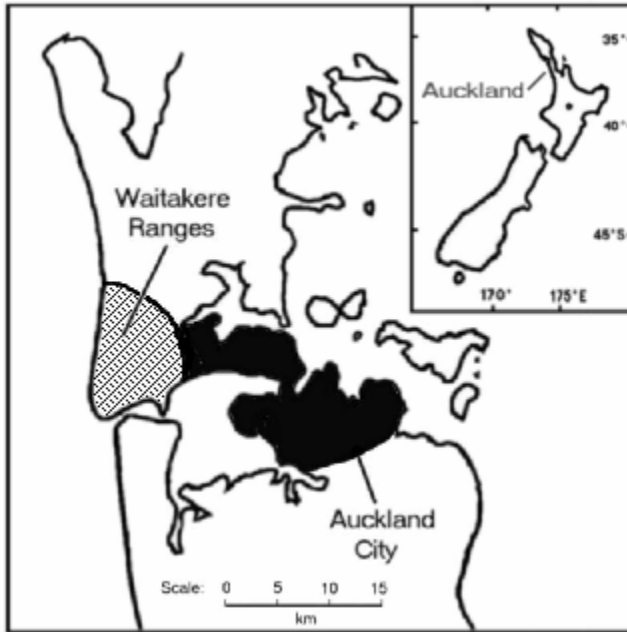


Figure 1: Location of the Waitakere Ranges

The vegetation is a mosaic of original podocarp-broadleaf forest and kauri forest, cut-over, burnt and completely cleared forest (Esler, 1983). Mature kauri forest in the Waitakere Ranges are different in structure and associated mid tier species compared to other mature kauri forests (Denyer *et al.*, 1993). For example in Hunua, kauri is associated with hard beech *Nothofagus truncata*, in Rodney and Waipoua forests kauri emerges over a taraire *Beilschmiedia tarairi* canopy. In the Waitakere Ranges, kauri and the occasional podocarp emerge over a very low mid tier of cutty-grass (*Gahnia* spp.), kauri grass (*Astelia trinervia*), kiekie (*Freycinetia banksii*) and mingimingi (*Cyathodes fasciculata*) (Denyer *et al.*, 1993). Vegetation distinctive of cut over forest includes scattered emergent northern rata (*Meterosideros robusta*) and smaller quantities of tawa (*Beilschmiedia tawa*), rewerewa (*Knightia excelsa*) and rimu (*Dacrydium cupressinum*). Pigeonwood (*Hedycarya arborea*), *Coprosma* spp., mahoe (*Melicytus ramiflorus*), tree ferns (*Dicksonia* spp. and *Cyathea* spp.) and nikau palms (*Rhopalostylis sapida*) dominate the sub-canopy (Esler, 1983). Scrubland is a feature of burnt or completely cleared farmland that is

converting to forest. Species that are dominant in scrubland include: manuka (*Leptospermum scoparium*), kanuka (*Kunzea ericoides*), akepiro (*Olearia furfuracea*), hangehange (*Geniostoma rupestre*), karamu (*Coprosma lucida*) and mamangi (*C. arborea*) (Esler, 1983).

Research objectives

General aim

- To provide information on aspects of long-tailed bat ecology in the Waitakere Ranges which will assist the development of a long-term monitoring program

Specific objectives

- To determine the distribution of long-tailed bats in the Waitakere Ranges
- To investigate the factors influencing the distribution of long-tailed bats in the Waitakere Ranges
- To determine temporal and spatial patterns of long-tailed bat activity in the Waitakere Ranges
- To determine whether Automatic bat detectors can be used to detect population trends

Thesis structure

Chapters two, three and four of this thesis are written as stand alone papers intended for publication in scientific journals. Therefore, there are similarities in the introductions and methods sections of each. In the final chapter, I highlight the key management implications of this research and make recommendations on future research and management of long-tailed bat populations.

References

- Blaustein, A. R., Wake, D.B., Sousa, W.P. 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. *Conservation Biology* 8: 60-71.
- Borkin, K. 1999. *Long-tailed bat distribution in the Waikato Conservancy*. Unpublished Diploma of Wildlife Management Report. University of Otago, Dunedin.
- Buller, W.L. 1892. Notes on the bats of New Zealand. *Transactions of the New Zealand Institute* 25: 50-52.
- Cheeseman, T.F. 1893. Notes on the New Zealand bats. *Transactions of the New Zealand Institute* 26: 218-222.
- Cohen, J. 1988. *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum, Hillsdale, New Jersey, USA.
- Daniel, M.J. 1990. Order Chiroptera. In C.M. King (ed.) *The handbook of New Zealand mammals*: 114-133. Oxford University Press, Auckland.
- Daniel, M.J., Williams, G.R. 1984. A survey of the distribution, seasonal activity and roost sites of New Zealand bats. *New Zealand Journal of Ecology* 7: 9-25.
- Denyer, K.; Cutting, M.; Campbell, G.; Green, C.; Hilton, M. 1993. *Waitakere ecological district: survey report for the protected natural areas programme*. Auckland Regional Council, Auckland.
- Dwyer, P.D. 1960. *Studies on New Zealand Chiroptera*. Master of Science Thesis. Victoria University, Wellington.
- Dwyer, P.D. 1962. Studies on the two New Zealand bats. *Zoology Publications from Victoria University* 28: 1-28.
- Eslar, A.E. 1983. Forest and scrubland zones of the Waitakere Range, Auckland. *Tane* 29: 109-118.
- Gannon, M.R., Willig, M.R. 1998. Long-term monitoring protocol for bats: lessons from the Luquillo experimental forest of Puerto Rico. *Man and the Biosphere* 21: 271-291.
- Gillingham, N. 1996. *The behaviour and ecology of long-tailed bats in the central North Island*. Unpublished M.Sc. Thesis. Massey University, Palmerston North.
- Grace, A. 1992. *Waitakere Ranges regional parkland management plan*. Auckland Regional Council, Auckland. 140p.
- Griffiths, R. 1996. Aspects of the ecology of a long-tailed bat, *Chalinolobus tuberculatus*,

- population in a highly fragmented habitat. Unpublished M.Sc. Thesis. Lincoln University, Canterbury.
- Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation monitoring studies. *Journal of Mammalogy* 78(2): 514-524.
- Hill, J.E., Smith, J.D. 1984. *Bats. A natural history*. Rigby, London.
- Molloy, J. 1995. *Bat (pekapeka) recovery plan*. Department of Conservation, Wellington.
- Molloy, J., Davis, A. 1994. *Setting priorities for the conservation of New Zealand's threatened plants and animals*. Department of Conservation, Wellington. 44pp.
- New Zealand Meteorological Service. 1980. *Summaries of climatological observations to 1980*. New Zealand Meteorological Service Miscellaneous Publication 177.
- Norton, D.A. 1996. Monitoring biodiversity in New Zealand's terrestrial ecosystems. In McFadgen, B and Simpson, P (Ed.). *Papers from a seminar on biodiversity*. Department of Conservation, Wellington.
- Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* 4: 355-364.
- O'Donnell, C.F.J. 2000a. Conservation status and causes of decline of the threatened New Zealand Long-tailed bat. *Mammal Review* 30(2): 89-106.
- O'Donnell, C.F.J. 2000b. Influence of season, habitat, temperature, and invertebrate availability on nocturnal activity of the New Zealand long-tailed bat. *New Zealand Journal of Zoology* 27: 207-221.
- O'Donnell, C.F.J. 1999. The ecology, spatial organisation and conservation of long-tailed bats *Chalinolobus tuberculatus*. Unpublished PhD thesis. University of Otago, Dunedin.
- O'Donnell, C.F.J. 1999b. Development of methods for monitoring long-tailed bat populations: progress reports. *Pekapeka* 6: 15-16.
- O'Donnell, C.F.J. 2001a. Advances in New Zealand mammalogy 1990-2000: long-tailed bat. *Journal of the Royal Society of New Zealand* 31(1): 43-57.
- O'Donnell, C.F.J. 2001b. Home range and use of space by *Chalinolobus tuberculatus*, a temperate rainforest bat from New Zealand. *The Journal of Zoology London*: 253: 253-264.
- O'Donnell, C.F.J. and Sedgeley, J.A. 1994. An automatic monitoring system for recording bat activity. *Department of Conservation Technical Series No.5*. Department of Conservation, Wellington.

- O'Donnell, C.F.J. and Sedgely, J.A., 1999. Use of roosts by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate rainforest in New Zealand. *Journal of Mammalogy* 80(3): 913-923.
- Parsons, S. 1997. Search phase echolocation calls of the New Zealand lesser short-tailed bat (*Mystacina tuberculata*) and long-tailed bat (*Chalinolobus tuberculatus*). *Canadian Journal of Zoology* 75: 1487-1494.
- Ryan, C. 1999. Hanging out at Grand Canyon. *Pekapeka* 6: 23-25.
- Sedgely, J.A. and O'Donnell, C.F.J. 1999a. Roost selection by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate New Zealand rainforest and its implications for the conservation of bats in managed forests. *Biological Conservation* 88: 261-276.
- Sedgely, J.A. and O'Donnell, C.F.J. 1999b. Factors influencing the selection of roost cavities by a temperate rainforest bat (Vespertilionidae: *Chalinolobus tuberculatus*) in New Zealand. *Journal of Zoology London* 249: 437-446.
- Stead, E.F. 1936. Notes on the short-tailed (*Mystacops tuberculatus*). *Transactions of the Royal Society of New Zealand* 66: 188-191.
- Taylor, B.L. and Gerrodette, T. 1993. The use of statistical power in conservation biology: the vaquita and northern spotted owl. *Conservation biology* 7: 489-500.
- Thomas, D.W. and La Val, R.K. 1988. Survey and census methods. In: Kunz, T.H. (Ed.) *Ecological and behavioral Methods for the study of bats*. Smithsonian Institution Press, Baltimore, pp. 77-89.
- Walsh, A.L., Harris, S. 1996. Factors determining the abundance of vespertilionid bats in Britain: geographical, land class and local habitat relationships. *Journal of Applied Ecology* 33: 519-529.
- Waitakere City Council. 2000. *Draft visitor strategy*. Waitakere City Council, Auckland.
- Winnington, A. 1999. *Ecology, genetics and taxonomy of pekapeka (Chiroptera: Mystacina tuberculata and Chalinolobus tuberculatus)*. PhD Thesis. University of Otago, Dunedin.
- Zielinski, W.J. and Stauffer, H.B. 1996. Monitoring Martes populations in California: survey design and power analysis. *Ecological Applications* 6(4): 1254-1267.

Chapter 2: The distribution and roosts of long-tailed bats in the Waitakere Ranges

Introduction

The New Zealand long-tailed bat (*Chalinolobus tuberculatus* Forster, Vespertilionidae) is one of two extant New Zealand bat species. It is an endemic small insectivorous bat which is largely forest dwelling (O'Donnell, 2001). The long-tailed bat is listed by the Department of Conservation as a category B species (second priority species for conservation action) (Molloy and Davis, 1994). Species in this category are considered to be at risk of extinction in the medium term if population trends continue (Molloy and Davis, 1994; O'Donnell, 2000a).

Prior to the mid-1800s long-tailed bats were common and widespread throughout New Zealand. Buller (1892) related Maori describing bats congregating in roosts that contained 'hundreds or thousands, and clinging to the sides in successive tiers, packed so closely as to occupy the interior surface'. By the 1900s naturalists had noticed declines in some long-tailed bat populations. For example, Stead (1936) recalled that 'It is, unfortunately, no longer correct perhaps, to refer to the long-tailed bat as a common species, for it is quite gone from most districts, and is rapidly becoming scarcer in those where it still remains'. By the 1930s bats were absent from most urban centres including Wellington, Invercargill, Christchurch, and Dunedin (Hutton and Drummond, 1904; Bathgate, 1922; Dwyer 1960).

During the 1990s, survey effort concentrated in the South Island indicated that long-tailed bats were absent from some areas where they had previously been observed. Where they persisted, with the exception of the Eglinton and Dart Valleys, they were uncommon or rare (O'Donnell, 2000a). At Banks Peninsula and South Westland the declines have occurred during the last thirty years and while some population declines have occurred in very modified and fragmented habitat (e.g., Arahura and Geraldine), populations in some forested areas (e.g., Northern Nelson, South Westland) have fared no better (Griffiths, 1996; O'Donnell, 2000a). In Eglinton Valley, where bats are considered common (O'Donnell, 2000a), the average colony was small, averaging 35 bats (O'Donnell and Sedgeley, 1999).

Factors attributed to the decline of long-tailed bats include forest clearance, urbanisation, predation, competition from introduced species, and disturbance at roost sites (O'Donnell, 2000a). However, these suggestions are speculative and unsubstantiated (O'Donnell, 2000a). Dwyer (1960) suggested that there was no evidence of long-tailed bat population declines in areas of unmodified forest and attributed the reduction in long-tailed bat distribution to the clearance of indigenous forest cover and increasing urbanisation. The extirpation of long-tailed bats from Canterbury, Otago and Southland coincided with forest clearance (Hutton and Drummond, 1904; Barrie, 1995). Prior to 1930s bat sightings were generally closer to towns and the coast than observations made after 1930 (Dwyer 1960). This was interpreted as reflecting the increased development of these areas post 1930 (Dwyer 1960; Barrie, 1995).

Bats have been killed by cats (*Felis catus*) and moreporks (*Ninox novaeseelandiae*), and when roost trees were felled (Daniel and Williams, 1984). Although stoats (*Mustela erminea*) and rats (*Rattus* spp.) probably prey on long-tailed bats (e.g., Daniel and Williams, 1984; Daniel, 1990; Molloy, 1995; Griffiths, 1996) no instances have been reported and there is little evidence to support or reject this suggestion (O'Donnell, 2000). Introduced species have been reported making nests in long-tailed bat roosts (starlings *Sturnus vulgaris* and ship rats *R. rattus*, Sedgeley and O'Donnell, 1999b) and in cavities that appeared to be suitable for bat roosts (wasps *Vespula* spp, sparrows *Passer domesticus* and feral pigeons *Columbia livia*; Griffiths, 1996). However, the relative impact of these factors on the long-term population viability has not been assessed (O'Donnell, 2000a).

Few remaining long-tailed bat populations survive near urban areas or in highly fragmented habitat (O'Donnell, 2000a). A long-tailed bat population has survived in the Waitakere Ranges, West Auckland. Since the 1980s bats have been regularly observed foraging at a grass clearing at Cascade Kauri Park during summer and Auckland Regional Council Park Rangers have guided walks to watch long-tailed bats foraging (G. Wittmer, pers. comm.). Given documented declines in other bat populations it is likely that the Waitakere bat population is in a similar predicament. The first step in developing a conservation management plan for long-tailed bats in the Waitakere Ranges is to determine their distribution. The aims of this study were to: (1)

determine the distribution of long-tailed bats in the Waitakere Ranges, (2) locate and describe bat roosts, and (3) examine the use of roosts by bats.

Methods

Study area

This research was undertaken in the Waitakere Ranges, Auckland, New Zealand (36° 57'S, 174° 32'E). The Ranges are an uplifted dissected plateau of volcanic origin, and one of two largest remaining areas of continuous indigenous vegetation in the Auckland region. Altitude ranges from 474 m down to sea level along the western and southern boundaries, where the Ranges give way to the Tasman Sea and Manukau Harbour respectively. The northern boundary is delineated by Mokoroa stream catchment and the eastern slopes merge with the western suburbs of Auckland. The northern Waitakere Ranges are relatively undulating, the southern Waitakere Ranges are extremely rugged with a deeply dissected topography (Denyer *et al.*, 1993). Annual rainfall averages 1569 mm (Grace, 1992) and average daily minimum and maximum temperatures are between 5°C in July to 24°C in February (New Zealand Meteorological Service, 1980).

The vegetation is a mosaic of remnants of non-cutover podocarp-broadleaf forest and kauri (*Agathis australis*) forest, cutover, burnt and completely cleared forest (Esler, 1983). Typically kauri and the occasional podocarp emerge over a low mid tier of cutty-grass (*Gahnia* spp.), kauri grass (*Astelia trinervia*), kiekie (*Freycinetia banksii*) and mingimingi (*Cyathodes fasciculata*), *Corokia* spp., *Dracophyllum* spp. and *Alseuosmia macrophylla* (Esler, 1983; Denyer *et al.*, 1993). In the Waitakere Ranges, vegetation characteristic of cut over forest includes scattered emergent northern rata (*Metrosideros robusta*) and smaller numbers of tawa (*Beilschmiedia tawa*), rewerewa (*Knightia excelsa*) and rimu (*Dacrydium cupressinum*). Pigeonwood (*Hedycarya arborea*), *Coprosma* spp., mahoe (*Melicytus ramiflorus*), tree ferns (*Dicksonia* spp., *Cyathea* spp.) and nikau palms (*Rhopalostylis sapida*) dominate the sub-canopy (Esler, 1983). Scrubland is a feature of burnt or completely cleared farmland that is reverting to forest. The species that dominate scrubland include manuka (*Leptospermum scoparium*), kanuka (*Kunzea ericoides*), akepiro (*Olearia furfuracea*), hangehange (*Geniostoma rupestre*), karamu (*Coprosma lucida*) and mamangi (*C. arborea*) (Esler, 1983).

Public sightings

Literature relating to the Waitakere Ranges was reviewed for references to bats. The National Bat Database administered by the Department of Conservation was also searched for records of bats from the study area. Sightings of bats were elicited from the public by placing notices in local newsletters, newspapers, shop windows, speaking at various local interest group meetings, and by interviewing current and former Waitakere Ranges Park Rangers. Where possible, surviving members of pioneer families were also contacted.

Automatic bat detector survey

This survey was undertaken between November 1998 and March 2001. The automatic bat detection system described by O'Donnell and Sedgeley (1994) was used to survey 92 sites that were selected on the basis of vegetation characteristics, landforms, topography and water features that would be attractive to bats. Bat detectors were set to 40 khz to maximise the likelihood of detecting long-tailed bats (O'Donnell and Sedgeley, 1994). The presence or absence of bats was recorded for each site.

Line transects

Standardised 1 km transects were undertaken during the summer of 1999/2000. They involved walking a length of road slowly (3 km h^{-1}), while holding a bat detector. They were only undertaken during the first two hours after sunset when the weather was fine (no rain or strong wind) and the minimum temperature was greater than 10° C (see O'Donnell, 2000a for a full description of the method). Presence or absence of bat passes on each transect was recorded.

Personal observations

One observation of a bat was made at a site where no other method revealed the presence of bats.

Locating roosts

Roosts were located by following radio-tagged bats during the day. Eleven bats (eight females and three males) were radio-tracked between 10 December 1999 and 11 March 2001. Bats were captured using double-framed harp traps (Austbat, Melbourne, Australia) or mist nets (Dilks, Elliott and O'Donnell, 1995) set across bat flight paths. Bats were fitted with 0.7 g radio

transmitters (Type BD-2A, Holohil, Ontario, Canada) and tracked using a radio receiver (model Regal 1000, I. Trethowen, Waipara, New Zealand) and a hand held, three element, yagi antenna (Sirtrack, Havelock North, New Zealand).

Describing roosts

For each roost tree located, the species, tree height, DBH (diameter at breast height in centimetres; i.e., trunk diameter at 1.4 m above ground level on the uphill side of the tree), forest type, slope, aspect, distance from capture site, distance from forest edge, and the position in the catchment was recorded. Whenever possible roost trees were watched at dusk to locate the cavity entrance, count the number of bats departing (not necessarily the number of roost occupants), and determine the number of days each roost was occupied. During roost watches, the presence of any potential predators was noted. Five characteristics of the cavity entrances were described: entrance orientation, height of cavity from the ground, diameter of cavity entrance (estimated from the ground, therefore subjective), cavity type (knot hole or hollow branch tip) and location on the tree (trunk, major or minor lateral branch). A clinometer (Suunto, Helsinki, Finland) was used to measure tree height, the height of the cavity from the ground, and the slope of the ground.

Locating foraging areas

Locating bats' day roosts was a priority of this research but when possible, bats were also tracked during the night to locate foraging areas. A bat was considered to be active when the signal strength and direction constantly changed and inactive when the signal did not alter in intensity or direction (Harris *et al.*, 1990). Both the direction and strength of the signal was recorded. Location estimates were made using two methods: close approach and triangulation (White and Garrott, 1990). To ensure fixes were independent, fixes were recorded every 15 minutes during the night. Estimated bat locations were recorded as a six digit grid reference determined from the Waitakere Ranges topographical map (New Zealand Map Series 260 Q11 and Pt. R11). As there is considerable error associated with radio tracking, only those locations that were not revealed with other methods are shown.

Results

Public sightings

Seventeen historical and recent sightings were found (Table 1; Figure 1 and 2)

Automatic bat detector surveys

A total of 341 nights at 92 sites was sampled (Table 1; Figure 2 and 3). Bats were recorded at 32 of the sites. At 27 (84.4%) of the 32 sites where bats were recorded, they were detected on the first night of recording (Figure 4). Only at one (1.1%) of these sites did it take more than three nights to detect them. At that site, bats were detected on the fourth night of sampling. At the 60 sites where bats were not detected, between one and seven nights were sampled (Figure 5). The proportion of sites where bats were recorded varied significantly between habitats. Bats were recorded at fewer sites than expected in forest (excluding grassland and lake habitats as sample sizes were too small) ($\chi^2 = 7.32$, d.f = 2, $P < 0.05$; Figure 6).

Line transects

Seventy 1km line transects were completed in the Waitakere Ranges, Long-tailed bats were recorded on two of the transects. One was along Huia Dam Rd and the other was along Anawhata Rd.

Table 1: Summary of bat sightings reported by the public in the Waitakere Ranges

Site	Date	Number of bats	Comments	Source
Whatipu	1920s	Several	Roosting in caves	Miriam Cameron
Huia	1920s	Many	A number of bats hung upside down on the branches of a loquat tree that grew near the Higham's farmhouse (Huia Reserve)	Norm Laing (1985)
Karamatura Huia	1930s-1970s 1950s	Up to 10 Colony	Numerous observations over farmland Roost in old kauri tree behind the Huia Store, has since been cut down	Dave Fletcher Greg Wittmer
Bendall Bluff, Waiatarua	1950s, 1980s		Roosting in crevice in rocky bluff	Tom Whyte, Harry Beacham
Bush Rd, Waiatarua	1960s	2+	Flying over orchards	Tom Whyte
View Rd, Waima	1960s	12+	Roosting in a <i>Cupressus macrocarpa</i> which has since been cut down	Bill Beveridge
Mount Atkinson, Titirangi	1970s	1	Roosting in the trig on the summit	Greg Wittmer
Huia	1982	Several	Roosting on ceiling of a coastal cave	DOC National Bat Database
Waimauku	1985	Several	Flying over farmland	DOC National Bat Database
Cascades	1983, 1986	Several	Detected flying along Waitakere River	John Powell, DOC National Bat Database
Lower Nihotupu Dam	no date	Colony	Roosting in a <i>Cupressus macrocarpa</i> which has since been cut down	Ormiston Walker (1990)
Henderson Valley	1990s	1+	Foraging over orchard	Morris Coglán
Arataki	1999	2+	Roosting in train tunnel	Steve Knox

Table 1: (continued)

Site	Date	Number of bats	Comments	Source
Piha Rd/ Anawhata Rd	1999	several	Occasionally seen when outside light is on	Jim Forbes
Karekare	1998	several	Observed chasing puriri moths near outside light	John Edgar
Karekare	1999	7+	Seen on several occasions at same site, foraging under and above taraire canopy	Dave Bryan



Figure 1: Catchment areas and place names mentioned in the text.

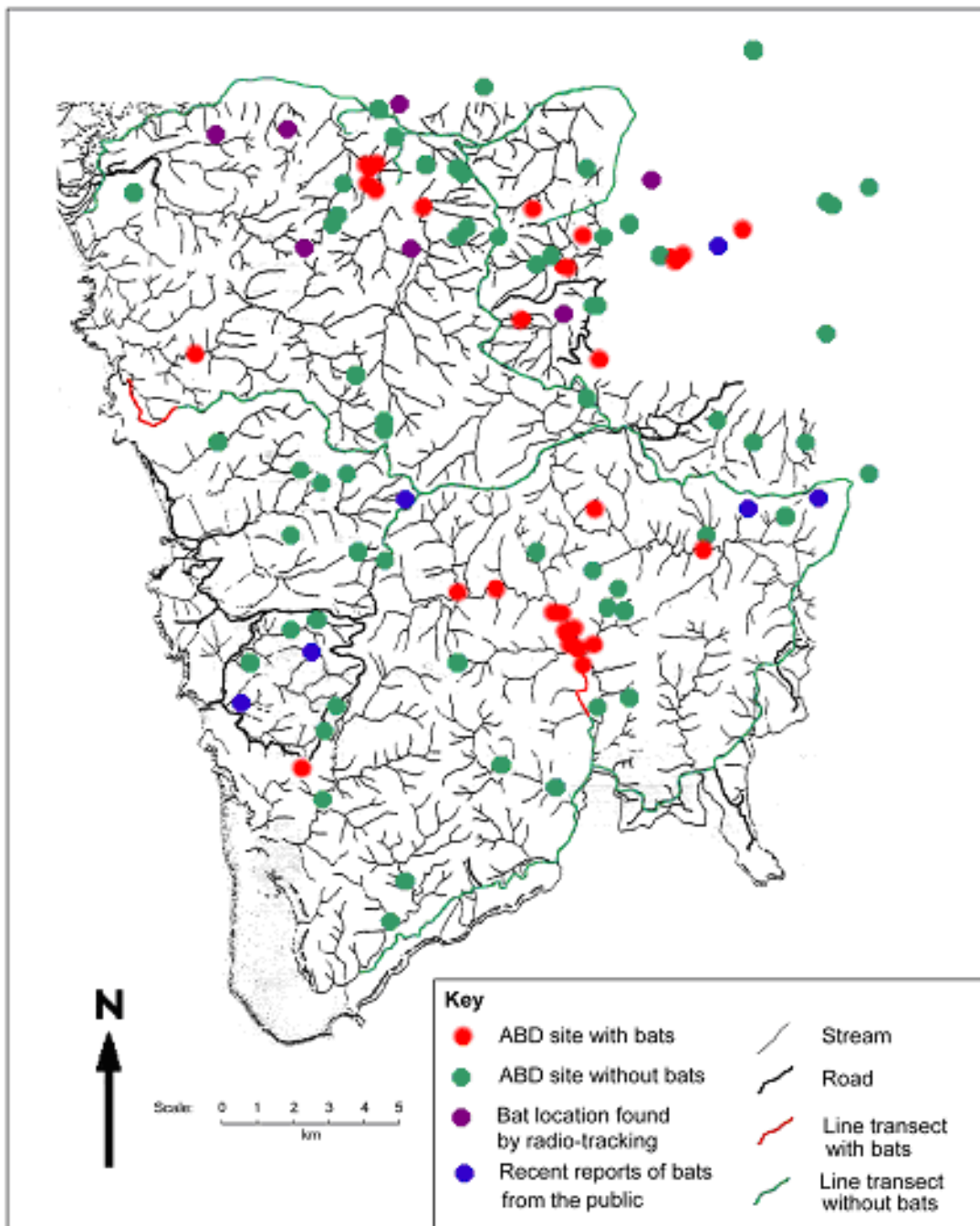


Figure 2: Distribution of long-tailed bats in the Waitakere Ranges.

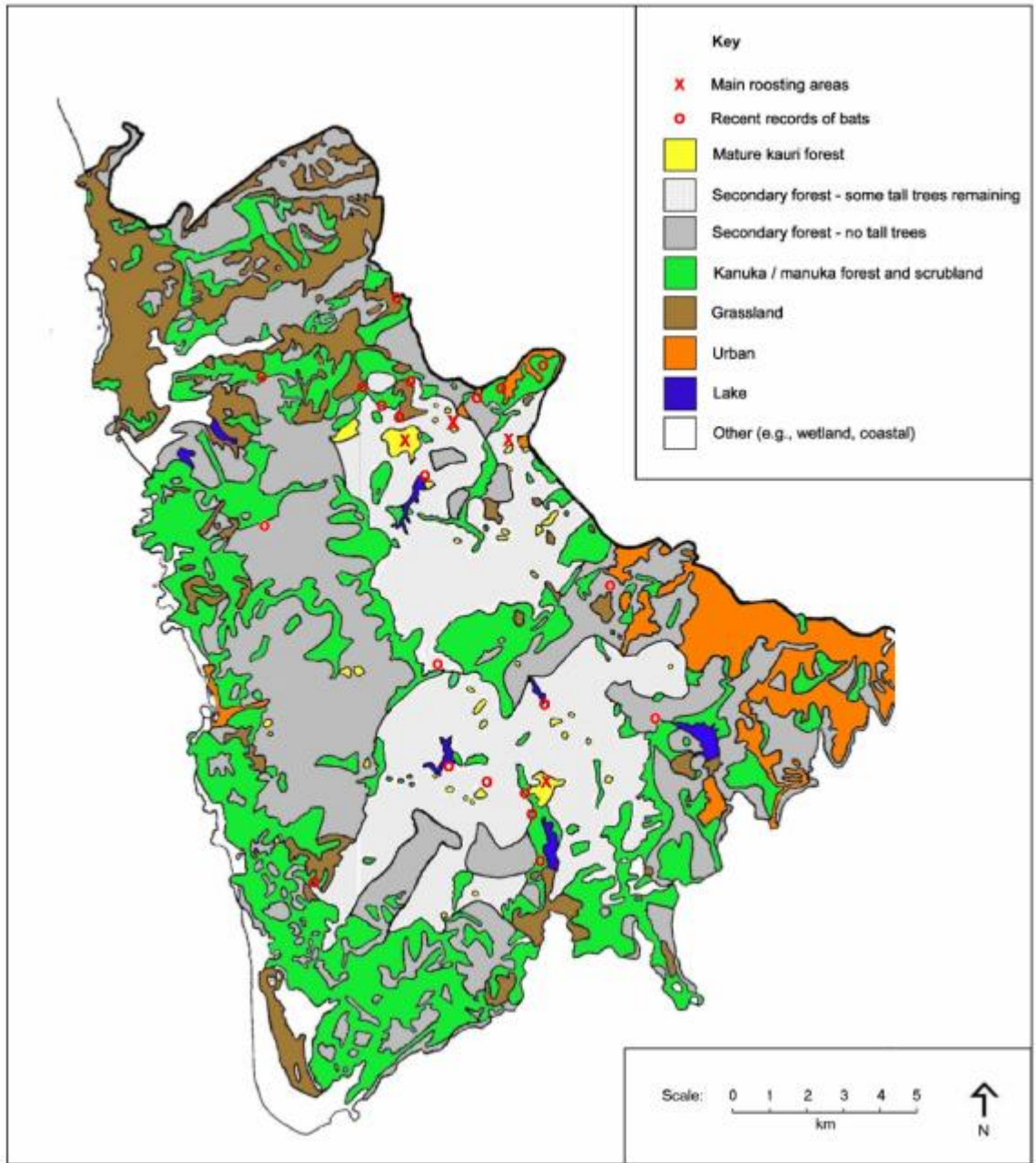


Figure 3: Dominant land classes in the Waitakere Ranges, and the distribution of long-tailed bats and their roost sites.

Table 2: Frequency of occurrence of long-tailed bats at automatic bat detector sites in different areas of the Waitakere Ranges

Area	Number of nights sampled	Number of nights with bats	% of nights bats present	Number of sites surveyed	Number of sites with bats	% of sites with bats
Cascade Kauri	113	66	58.4	20	8	40.0
Huia	74	50	67.6	17	10	58.8
Piha	19	0	0	7	0	0
Karekare	15	1	6.7	5	1	20.0
Arataki / Rangemore / Bendall's Bluff	16	0	0	3	0	0
Nihotupu	15	3	20.0	6	2	33.3
Swanson	10	2	20.0	3	1	33.3
Karamatura	9	0	0	2	0	0
Goodfellow / Fairy Falls / Opanuku	51	19	37.3	20	9	45.0
Waitakere Dam	5	0	0	3	0	0
Anawhata	6	1	16.7	3	1	33.3
Whatipu	3	0	0	1	0	0
Goldie's Bush	6	0	0	2	0	0
Total	342	142	41.5	92	32	34.8

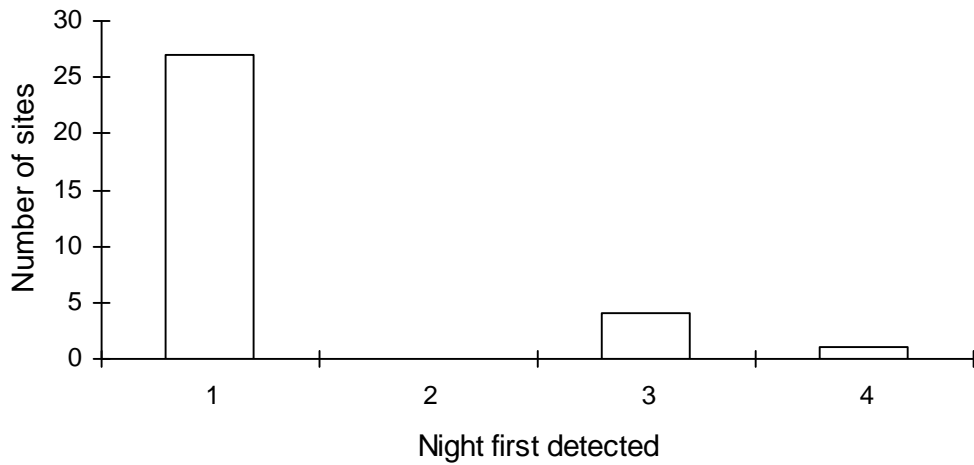


Figure 4: The number of sites that long-tailed bats in the Waitakere Ranges were detected on the 1st, 2nd, 3rd and 4th nights of recording.

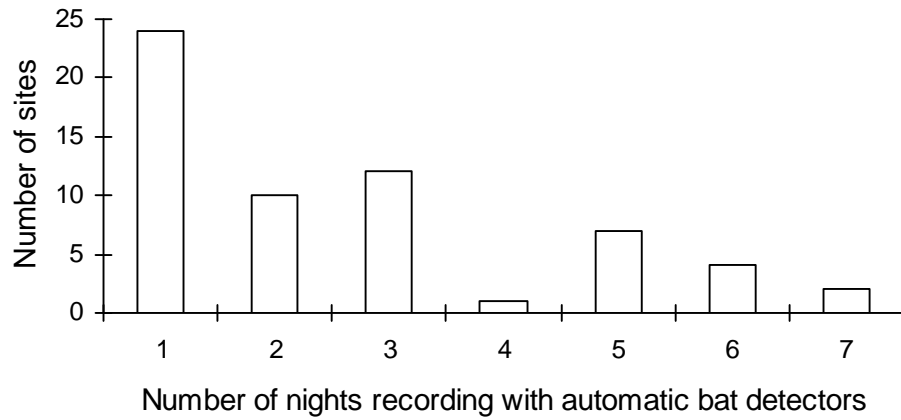


Figure 5: Survey effort at sites where long-tailed bats were not detected in the Waitakere Ranges.

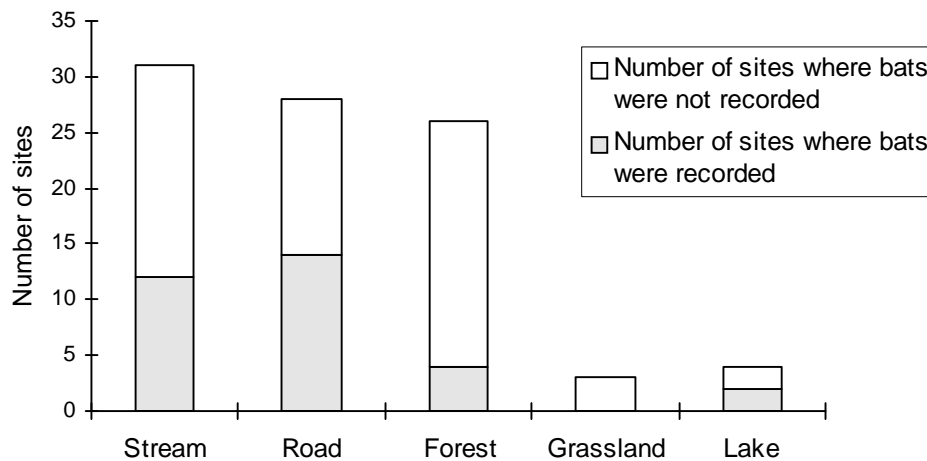


Figure 6: Proportion of sites where bats were and were not recorded in each habitat type.

Additional sites revealed by radio tracking

Radio tracking revealed that long-tailed bats roosting at Cascades Kauri Park foraged over farmland and scrubland in the Upper Bethels Valley and towards Anawhata Rd and Swanson. Long-tailed bats roosting in Fairy Falls / Opanuku catchments were found to forage along Mountain Rd, Stoney Creek and along Opanuku Stream in the Lower Henderson Valley region (Figure 2).

Roost tree and cavity characteristics

Twenty long-tailed bat day roosts were located. All were in live, mature trees (Table 3). No night roosts were found. Most roosts (85%) were in kauri, 2 (10%) were in mature rimu (*Dacrydium cupressinum*) and 1 (5%) was in a kahikatea (*Dacrycarpus dacrydioides*). All roosts were in large, live, emergent trees. Mean height of roost trees was 38.4 ± 1.3 m and average DBH was 186 ± 12 cm (Table 3). Mean distance of roosts from the forest edge was 557 ± 48 m (Table 3). The entrances of six roost cavities were identified (Table 4). Entrances were all located in minor lateral branches in the crown of the tree and were primarily near the tip of branches (67 %; Table 4). Roosts were a mean height of 24.6 ± 3.7 m above ground level (Table 4). Entrances were generally circular, and entrances appeared to have a mean diameter of between 6 and 7cm (Table 4).

Use of roosts

The average number of bats counted leaving roosts was 10.0 ± 1.5 (maximum = 24) but summer counts were significantly higher than autumn counts (Mann-Whitney *U*-test, $P < 0.05$; Table 4). All roosts watched during summer ($n = 18$ roost watches) were communal, with an average of 13.7 ± 1.8 occupants. Ten roost watches were undertaken during autumn. The average number of bats was 3.3 ± 0.7 . Roosts were occupied by radio-tagged bats for an average of 2.0 ± 0.4 days, and 11 (55 %) were occupied for only one day (Table 4).

Table 3: Characteristics of long-tailed bat roost trees located in the Waitakere Ranges.

Roost number	Tree species	Tree height (m)	Trunk DBH (cm)	Distance to forest edge (m)	Distance to capture site (m)	Slope (°)	Catchment position	Tree aspect	Habitat type
Cascades									
1	Kauri	41	210	700	1000	30	Ridge top	E	Mature kauri forest
2	Kauri	42	127	700	1000	40	Ridge side	SE	Mature kauri forest
3	Kauri	35	237	750	1000	25	Ridge top	SE	Mature kauri forest
4	Kauri	50	190	650	1000	65	Stream bank	NE	Mature kauri forest
5	Kauri	33	225	250	600	9	Ridge top	SW	Mature kauri forest
6	Kauri	41	210	300	500	35	Ridge side	N	Mature kauri forest
7	Kauri	33	174	310	660	18	Ridge top	SW	Mature kauri forest
8	Kauri	42	262	280	630	20	Ridge top	SW	Mature kauri forest
9	Kauri	46	173	600	1500	19	Ridge side	NW	Mature kauri forest
10	Kauri	50	220	500	750	47	Ridge side	SE	Mature kauri forest
11	Kauri	40	156	750	350	35	Ridge side	E	Mature kauri forest
12	Kauri	36	170	750	350	37	Ridge top	E	Mature kauri forest
13	Kauri	37	188	750	350	12	Ridge top	E	Mature kauri forest
Huia									
14	Kauri	38	309	1000	2500	25	Ridge top	SE	Podocarp forest
16	Kauri	30	213	500	1000	4	Ridge side	W	Mature kauri forest
17	Kahikatea	43	130	600	1000	45	Gully	W	Podocarp forest
Opanuku-Fairy Falls									
15	Kauri	33	210	300	N/A	4	Ridge top	W	Podocarp forest
18	Rimu	30	108	450	3000	60	Ridge top	N	Podocarp forest
19	Rimu	33	87	300	2000	8	Ridge top	W	Podocarp forest
20	Kauri	35	124	700	3000	45	Ridge side	S	Mature kauri forest

Table 4: Summary of bat roost cavity entrance characteristics and roost use by long-tailed bats in the Waitakere Ranges.

Roost No.	Season	No. of bats emerging	Days roost occupied	Roost height (m)	Cavity entrance type	Location within tree	Estimated entrance diameter (cm)	Entrance orientation
Cascades								
1	Summer	15	1	13.5	Hole at branch tip	Small lateral branch	6	E
2	Summer	10, 5, 24	3	23	Hole at branch tip	Small lateral branch	6	N
3	Summer		1					
4	Summer	7	1					
5	Summer	10, 24, 18, 13, 19, 16, 23	7	15	Hole at branch tip	Small lateral branch	7	W
6	Summer	4	1					
7	Summer	19	1					
8	Summer	11	1					
9	Summer	?, 23	2	32	Hole in branch side	Small lateral branch	5	N
10	Summer	9	1	35	Hole in branch side	Small lateral branch	6	NW
11	Autumn	8, 5, 4, 1, 1	5	29	Hole at branch tip	Small lateral branch	5	E
12	Autumn	5	1					
13	Autumn	1, 1	2					
Huia								
14	Autumn		3					
16	Autumn	1, 2	2					
17	Autumn	2	1					

Table 4: (continued)

Roost No.	Season	No. of bats emerging	Days roost occupied	Roost height (m)	Cavity entrance type	Location within tree	Estimated entrance diameter (cm)	Entrance orientation
Opanuku-Fairy Falls								
15	Autumn		2					
18	Autumn		2					
19	Autumn	3	1					
20	Autumn		1					

Discussion

Presence of bats

In the Waitakere Ranges most records of long-tailed bats were associated with indigenous forest. Bats appeared to be largely absent from urban areas around the periphery of the forest. Given that public sightings are more likely to reflect the distribution of observers than of bats (O'Donnell, 2000), the scarcity of records from residential sites is significant. Where bats were recorded near urban areas, they were using less developed areas such as orchards, riparian strips and roads with little vehicular traffic. At one site bats were recorded flying along a stream that was <1 km from dense housing. At this site bats were foraging beneath a road bridge, even during periods of heavy traffic flow. The stream margins were weed infested and the stream appeared to be polluted with household rubbish and car parts. These findings support previous assertions that if bats have persisted in an area their foraging strategy may be flexible enough to allow them to forage in highly modified habitats (Griffiths, 1996). Thus populations are more likely to be limited by a lack of suitable roosting habitat than a lack of foraging habitat (Griffiths, 1996). Long-tailed bats may benefit from programmes that maintain and enhance riparian corridors, however this requires further research.

If bats were not detected at a site, it does not mean that they were absent. The type of bat detector used in this study has a range of 50 metres (O'Donnell and Sedgeley, 1994). Long-tailed bats often fly higher than this and occasionally they fly without echolocating (pers. obs.). Furthermore, bats may use certain habitats or sites at only certain times of the year (O'Donnell, 2001a). These factors mean that surveys with bat detectors are not strictly presence - absence surveys, rather, they should be considered 'presence - presence not confirmed' surveys. However, in this study, if the presence of bats was confirmed at a site, they were usually detected on the first nights sampling at that site. This suggests that future survey efforts should focus on sampling a greater number of sites rather than sampling more intensively at fewer sites. The results of this study indicate that for distribution studies sampling more than three or four nights at a site is unproductive.

Roost location

In the Waitakere Ranges mature kauri forest appears to be the most important roosting habitat for long-tailed bats and it may be particularly important for breeding bats. All communal roosts found during the breeding season were in large mature kauri trees. These findings are significant because kauri forest represents less than 5% (Denyer *et al.*, 1993) of the total forested area of the Waitakere Ranges. The three non-kauri roost trees were found during autumn (post lactation), when bats' roost requirements are probably less specific (Sedgeley, 2001). Thus I predict that cavities in mature kauri provide the most suitable microclimate conditions for long-tailed bats, especially during the breeding season.

The findings of this study support Sedgeley and O'Donnell's (1999b) prediction that trees with greater numbers of cavities, larger surface area and lower canopy closure are likely to be used as roosts by long-tailed bats. Because so few roost trees were located, roost trees were not compared with random available trees (cf. Sedgeley and O'Donnell, 1999b). Therefore, it is not possible to accurately quantify roost site selection by long-tailed bats in the Waitakere Ranges. However, trees used as roosts by long-tailed bats in the Waitakere Ranges were amongst the largest and oldest trees recorded in the Waitakere Ranges and elsewhere in New Zealand (Ahmed and Ogden, 1987; Salmon, 1996). Nine of the twenty roost trees exceeded 2 m DBH and one exceeded 3 m DBH. In a study of twenty-five stands of mature kauri forest throughout northern New Zealand, Ahmed and Ogden (1987) found that kauri in such large diameter classes are rare. Most kauri greater than 2 m (DBH) are probably more than 1000 years old (Ahmed and Ogden, 1987) and rimu trees in the diameter classes used by bats in this study have been calculated to be over 650 years old (Lusk and Ogden, 1992). As both tree diameter and height are positively correlated with tree age (e.g., Ahmed and Ogden, 1987; Lusk and Ogden, 1992), it is possible that bats selected trees on the basis of functional characteristics associated with age, diameter or height (e.g., older trees generally have more cavities than younger trees; Sedgeley and O'Donnell, 1999a).

Sedgeley and O'Donnell (1999a) suggested that bats may select trees with large stem diameter because cavities within such trees are the best insulated cavities available. While bats roosted in large diameter trees in this study, they appeared to roost mostly in cavities in lateral branches in

the crown of the tree. Such cavities probably do not provide greater insulation than cavities in trees in smaller trunk diameter classes therefore they must select such cavities for other reasons (e.g., predator avoidance). Internal cavity characteristics were not measured so it is possible that cavities extended down into the trunk of tree. However, this is unlikely in the case of kauri for two reasons: 1) when decay occurs in a kauri branch, resin flows and hardens around the site forming a barrier to further damage (Ecroyd, 1982), and 2) kauri has the ability to self-prune, and damage or decay has been found to trigger self-pruning of the affected branch (Wilson *et al.*, 1998).

Compared to other vegetation types in the Waitakere Ranges, the structure of mature kauri forest may be advantageous for long-tailed bat flight. O'Donnell (1999) concluded that long-tailed bat wing morphology probably limits their use of dense forest, and that the species is more suited to edge foraging (O'Donnell, 1999). In the Eglinton Valley, Sedgeley and O'Donnell (1999a; 1999b) found long-tailed bats selected for roosts, trees with open structured canopies, and cavities with uncluttered entrances. Mature kauri forest is usually open-structured and uncluttered between the crown and top of the subcanopy, and there are often large gaps between emergent trees (Ahmed and Ogden, 1987; Ogden, Wardle and Ahmed, 1987).

Gray and Craig (1991) highlighted the problems that can arise when habitat requirements are inferred from observed current patterns of habitat use. Long-tailed bats may preferentially select kauri because they offer optimal roosting opportunities or alternatively, human induced ecological changes may have rendered other historically important roost sites unsuitable or removed them altogether. The Waitakere kauri forest remnants have been subjected to a lower level of disturbance than most of the surrounding landscape (Denyer *et al.*, 1993) and this could mean that the occurrence of long-tailed bats in kauri is a result of logging of other important roost tree species. However, this is unlikely because while rimu, matai (*Prumnopitys taxifolia*), tawa, totara (*Podocarpus hallii* and *P. totara*), kahikatea, puriri (*Vitex lucens*), manukua and northern rata were logged in the Waitakere Ranges, kauri was by far the most extensively logged species (Cheeseman, 1872; Esler, 1983; Denyer *et al.*, 1993).

Roosting in the crowns of kauri trees may be an artefact of introduced mammalian predators having located other more accessible roosts. Cavities in the crowns of kauri may be inaccessible to non-volant predators because the abscission of lower branches results in a straight, branchless, lower trunk (Ecroyd, 1982). Furthermore, kauri trunks shed bark in large scales often preventing the establishment of epiphytes and climbers (Ecroyd, 1982) which may further hinder the ability of predators to access roosts in the crown of kauri trees. Historical accounts of long-tailed bats formerly roosting in caves and under rocky outcrops in the Waitakere Ranges do indicate that long-tailed bats have in the past utilised a wider range of roosting habitats.

The results of this study indicate that in the Waitakere Ranges, long-tailed bat roosts are clustered in remnant patches of mature kauri forest. Suitable roosting habitat may therefore be more fragmented than might be inferred from overall forest cover both in the Waitakere Ranges and elsewhere in New Zealand. For example only 5% of New Zealand's pre-European kauri forest remains, only 12% (7455 ha) of which can be regarded as mature, and those remnants are highly fragmented (Ahmed and Ogden, 1987). The availability of suitable roosts may limit dispersal and connectivity of bat populations. The only long-tailed bat population that has been the subject of intensive long-term research was found to consist of at least three social groups that rarely roosted together even though their foraging ranges overlapped (O'Donnell, 2000b). If this type of population sub-structuring occurs in other long-tailed bat populations then forest fragmentation may have a greater impact on population viability than would be the case for populations that do not exhibit sub-structuring (O'Donnell, 2000b). Further research on the population structure of long-tailed bat populations in fragmented habitats is required. Kauri forest would be suitable for such a case study because where it occurs it is probably the most suitable roosting habitat and it may be possible to compare bat populations in fragments with different characteristics (e.g., size and isolation).

Roost use

The average number of bats in communal roosts in the Waitakere Ranges was the lowest reported in any forested environment in New Zealand (O'Donnell, 2001a). The rate of roost reuse appears to be higher in the Waitakere Ranges than in Fiordland, where communal roosts

were occupied for an average of 1.4 days (O'Donnell and Sedgely, 1999), and Geraldine where each roost was used for an average of 1.7 days (Griffiths, 1996). These apparent differences could be a result of the small sample size obtained in this study. However, if the differences are real, they may indicate that there is a relatively small pool of suitable roosts or alternatively, that the roosts used by bats are of such high quality that do not need to switch roosts as often as in other areas. As in Geraldine where roosts are probably limited (Griffiths, 1996), but in contrast to the Eglinton Valley where roosts are abundant (Sedgely and O'Donnell, 1996), roosting occupants did not abandon roosts simultaneously in the Waitakere Ranges. Furthermore, at least one communal roost was used during consecutive breeding seasons. Further research is required to determine if bats in the Waitakere Ranges are cycling around a relatively small number of roosts and if so, why.

If there are limited roosting sites predators may target bats at their roosts more effectively, thereby heightening predation pressure on the population. In particular, if predators are able to home in on maternity roosts, they could have a significant impact on population viability. Pregnant females, mothers carrying their young, and newly volant young bats are probably easy targets for a predator such as the morepork (*Ninox novaeseelandiae*), which is known to prey on bats (Dwyer, 1962; Daniel, 1990; O'Donnell, 2001a). Moreporks attempted to prey on emerging bats during six percent of roost watches in Eglinton Valley (O'Donnell and Sedgely, 1999). In the Waitakere Ranges, moreporks were observed attempting to catch emerging bats during twenty percent of roost watches. The impact that predation by moreporks has on long-tailed bat populations requires further investigation.

References

- Ahmed, M., Ogden, J. 1987. Population dynamics of the emergent conifer *Agathis australis* (D. Don) Lindl. (kauri) in New Zealand I. Population structures and tree growth rates in mature stands. *New Zealand Journal of Botany* 25(2): 217-231.
- Barrie, A.M. 1995. *New Zealand bats: A summary of historical records and a survey of their current distribution*. University of Otago, Dunedin.
- Bathgate, A. 1922. Some changes in the fauna and flora of Otago in the last sixty years. *New Zealand Journal of Science and Technology* 4: 273-283.

- Buller, W.L. 1892. Notes on the bats of New Zealand. *Transactions of the New Zealand Institute* 25: 50-52.
- Cheeseman, T. T. 1872. On the botany of the Titirangi district of the Province of Auckland. *Transactions of the New Zealand Institute* 4: 270-284.
- Daniel, M.J. 1990. Order Chiroptera. In C.M. King (ed.) *The handbook of New Zealand mammals*: 114-133. Oxford University Press, Auckland.
- Daniel, M.J., Williams, G.R. 1984. A survey of the distribution, seasonal activity and roost sites of New Zealand bats. *New Zealand Journal of Ecology* 7: 9-25.
- Denyer, K.; Cutting, M.; Campbell, G.; Green, C.; Hilton, M. 1993. *Waitakere ecological district: survey report for the protected natural areas programme*. Auckland Regional Council, Auckland.
- Dilks, P., Elliot, G., O'Donnell, C. 1995. Mist netting techniques. *Ecological Management* 3: 20-28.
- Dwyer, P.D. 1960. *Studies on New Zealand Chiroptera*. Master of Science Thesis. Victoria University, Wellington.
- Dwyer, P.D. 1962. Studies on the two New Zealand bats. *Zoology Publications from Victoria University of Wellington* 28: 1-28.
- Ecroyd, C.H. 1982. Biological flora of New Zealand. 8. *Agathis australis* (D. Don) Lindl. (Araucariaceae) kauri. *New Zealand Journal of Botany* 20: 17-36.
- Esler, A.E. 1983. Forest and scrubland zones of the Waitakere Range, Auckland. *Tane* 29: 109-118.
- Gillingham, N. 1996. *The behaviour and ecology of long-tailed bats in the central North Island*. Unpublished M.Sc. Thesis. Massey University, Palmerston North.
- Grace, A. 1992. *Waitakere Ranges regional parkland management plan*. Auckland Regional Council, Auckland. 140p.
- Gray, R.D., Craig, J.L. 1991. Theory really matters: hidden assumptions in the concept of habitat requirements. *Acta XX congressus internationalis ornithologici*: 2553-2558.
- Griffiths, R. 1996. *Aspects of the ecology of a long-tailed bat, Chalinolobus tuberculatus, population in a highly fragmented habitat*. Unpublished M.Sc. Thesis. Lincoln University, Canterbury.

- Harris, S., Cresswell, W.J., Forde, P. G., Trewhella, W.J., Wollard, T., Wray, S. 1990. Home range analysis using radio-tracking data – a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* 20: 97-123.
- Hutton, F.W., Drummond, J. 1904. *The animals of New Zealand*. Whitcomb & Tombs, Christchurch.
- Laing, N. 1985. The settlement of The Huia. Lincoln Printing, Henderson 68 p.
- Lusk, C., Ogden, J. 1992. Age structure and dynamics of a podocarp-broadleaf forest in Tongariro National Park, New Zealand. *Journal of Ecology* 80:379-393.
- Molloy, J. 1995. *Bat (pekapeka) recovery plan*. Department of Conservation, Wellington.
- Molloy, J., Davis, A. 1994. *Setting priorities for the conservation of New Zealand's threatened plants and animals*. Department of Conservation, Wellington. 44pp.
- New Zealand Meteorological Service. 1980. *Summaries of climatological observations to 1980*. New Zealand Meteorological Service Miscellaneous Publication 177.
- O'Donnell, C.F.J. 2000a. Conservation status and causes of decline of the threatened New Zealand Long-tailed bat. *Mammal Review* 30(2): 89-106.
- O'Donnell, C.F.J. 2000b. Cryptic local populations in a temperate rainforest bat *Chalinolobus tuberculatus*, in New Zealand. *Animal Conservation* 3: 287-297.
- O'Donnell, C.F.J. 2001. Advances in New Zealand mammalogy 1990-2000: long-tailed bat. *Journal of the Royal Society of New Zealand* 31(1): 43-57.
- O'Donnell, C.F.J., Sedgeley, J.A., 1999. Use of roosts by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate rainforest in New Zealand. *Journal of Mammalogy* 80(3): 913-923.
- Ogden, J., Wardle, G.M., Ahmed, M. 1987. Population dynamics of the emergent conifer *Agathis australis* (D. Don) Lindl. (kauri) in New Zealand II. Seedling population sizes and gap-phase regeneration. *New Zealand Journal of Zoology* 25: 231-242.
- Salmon, J.T. 1996. *The native trees of New Zealand (Rev. Ed.)*. Reed Books, Auckland, New Zealand.
- Sedgeley, J.A., O'Donnell, C. 1994. An automatic monitoring system for recording bat activity. *Department of Conservation Technical Series No.5*. Department of Conservation, Wellington.

- Sedgeley, J.A., O'Donnell, C.F.J. 1999a. Roost selection by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate New Zealand rainforest and its implications for the conservation of bats in managed forests. *Biological Conservation* 88: 261-276.
- Sedgeley, J.A., O'Donnell, C.F.J. 1999b. Factors influencing the selection of roost cavities by a temperate rainforest bat (Vespertilionidae: *Chalinolobus tuberculatus*) in New Zealand. *Journal of Zoology London* 249: 437-446.
- Sedgeley, J.A. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. *Journal of Applied Ecology* 38: 425-438.
- Stead, E.F. 1936. Notes on the short-tailed (*Mystacops tuberculatus*). *Transactions of the Royal Society of New Zealand* 66: 188-191.
- Walker, O. 1990. *The bat*. MacMillian, South Melbourne, Australia
- White, G.C., Garrott, R.A. 1990. *Analysis of wildlife tracking data*. New York, Academic Press
- Wilson, V.R, Gould, K.S., Lovell, P.H., Aitken-Christie, J. 1998. Branch morphology and abscission in kauri, *Agathis australis* (Araucariaceae). *New Zealand Journal of Botany* 36: 141-148.

Chapter 3: Nocturnal activity patterns of the long-tailed bat in the Waitakere Ranges

Introduction

The New Zealand long-tailed bat (*Chalinolobus tuberculatus* Forster, Vespertilionidae) is a small insect-eating bat that is largely forest dwelling (Daniel and Williams, 1984; O'Donnell, 2001b). During the 1800s long-tailed bats were common and widespread throughout New Zealand. Evidence suggests that since the 1900s there has been a steady decline in long-tailed bat populations and these declines have continued during the last decade (O'Donnell, 2000a). The long-tailed bat is considered to be threatened with extinction in the medium term if declines cannot be reversed (Molloy, 1995; O'Donnell, 2000a). The development and implementation of rigorous monitoring at an extensive network of sites throughout New Zealand is urgently required (Molloy, 1995; O'Donnell, 2000a). Such a monitoring network would enable managers to identify which populations are stable, declining or increasing. Restoration efforts could then be directed towards those bat populations that are declining.

An effective monitoring programme that aimed to detect population trends of long-tailed bats would need to account for both temporal and spatial variation in bat populations otherwise valid comparisons between successive counts, and with other populations, could not be made (O'Donnell, 2000b), and researchers may have limited ability to detect small differences, which may be biologically significant (Hayes, 1997). Habitat, season, time of night, dusk temperature, minimum overnight temperature, maximum daily temperature, invertebrate activity, cloud cover, moon phase, and moonlight have all been reported to influence patterns of long-tailed bat activity (Gillingham, 1996; Griffiths, 1996; O'Donnell, 2000b). However, factors that are correlated with bat activity differ among studies and may be area-specific (Hayes, 1997).

As the ability of monitoring programmes to detect population change is greatest when sample sizes are large and there is little variation between counts (Cohen, 1988), activity patterns in relation to season, temperature, weather conditions and habitat types should be assessed when designing a monitoring programme in a new area (O'Donnell, 2000b). Nocturnal activity patterns have been investigated in Eglinton Valley, Fiordland, Geraldine, South Canterbury and

Hawkes Bay (O'Donnell, 2000b; Griffiths, 1996; Gillingham, 1996). However, the activity patterns of long-tailed bats may differ in the Northern regions of New Zealand. For example, the temperature thresholds that long-tailed bats are active may be different (C. O'Donnell pers. comm.). In this study I examine the nocturnal activity patterns of a kauri (*Agathis australis*) forest dwelling long-tailed bat population. I aim to identify the influence that season, habitat and environmental variables have on the nocturnal activity of long-tailed bats in the Waitakere Ranges. I examine the implications of nocturnal activity patterns of long-tailed bats for designing a monitoring programme.

Study site and Methods

Study site

This study was conducted in the Waitakere Ranges, in northern New Zealand (36° 57'S, 174° 32'E). The Ranges are an uplifted dissected plateau of volcanic origin (Searle, 1981). The average altitude is 330 m, ranging from 474 m above mean sea level down to sea level. The area harbors one of the two largest remnants of indigenous forest in the Auckland region. A predominant feature of the Waitakere Ranges is the Auckland Centennial Memorial Park, comprising 14 899 ha of largely forested protected land, surrounded by rural and semi-urban development. The northern Waitakere Ranges are relatively undulating whereas the southern Waitakere Ranges are extremely rugged with a deeply dissected topography (Denyer *et al.*, 1993). Average annual rainfall varies from 1397 mm in the foothills to 2032 mm in the higher central region (Grace, 1992). Average daily temperatures range from a minimum of 5°C in July to a maximum of 24°C in February (New Zealand Meteorological Service, 1980).

The vegetation in the Waitakere Ranges is a mosaic of original podocarp-broadleaf forest and kauri (*Agathis australis*) forest, cutover forest, burnt and completely cleared forest (Esler, 1983). In pre-European times kauri dominated the forest but between 1840s and 1940s it was targeted for logging and its distribution is now patchy. In the Waitakere Ranges, clusters of kauri, or individual kauri trees, and the occasional podocarp tree emerge over a low mid tier of shrubs, vines and small trees. The understorey is dominated by ferns, shrubs and tall grasses (Esler, 1983; Denyer *et al.*, 1993). Vegetation characteristic of cut over forest in the region includes scattered emergent northern rata (*Meterosideros robusta*) and smaller quantities of

hardwood tree species. Scrubland is a feature of burnt or completely cleared land that is reverting to forest. It is dominated by manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) (Esler, 1983).

Recording bat activity

Bat activity was sampled in four habitats (forest, road, stream, lake) between November 1998 and March 2001. Bat activity was recorded using automatic bat detection units described by O'Donnell and Sedgely (1994). For this study, a bat pass was defined as a set of two or more echolocation calls (heard as clicks) as a bat flew within the range of the detector's microphone (Furlonger, Dewar and Fenton, 1987). Bat activity was assessed as total number of bat passes per night and as the number of bat passes during each hour after sunset. Feeding attempts were easily recognised because the pulse rate of a feeding bat's echolocation calls was much faster and sounded like a buzz when heard through a bat detector. An index of feeding activity was recorded as the number of bat passes that contained feeding buzzes.

Automatic bat detectors were set opportunistically rather than systematically or randomly (see appendices one and two for a summary of sampling effort at each site per season). At the start of this study, only one site was known in the Waitakere Ranges where bats were regularly present (G. Wittmer pers. comm.). While another 91 sites were sampled with automatic bat detectors during this study, and bats were recorded at 31 of them, only two further sites were used by bats on a regular enough basis to be considered suitable for ongoing monitoring. A third site was found only near the end of the study, therefore, most data were obtained from only two sites, one a road habitat and the other a stream. However, bat activity data from all sites where bats were recorded were included in all analyses.

Bat activity patterns were compared, among habitats and seasons (spring = September-November; summer = December-February; autumn = March-May; winter = June-August). Forest habitats were not sampled during autumn and winter and sampling effort was not equal between seasons and habitats. Huia and Cascades were chosen to compare the influence of bat reproductive stages on bat activity because a concurrent demographic study indicated that the Huia bat population consisted mostly, if not entirely, of males whereas at Cascades, more

females than males were captured (S. Chapman unpubl. data). Pregnancy and lactation periods were assumed to approximate those recorded in Hawkes Bay (the nearest long-tailed bat population from which data on both pregnancy and lactation are available; O'Donnell, 2001b). In the Hawkes Bay, pregnancy has been documented as occurring from September until mid-November, and lactation from mid-November until the end of December (Gillingham, 1996).

Measuring environmental variables

Moon phase and times of sunset and sunrise were obtained from sun, moon and tide charts for the Auckland region (The New Zealand Herald, 1999, 2000 and 2001). Maximum and minimum temperatures and humidity data recorded at Henderson, West Auckland, were supplied by the National Institute of Weather and Atmosphere (NIWA). Dusk temperatures were obtained from a privately owned weather station in Massey, West Auckland. A range of estimates of climatic conditions at dusk were also made. Wind strength was estimated as one of four categories: calm, light, moderate or strong. Precipitation was recorded as one of three categories: fine, drizzle/showers or rain. Dusk temperature was estimated as cool, mild or warm and cloud cover was estimated on a scale from 0-8 where 0 was clear skies and 8 was overcast.

Data analysis

Most data sets could not be analysed using parametric tests because even when transformed the data did not conform to the assumption of normality, therefore, non-parametric statistical tests were used (Conover, 1980). Where three or more categories were compared, a Kruskal-Wallis one-way analysis of variance by ranks (*H*-test) (Zar, 1999) was used to assess differences in numbers of bat passes per night and per hour both among habitats and seasons. If a significant difference was detected in a comparison of three or more categories, Kruskal-Wallis pairwise comparisons of mean ranks, using *Z*-tests, were used to determine which categories differed (Conover and Iman, 1981). In comparisons of two categories, Mann-Whitney *U*-tests were used to test for differences in the number of bat passes per night, between habitats and seasons. The Mann-Whitney *U*-test was used to test differences in levels of bat activity between Huia and Cascades. Spearman's rank correlation coefficient (r_s) was used to test for correlation between environmental variables. All statistical analyses were conducted using Statistix for Windows (version 1.0, Analytical Software, Tallahassee, FL, U.S.A). While all statistical tests are carried out on ranks, for clarity data are presented graphically as means \pm 1 standard error.

Limitations of the study

Despite intentions of having a randomized block design (or, in the case of comparing pass rates between Huia and Cascades, a paired design) to reduce experimental error, this was not achieved. This was due to several factors including the high rate of equipment failure and that other aspects of the research programme (e.g., a distribution survey, locating and describing bat roosts) were given higher priority. There were also logistical difficulties with operating automatic bat detectors simultaneously at two or more sites that were considerable distances apart. The sampling design used in this study falls short of many of the requirements for rigorously testing hypotheses. For example, in this study samples and sample units may not have been truly independent or representative (Underwood, 1994). The problems encountered during this study have also been highlighted by other authors (e.g., Hayes, 1997). An unbalanced sampling design is a feature likely to be common to other long-tailed bat studies, except where studies are in areas where long-tailed bats are common and research is long-term (e.g., Eglinton Valley; O'Donnell, 2000b). Given the above constraints the results from this study must be interpreted cautiously and all conclusions are considered tentative.

Results

Patterns of bat activity

Activity levels did not differ significantly between years (Kruskal-Wallis H -tests, $P > 0.05$). Therefore, data for all years were pooled and year was ignored as a factor in all subsequent analysis. Stream and road habitats were sampled in all seasons, forest was only sampled during spring and summer. A total of 5050 bat passes, 663 (12.5 %) of which contained feeding buzzes, were detected during 182 nights of recording in the three habitats included in the analyses. Overall pass rates averaged 27.7 ± 4.7 s.e. passes per night.

Pass rates per night varied among seasons (all habitats combined; $H_{3, 178} = 12.3$, $P < 0.01$) and among habitats (all seasons combined; $H_{2, 179} = 7.2$, $P < 0.05$). In spring, the number of bat passes per night varied among habitats ($H_{2, 55} = 11.0$, $P < 0.01$) where they were higher along roads than along streams and in forest, but those for stream and forest did not differ significantly (pairwise comparison of mean ranks, $P < 0.01$; Fig. 1), although the sample size for forest ($n = 3$) was very small. During summer there were no significant differences in the

average pass rates among habitats ($H_{2,68} = 0.1, P > 0.1$; Fig. 2). There were no differences in the average number of feeding buzzes among habitats during spring ($H_{2,55} = 6.2, P > 0.05$; Fig. 1) or summer ($H_{2,68} = 1.3, P > 0.1$; Fig. 2). During autumn and winter, average pass rates and feeding buzzes were significantly higher along roads than streams (Fig. 3 and Fig. 4).

The percentage of total bat passes that contained feeding buzzes was greatest along roads and lowest in forest (all seasons pooled; Fig. 5). The overall pattern of bat activity during the night appeared to be bimodal, with a peak during the first two hours after sunset and during the ninth hour after sunset. However, the pattern varied according to habitat. Bat activity peaked along roads during the first two hours after sunset. Activity within the forest and along streams was greatest during the ninth hour after sunset (Fig. 6).

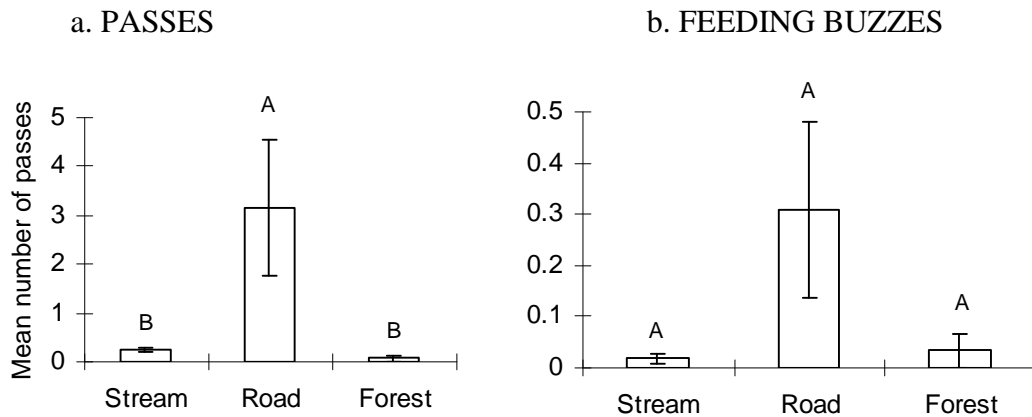


Figure 1: Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during spring in three habitats: stream ($n = 31$ nights), road ($n = 24$) and forest ($n = 3$). Means presented ± 1 standard error; different letters denote groups that are significantly different from each other at $P < 0.05$ (Kruskal-Wallis pairwise comparisons of average ranks).

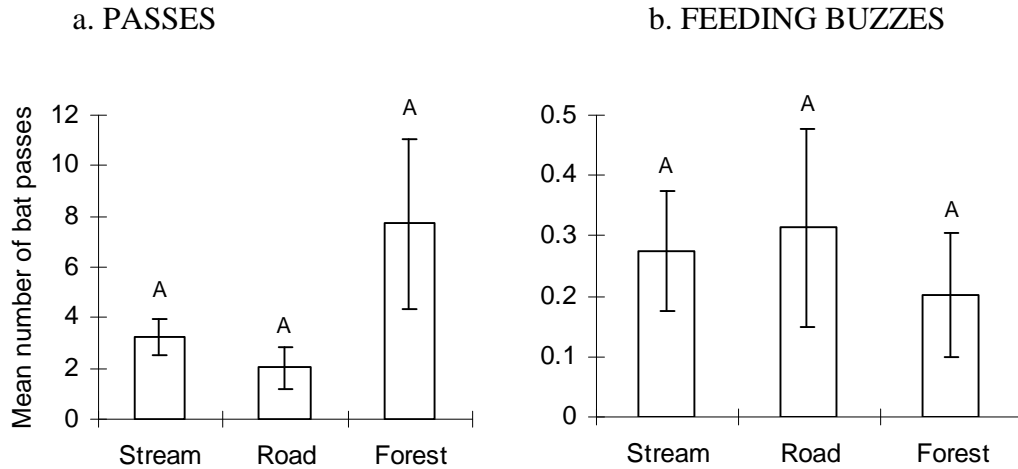


Figure 2: Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during summer in three habitats: stream ($n = 45$ nights), road ($n = 10$) and forest ($n = 16$). Means presented ± 1 standard error; different letters denote groups that are significantly different from each other at $P < 0.05$ (Kruskal-Wallis pairwise comparisons of average ranks).

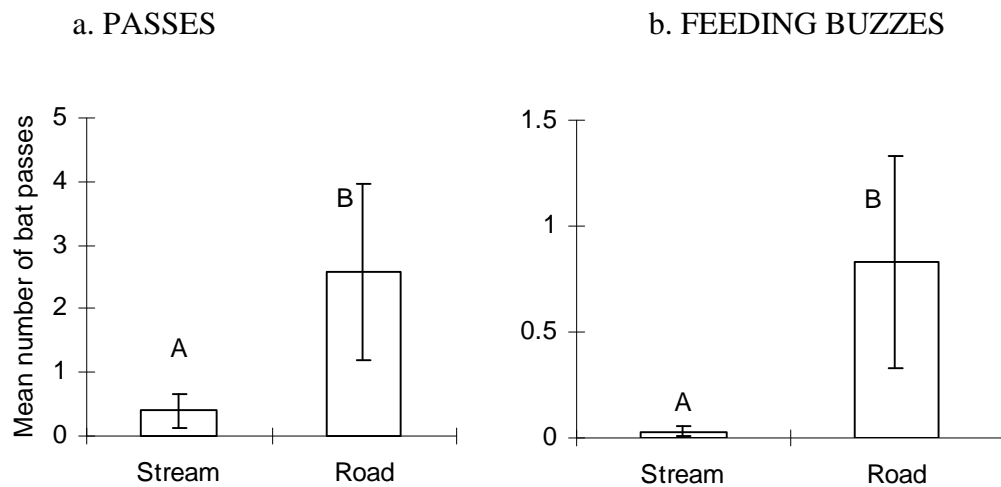
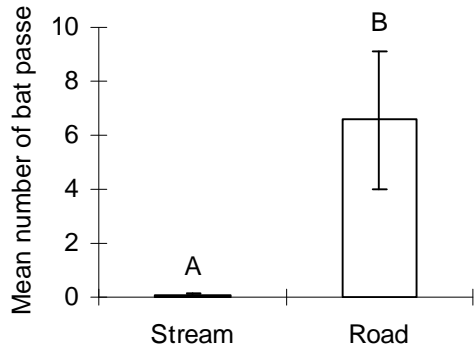


Figure 3: Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during autumn in two habitats: stream ($n = 21$ nights) and road ($n = 10$). Means presented ± 1 standard error; different letters denote significant differences among means at $P < 0.05$ (Mann-Whitney U -tests).

a. PASSES



b. FEEDING BUZZES

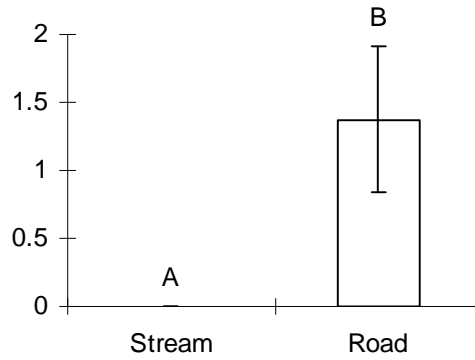


Figure 4: Number of (a) bat passes and (b) number of passes containing feeding buzzes per night during winter in two habitats: stream ($n = 10$ nights) and road ($n = 12$). Means presented ± 1 standard error; different letters denote significant differences between means at $P < 0.05$ (Mann-Whitney U -tests).

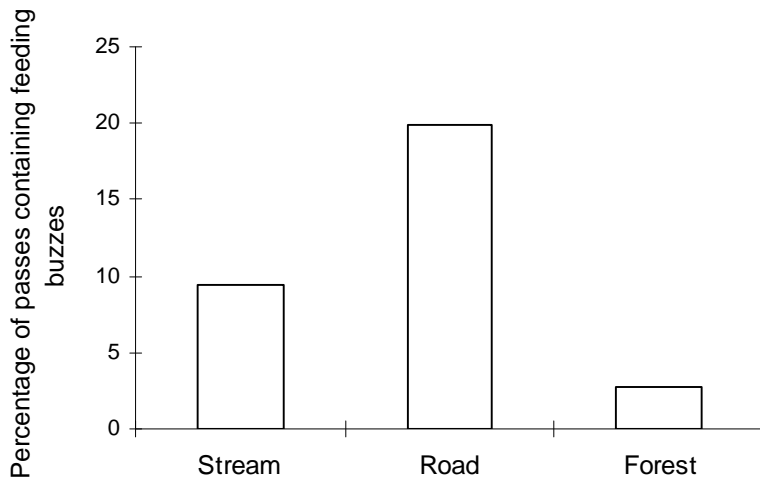


Figure 5: Percentage of bat passes containing feeding buzzes in three different habitats (all seasons combined).

a. STREAM

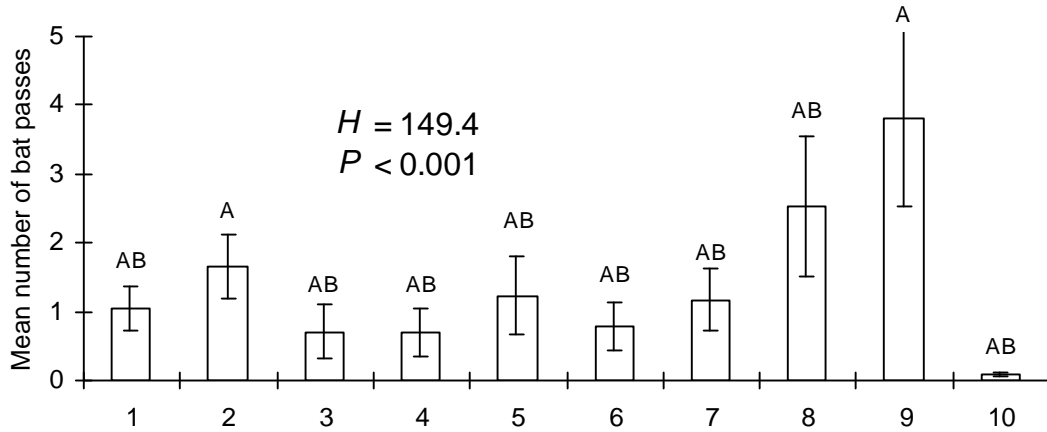
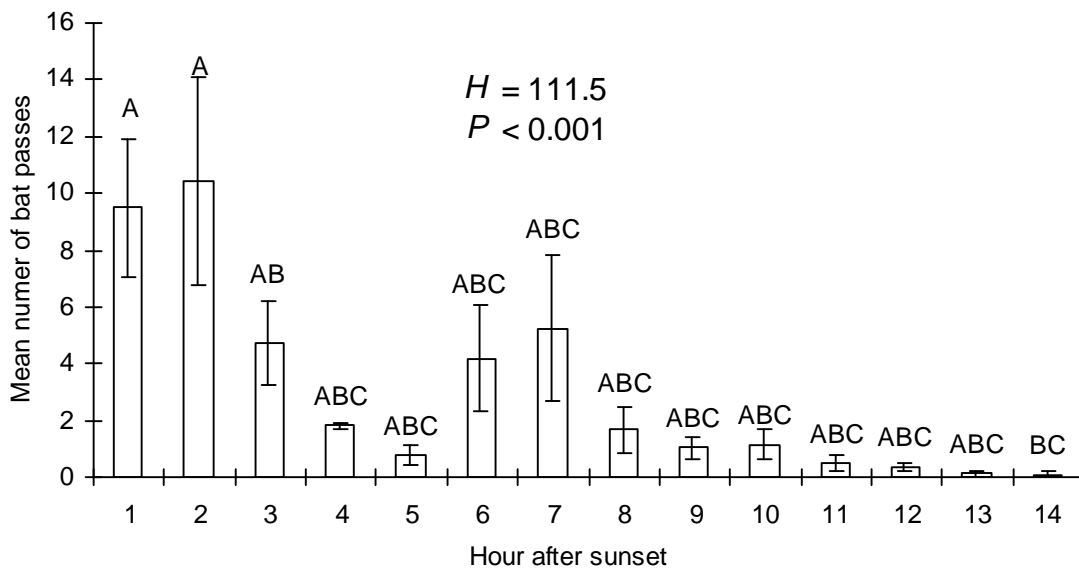


Figure 6: (continued over page) Mean number of bat passes (all seasons combined) through the night in three habitat types: (a) stream ($n = 107$ nights), (b) road ($n = 56$), and (c) forest ($n = 19$). Means presented ± 1 standard error. Different letters denote significant differences between means at $P < 0.05$ (Kruskal-Wallis pairwise comparisons of average ranks).

b. ROAD



c. FOREST

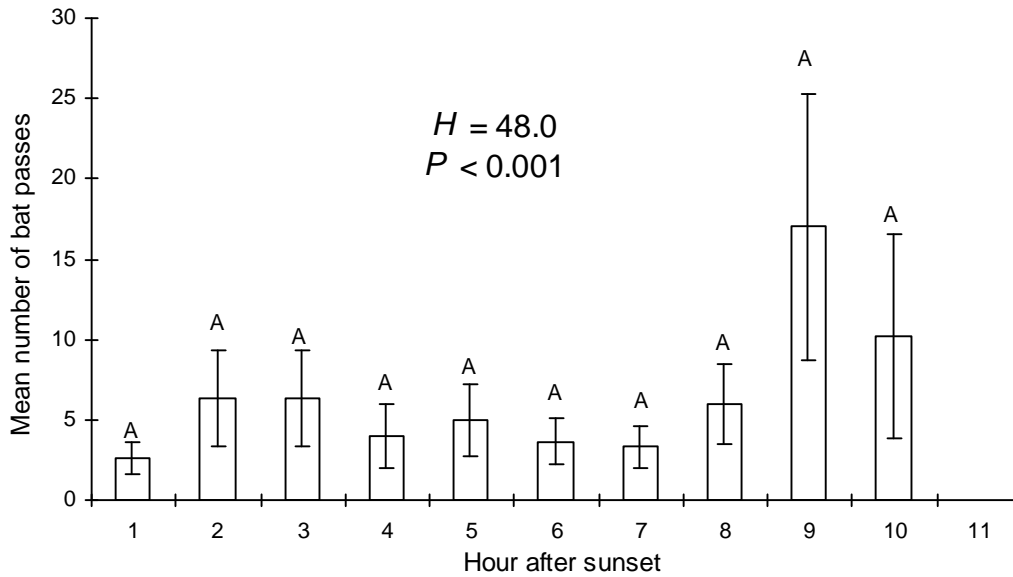


Figure 6: (continued)

Influence of environmental variables on bat activity

Bat activity was significantly positively correlated with dusk temperature, maximum temperature and minimum temperature (Table 1). Average pass rates varied significantly among the categories of minimum overnight temperature ($H_{3, 178} = 15.9, P < 0.01$) and increased exponentially with increasing temperature (Fig. 7). However, average pass rates were not significantly curtailed in the lower categories of minimum overnight temperature (0-5°C and 5-10°C; Fig. 7) where pass rates were approximately 19 and 20 per night on average.

Table 1: Association of bat activity with environmental variables as indicated by Spearman's Rank correlation coefficient (r_s) for sample size n (* significant association at $P < 0.05$; ** significant association at $P < 0.01$).

Variable	r_s	n
Altitude	0.053	185
Estimated cloud cover	0.024	101
Dusk temperature	0.189*	156
Humidity	0.001	185
Maximum temperature	0.163*	185
Minimum temperature	0.257**	185
Moon phase	0.003	173
Estimated temperature	0.012	74
Estimated wind	0.123	99
Estimated precipitation	0.003	122

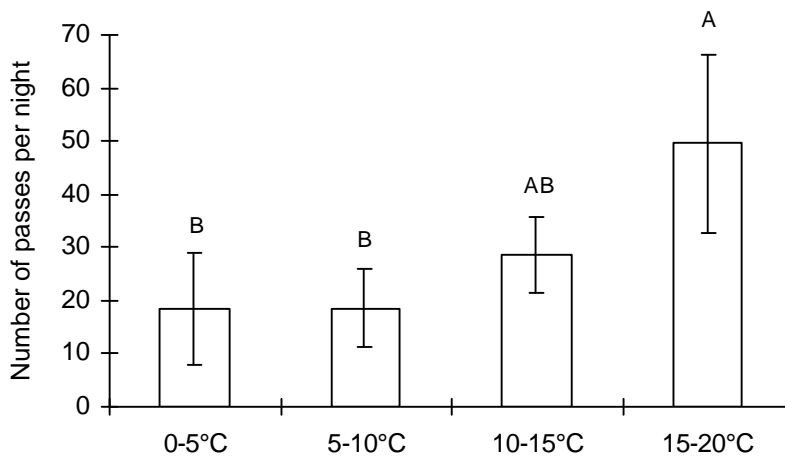


Figure 7: Bat activity levels during different minimum overnight temperature categories (all seasons and habitats pooled; 0-5°C: $n = 19$ nights; 5-10°C: $n = 50$; 10-15°C: $n = 92$; 15-20°C: $n = 21$). Different letters denote significant differences between means at $P < 0.05$ (pairwise comparison of mean ranks). Mean passes are presented \pm standard error.

The influence of reproduction on patterns of bat activity

At Cascades there appeared to be a change in the pattern of bat activity that coincided with assumed pregnancy and lactation periods. During pregnancy bat activity did not vary throughout the night ($H_{10, 231} = 9.9, P > 0.05$; Fig. 8). However, during lactation an overall Kruskal-Wallis test did indicate that bat activity did vary throughout the night with two apparent main peaks in activity ($H_{10, 242} = 50.1, P < 0.001$; Fig. 8). However, a pairwise comparison of mean ranks did not reveal any significant pairwise differences between activity in any single hour. Bat activity at Huia varied throughout the night during the assumed pregnancy period ($H_{10, 118} = 20.0, P < 0.05$; Fig. 9), but not during lactation ($H_{8, 45} = 3.3, P > 0.05$; Fig. 9). However, again there were no significant pairwise differences between activity in any hour for either lactation or pregnancy at Huia. At Cascades, the mean number of bat passes per night was significantly greater during lactation than during pregnancy (Mann-Whitney U -test $P > 0.001$; Fig. 10). However, there were no differences in the mean number of bat passes during pregnancy and lactation at Huia (Mann-Whitney U -test $P > 0.1$; Fig. 10).

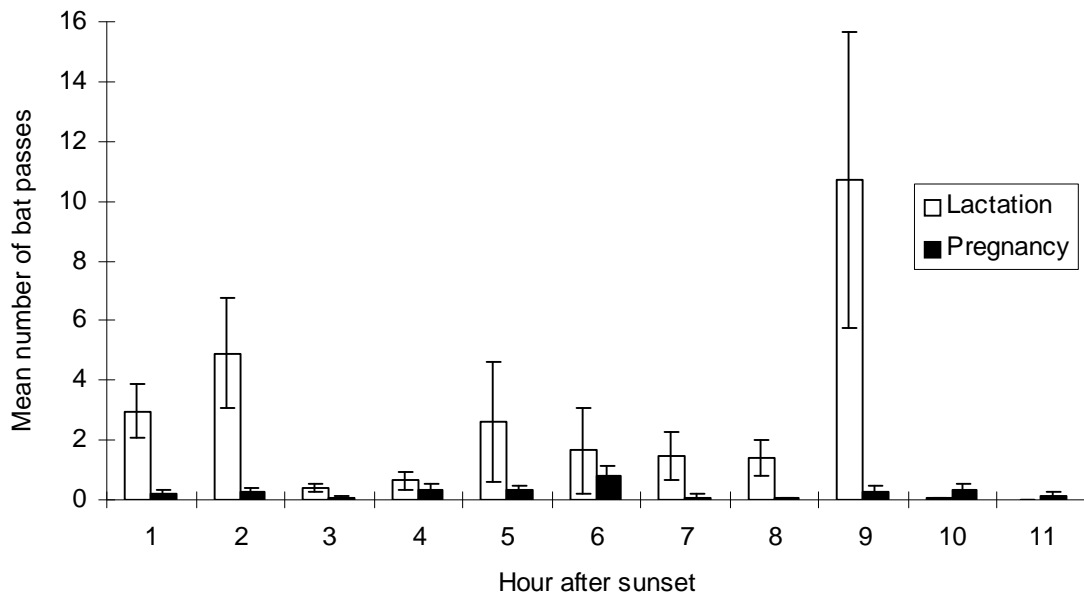


Figure 8: Patterns of bat activity throughout the night at Cascades during lactation ($n=22$ nights) and pregnancy ($n=23$).

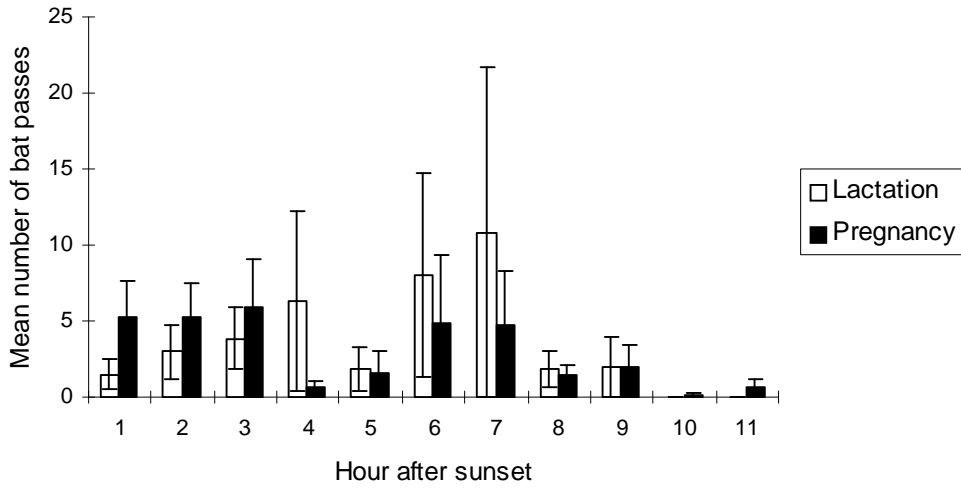


Figure 9: Patterns of bat activity throughout the night at Huia during lactation ($n=13$ nights) and pregnancy ($n=6$) (all habitats combined).

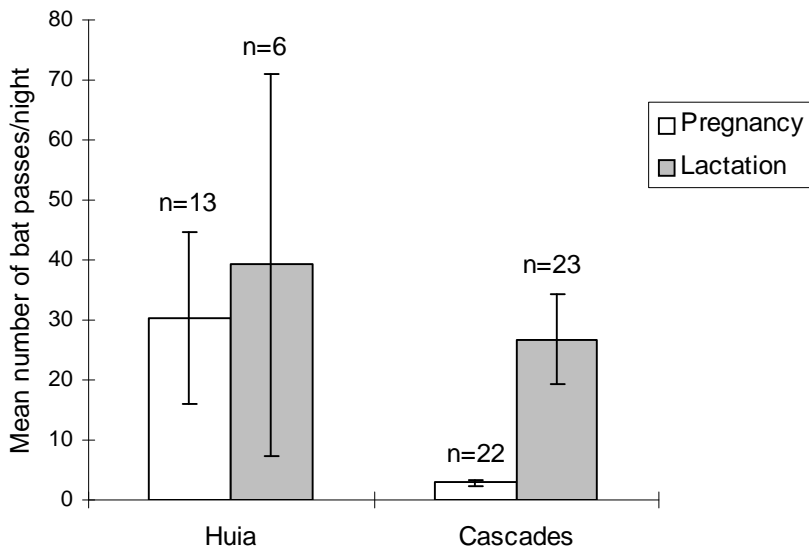


Figure 10: Comparison of bat activity between pregnancy and lactation at Huia and Cascades (all habitats combined; n = number of nights sampled).

Discussion

Bat activity was most variable in forests, particularly during the ninth and tenth hours after sunset. While this may be due to simple random variation alternatively, bats may have occasionally roosted in the vicinity of some sampling sites resulting in high levels of bat activity being recorded on some nights, and little or no activity being recorded on other nights. The influence of nearby roosts on the forest sites is further supported by the lower proportion of passes containing feeding passes in forests and that bat activity within forest was concentrated within the 1-2 hours prior to sunrise, indicating that bats may have primarily used forest habitats while they were commuting back to their diurnal roosts. However, bats were frequently observed foraging above the canopy and radio-tracking also indicates that long-tailed bats forage extensively within the forest (S. Chapman pers. comm.). Bats flying above the forest canopy were often not detected because they were outside the range (≤ 50 m) of the bat detectors (O'Donnell and Sedgeley, 1994). Therefore, bat activity in forest habitats was probably underestimated in this study.

The results of this study indicate that temperature is the environmental variable that most influences long-tailed bat activity. This is consistent with other studies on the nocturnal activity patterns of the long-tailed bat (Gillingham, 1996; Griffiths, 1996; O'Donnell, 2000b). While long-tailed bat activity patterns are difficult to predict and are influenced by a range of interacting variables (Gillingham, 1996), a complete understanding of all the factors that influence bat activity may not be necessary or achievable when designing a monitoring programme to detect trends in bat populations. Rather, monitoring programmes primarily need to control for temporal variation by ensuring that repeat surveys are undertaken at the same site, during similar weather conditions and at the same time of year (O'Donnell, 2000b). The design of such programmes should aim to maximise indices of bat activity while keeping variability between consecutive counts low. Bat activity was positively correlated with dusk, maximum diurnal temperature and minimum overnight temperature. However, minimum overnight temperature showed the strongest correlation with bat activity and it can be easily incorporated into monitoring programmes (e.g., by placing a maximum-minimum thermometer with each automatic bat detector). While average pass rates were greater in higher categories of minimum overnight temperature, activity was less variable on nights where minimum overnight

temperature was between 10 and 15°C. Monitoring programmes could account for temperature by comparing activity in each temperature category separately in addition to controlling for habitat and season.

Compared with other areas in New Zealand where long-tailed bats have been studied, the Waitakere Ranges may represent a climatically benign environment. The average dusk temperature over all the nights sampled was 16.3°C (range = 9.8-22.7°C) and minimum overnight temperature was rarely below 5°C (cf. the Eglinton Valley; O'Donnell, 2000b). Bat activity through the night generally appeared to consist of two or three peaks in bat activity. This is not consistent with results from other New Zealand studies. For example, in the Eglinton Valley, bat activity was generally unimodal, with a peak at dusk (O'Donnell, 1999). In Geraldine, bat activity was bimodal during summer and unimodal during winter (Griffiths, 1996). In contrast to the Eglinton Valley, there were significant peaks in pass rates during the first two hours after sunset along roads, and activity peaked two hours prior to sunrise along streams. In the Eglinton Valley, bat activity along roads was constant through the night (O'Donnell, 2000b). O'Donnell (2000b) suggested that this may be because sheltered roads are less exposed to the heat sink of the sky than open habitats and roads may provide more favourable foraging conditions, than other habitats, later during the night.

Peaks in bat activity generally mirror peaks in invertebrate activity that occur at dusk and just prior to dawn (Rydall, Entwistle and Racey, 1996). Bimodal patterns of activity are more obvious when prey density is high (Erkert, 1982). The number of bat passes that included feeding buzzes was three times greater than in the cool temperate Eglinton Valley, where (O'Donnell, 2000b) suggested that prey was limited because invertebrate activity is largely governed by temperature (Williams, 1940; Taylor, 1963; O'Donnell, 2000b). Compared with Eglinton Valley and South Canterbury the mild climate in the Waitakere Ranges may mean that the reduction in prey abundance during winter is less pronounced and movement of bats are not greatly governed by the invertebrate availability in different habitats.

If long-tailed bat activity in the Waitakere Ranges is not restricted by temperature or associated invertebrate availability, then there are a number of predictions that follow, all of which would

require testing. These predictions are that long-tailed bats in the warmer northern regions of New Zealand have:

- 1) Smaller home ranges (cf. O'Donnell, 2001a).
- 2) Longer breeding season (C. O'Donnell pers. comm.).
- 3) Higher productivity (C. O'Donnell pers. comm.).
- 4) Less dependence on stable roost microclimate (cf. Sedgely, 2001).
- 5) Less need to forage throughout the night (cf. O'Donnell, 2000b).
- 6) Shorter duration of torpor (cf. Webb, 1998).

The shift from a unimodal pattern of activity during pregnancy to a bimodal pattern during lactation has been observed in overseas studies (e.g., Maier, 1992; Wilkinson and Barclay, 1997). It occurs because energy demands are greater during lactation (Racey and Speakman, 1997) and female bats need to feed throughout the night. However, in the Eglinton Valley O'Donnell (1999) found no difference in the level or pattern of foraging activity by reproductive female bats. He postulated that this may have been a result of limited food availability forcing all classes of bats to be active throughout the night. In contrast to Cascades, at Huia the level and pattern of activity did not appear to differ between assumed reproductive stages. In a concurrent trapping study at Huia and Cascades, all bats captured at Huia were male ($n = 16$ captures of 10 individual bats; S. Chapman pers. comm.) whereas most bats captured at Cascades were female. Therefore, if reproduction influences the level and/or pattern of bat activity, and if only males are present at Huia, changes due to reproduction would only occur at Cascades. However, the sample size at Huia during summer was small and the observed changes in pass rates at Cascades may be due to other factors. For example, during pregnancy pass rates at Cascades may have been lower than during lactation because bats were utilising habitats that were under sampled during this study. But, if there are differences in patterns of activity between areas due to differences in population structure, it would be worthwhile investigating the potential to use bat detectors as a means of identifying if there are reproductive females in a population without the cost of a trapping study.

References

- Cohen, J. 1988. *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum, Hillsdale, New Jersey, USA.
- Conover, W.J. 1980. *Practical nonparametric statistics* (second edition). John Wiley and Sons, New York, USA.
- Conover, W.J., Iman, R.L. 1981. Rank transformations as a bridge between parametric and nonparametric statistics. *American Statistician* 35: 124-129.
- Daniel, M.J., Williams, G.R. 1984. A survey of the distribution, seasonal activity and roost sites of New Zealand bats. *New Zealand Journal of Ecology* 7: 9-25.
- Denyer, K.; Cutting, M.; Campbell, G.; Green, C.; Hilton, M. 1993. *Waitakere ecological district: survey report for the protected natural areas programme*. Auckland Regional Council, Auckland.
- Erkert, H.G. 1982. Ecological aspects of bat activity rhythms. In Kunz, T.H. (ed.) *Ecology of bats*. New York, Plenum Press. Pp. 201-242.
- Esler, A.E. 1983. Forest and scrubland zones of the Waitakere Range, Auckland. *Tane* 29: 109-118.
- Furlonger, C.L., Dewar, H.J., Fenton, M.B. 1987. Habitat use by foraging insectivorous bats. *Canadian Journal of Zoology* 65: 284-288.
- Gillingham, N. 1996. The behaviour and ecology of long-tailed bats in the central North Island. Unpublished M.Sc. Thesis. Massey University, Palmerston North.
- Grace, A. 1992. *Waitakere Ranges regional parkland management plan*. Auckland Regional Council, Auckland. 140p.
- Griffiths, R. 1996. Aspects of the ecology of a long-tailed bat, *Chalinolobus tuberculatus*, population in a highly fragmented habitat. Unpublished M.Sc. Thesis. Lincoln University, Canterbury.
- Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. *Journal of Mammalogy* 78: 514-524.
- Maier, C. 1992. Activity patterns of pipistrelle bats (*Pipistrellus pipistrellus*) in Oxfordshire. *Journal of Zoology London* 228: 69-80.
- Molloy, J. 1995. *Bat (pekapeka) recovery plan*. Department of Conservation, Wellington.
- New Zealand Meteorological Service. 1980. *Summaries of climatological observations to 1980*. New Zealand Meteorological Service Miscellaneous Publication 177.

- O'Donnell, C.F.J. 1999. The ecology, spatial organisation and conservation of long-tailed bats *Chalinolobus tuberculatus*. Unpublished PhD thesis. University of Otago, Dunedin.
- O'Donnell, C.F.J. 2000a. Conservation status and causes of decline of the threatened New Zealand Long-tailed bat. *Mammal Review* 30(2): 89-106.
- O'Donnell, C.F.J. 2000b. Influence of season, habitat, temperature, and invertebrate availability on nocturnal activity of the New Zealand long-tailed bat. *New Zealand Journal of Zoology* 27: 207-221.
- O'Donnell, C.F.J. 2001a. Home range and use of space by *Chalinolobus tuberculatus*, a temperate rainforest bat from New Zealand. *The Journal of Zoology London*: 253: 253-264.
- O'Donnell, C.F.J. 2001b. Advances in New Zealand mammalogy 1990-2000: long-tailed bat. *Journal of the Royal Society of New Zealand* 31(1): 43-57.
- O'Donnell, C., Sedgeley, J.A. 1994. An automatic monitoring system for recording bat activity. *Department of Conservation Technical Series No.5*. Department of Conservation, Wellington.
- Racey, P.A., Speakman, J.R. 1987. The energy costs of pregnancy and lactation in heterothermic bats. *Symposia of the Zoological Society* 57: 107-125.
- Searle, E.J. 1981. *City of Volcanoes, A Geology of Auckland*. Longman Paul, Auckland.
- Sedgeley, J.A. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. *Journal of Applied Ecology* 38: 425-438.
- Taylor, L.R. 1963. Analysis of the effects of temperature on insects in flight. *Journal of Animal Ecology* 32: 99-117.
- The New Zealand Herald. 1999. Sun, moon and tides 1999. OceanFun Unlimited, Auckland, New Zealand.
- The New Zealand Herald. 2000. Time and tide 2000. OceanFun Publishing, Auckland, New Zealand.
- The New Zealand Herald. 2001. Time tide 2001. OceanFun Publishing, Auckland, New Zealand.

- Underwood, A. J. 1994. Things environmental scientists (and statisticians) need to know to receive and give better statistical advice. Pp. 33-61 in *Statistics in ecology and environmental monitoring*. Fletcher, D.J. and Manly, B.F.J. 1997 (Eds). University of Otago Press.
- Webb, P. 1998. Torpor in long-tailed bats. In: B. Lloyd, (Compiler). *Proceedings of the second New Zealand bat conference, Ohakune, New Zealand, 28-29 March 1998. Science and Research Internal Report No. 162*. Wellington, Department of Conservation. 12 p.
- Williams, C.B. 1940. The analysis of four years captures of insects in a light trap. Part two. The effect of weather conditions on insect activity; and the estimation and forecasting of changes in the insect population. *Transactions of the Royal Entomological Society (London) 90*: 227-306.
- Wilkinson, L.C., Barclay, R.M.R. 1997. Differences in the foraging behaviour of male and female big brown bats (*Eptesicus fuscus*) during the reproductive period. *Ecoscience 4*: 279-285.
- Zar, J.H. 1999. *Biostatistical analysis*. Prentice Hall, London.

Appendix 1: Number of nights sampled at each site per season.

Site number	Habitat type	Number of nights sampled				
		Summer	Autumn	Winter	Spring	Total
1	Stream		1		4	5
2	Stream		1			1
3	Stream	30	5	5	25	65
4	Stream		5	5	1	11
5	Lake				1	1
6	Stream	1				1
7	Stream	4				4
8	Stream	6			1	7
9	Road	2				2
10	Road	5	7	12	20	44
11	Road	1				1
12	Road		1			1
13	Road		1			1
14	Stream		1			1
15	Stream		2			2
16	Road	1				1
17	Road	1				1
18	Stream	1				1
19	Forest	7			3	10
20	Lake	2				2
21	Stream	3				3
22	Road				3	3
23	Road				1	1
24	Forest	4				4
25	Forest	2				2
26	Forest	3				3
27	Road		1			1
28	Stream		1			1
29	Stream		1			1
30	Stream		2			2
31	Stream		1			1
32	Stream		1			1
Total		73	31	22	59	185

Appendix 2: Number of sampling nights per habitat type per season (number of sites sampled in parenthesis; *total of numbers of sites in the last column are lower than the sum of the number of sites for each row because some sites were sampled in more than one season).

Habitat	Number of nights sampled per season				Total*
	Summer	Autumn	Winter	Spring	
Stream	45 (6)	21 (11)	10 (2)	31 (4)	107 (16)
Road	10 (5)	10 (4)	12 (1)	24 (3)	56 (10)
Forest	16 (4)	-	-	3 (1)	19 (4)
Lake	2 (1)	-	-	1 (1)	3 (2)
Total	73 (16)	31 (15)	22 (3)	59 (9)	185 (32)

Chapter 4: Can bat detectors be used to detect changes in long-tailed bat populations?

Introduction

The New Zealand long-tailed bat (*Chalinolobus tuberculatus* Forster, Vespertilionidae) is one of only two surviving bat species endemic to New Zealand. It is a moderately small insect eating bat that primarily inhabits forest, roosting singly or in colonies (O'Donnell, 2001a). According to the International Union for the Conservation of Nature's (IUCN) criteria the long-tailed bat is a vulnerable species. This means it is at risk of extinction in the medium term (O'Donnell, 2000a).

There have been significant declines in the distribution and abundance of long-tailed bats during the last 150 years (O'Donnell, 2000a). During the 1990s, survey effort concentrated in the South Island found that long-tailed bats were absent from some areas where they had previously been observed. Where they persisted, with the exception of the Eglinton and Dart Valleys, they were uncommon or rare (O'Donnell, 2000a). At Banks Peninsula and South Westland the declines have occurred during the last thirty years and while some population declines have occurred in very modified and fragmented habitat (e.g., Arahura and Geraldine) others have been in forested areas (e.g., Northern Nelson, South Westland) (O'Donnell, 2000a). However, whether all populations have declined or whether declines are historical or ongoing is also unclear (O'Donnell, 2000a).

The development and implementation of a national network of long-tailed bat monitoring sites is a priority of the Department of Conservation's Bat Recovery Plan (O'Donnell, 2000a). Potentially, information gained from a national monitoring programme would assist conservation managers to effectively target resources towards those areas where bat populations are declining and provide baseline information to assist managers to gauge the impact of management techniques on bat populations (O'Donnell, 2000a). Of critical importance is that unless it can be demonstrated that long-tailed bat populations have declined and that, that decline is real, management will not be initiated (O'Donnell and Sedgeley, 1994; Molloy, 1995). Therefore, when designing a monitoring programme, it is essential to determine

the probability that we will be able to detect a biologically significant population change if one occurs (Zielinski and Stauffer, 1996).

The probability of detecting a change or trend if one has occurred is called statistical power. It is calculated as $1-\beta$ where β is the probability of failing to reject a false null hypothesis. There are two main ways that statistical power is used in conservation biology: 1) data from a pilot study are used to evaluate potential study designs in terms of their ability to detect changes or trends if they occur, and 2) testing whether non-significant results can be interpreted with confidence or whether the test had inadequate power to detect changes or trends (Taylor and Gerrodette, 1993; Norton, 1996). Generally, a study is considered to have adequate power if power exceeds 0.80 (Cohen, 1988; Zielinski and Stauffer, 1996; Thomas, 1997).

Sample size, data variability and the magnitude of the real change or trend all affect the likelihood of a monitoring program being powerful enough to detect a trend (Cohen, 1988). Unless the probability of detecting a biologically significant decline is known, managers may rely on monitoring programs that are incapable of detecting a decline before it is too late to prevent local extinctions (Taylor and Gerrodette, 1993). Misguided mitigation techniques may waste valuable resources and future conservation efforts may be compromised (Blaustein, Wake and Sousa, 1994).

At present the only means available to accurately determine long-tailed bat population sizes and trends are long-term mark-recapture studies. Typically, such studies are expensive as they are labour-intensive and time-consuming. As such, few populations are monitored in this way. The availability of low-cost bat detectors has resulted in an international surge in their use for monitoring the activity of bat populations (Hayes, 1997). In New Zealand several studies have investigated long-tailed bat activity patterns over time (e.g., Griffiths, 1996; Gillingham, 1996; Winnington; 1999; O'Donnell, 2000b) while other studies have focused on the presence or absence of long-tailed bats over a range of sites (Borkin, 1999; O'Donnell, 2000a; A. Arkins, S. Mcmanus, G. Moore pers. comm.).

Several authors have suggested that bat detectors may have application in the monitoring of bat populations (e.g., Hayes, 1997; Gannon and Willig, 1998; O'Donnell, 2000a and 2000b). While they can be used to confirm the presence of bats and provide estimates of bat activity, the relationship between activity levels and the number of bats present is unclear (Hayes, 1997; O'Donnell and Sedgeley 1994). This relationship is currently being explored for long-tailed bats (C. O'Donnell pers. comm.). If bat detectors can provide an index of bat abundance, then it is important to explore the power to detect changes in that index when designing a monitoring programme.

Bat detectors could potentially be used to detect changes in bat populations in at least two ways: 1) monitoring bat activity levels over time to determine trends; and 2) undertaking a baseline survey of a number of sites to determine the presence or absence of bats, and comparing data from an initial survey with a future survey of the same sites to determine whether there has been a change in the proportions of sites with and without bats. In this paper I use data gathered with automatic bat detectors (Sedgeley and O'Donnell, 1994) to examine the power to detect changes in the level of long-tailed bat activity and the proportion of sites with bats present. I explore the relationship between a range of feasible sample sizes, effect sizes, potential levels of variance and desired levels of α and statistical power. I discuss the implications for developing a long-tailed bat monitoring programme.

Methods

Study site

This study was conducted in the Waitakere Ranges, Auckland, New Zealand (36° 57'S, 174° 32'E). The Ranges are an uplifted dissected plateau and one of the two largest remaining areas of continuous indigenous vegetation in the Auckland region. Altitude ranges from 474 m down to sea level. The northern Waitakere Ranges are relatively undulating and the southern Waitakere Ranges are extremely rugged with a deeply dissected topography (Denyer *et al.*, 1993). Annual rainfall averages 1569 mm (Grace, 1992) and average daily minimum and maximum temperatures are between 5°C in July to 24°C in February (New Zealand Meteorological Service, 1980). Vegetation is a mosaic of original podocarp-broadleaf forest

and kauri forest, cut-over, burnt and completely cleared forest (Esler, 1983). Urban development occurs around the periphery of the forest.

Selecting sites for monitoring

Between November 1998 and March 2001, automatic bat detector units set to record at 40 kHz (the optimum frequency for detecting long-tailed bats; O'Donnell and Sedgeley, 1994) were placed at 92 sites throughout the Waitakere Ranges. Units were not placed randomly or systematically. Rather, as the long-tailed bat is a rare species and is uncommon almost everywhere it occurs (O'Donnell, 2000a), detectors were placed for one or more nights in habitats bats were likely to use. Bats were recorded at 32 (34.8%) of the 92 sites. A bat pass was defined as a set of two or more echolocation calls (heard as clicks) as a bat flew within the range of the detector's microphone (Furlonger, Dewar and Fenton, 1987). The number of bat passes per night was used as an index of bat activity. A site was selected for ongoing monitoring if it met the following criteria: bats were regularly present (> 40% of nights), bat activity levels were relatively high (> 10 bat passes per night on most nights), and variability between nights in the number of passes as measured by the coefficient of variability was low ($CV\% < 200$ where $CV\% = (S.D. / \text{mean}) \times 100$). Three sites met these criteria, one in each of the following areas: Huia, Cascades and Opanuku Stream. Two of the sites (Cascades and Opanuku) sampled stream habitats and the third site (Huia) monitored a road habitat. A concurrent trapping and banding study indicated that the monitoring sites were sampling three separate populations (S. Chapman, unpubl. data).

Determining the number of sample units

To ensure that potential bat monitoring programmes are cost effective, it is important to determine the influence that the number of nights sampled has on estimates of bat activity. Using the method outlined by Hayes (1997), the number of sample units (nights) required to obtain an index of activity (bat passes per night) closely approximating the mean was determined using an Excel spreadsheet (Microsoft Corporation, Redmond, WA, U.S.A). The random subset function in Excel was used to randomly sample 2-20 night subsets one hundred times each for the entire data set collected at Huia ($n = 44$ nights). The mean index of activity was calculated for each random sample. The percentage of the random samples were assigned

to the following categories of percentage deviation from the mean (unless they were not within 50% of the mean, in which case they were ignored): ≤ 10 , ≤ 20 , ≤ 30 , ≤ 40 , ≤ 50 . The data from Cascades were less variable and much of the variability resulted from many zero counts during winter and autumn. Therefore, the sub-sampling process for 2-12 nights was repeated for each of the summer ($n = 30$ nights) and spring ($n = 25$ nights) data sets from Cascades. The sample size from Opanuku ($n = 6$ nights) was too small for meaningful analysis.

Two of the main factors that influence variation in long-tailed bat activity are season and minimum overnight temperature (O'Donnell, 2000b). For each season, the mean number of bat passes was calculated for the following arbitrary minimum overnight temperature categories ($^{\circ}\text{C}$): 0-5, 5-10, 10-15, 15-20. Minimum overnight temperatures were recorded at Henderson, West Auckland, by the National Institute of Weather and Atmosphere (NIWA).

Estimating statistical power

Two computer-based power analysis software packages were used to calculate power, PASS (version 6.0; NCSS, Kaysville, UT, U.S.A) and Monitor (version 6.2; Gibbs, 1995; see Thomas and Krebs, 1997 for a review of power analysis software packages). PASS uses the non-central t -distribution to calculate power (Thomas and Krebs, 1997). PASS was used because it one of very few power analysis packages that calculates statistical power for non-parametric tests (Thomas and Krebs, 1997). Bat activity data sets were not normally distributed and unable to be transformed to a normal distribution with commonly used transformations (tested with Wilk-Shapiro Statistic W). PASS was used to calculate power to detect a change in bat activity between baseline data and any subsequent single survey using standard non-parametric Mann-Whitney U -tests. Monitor was used because it is available free of charge (see Thomas and Krebs, 1997) and it has been used in other studies of threatened species, including at least one New Zealand study (e.g., Lawrence and Palmer, 2000). A specialised package for estimating power to detect population trends over time, Monitor estimates power using Monte-Carlo simulations (Gibbs, 1995). In monitor, the user is able to specify the number of iterations to be used in the analysis. In this study Monitor was used to examine the power of detecting changes in the index of bat activity over time using annual surveys. The number of iterations used to generate power estimates was 1000. PASS was used calculate power to detect changes in the

proportion of sites where bats are present during a baseline survey and during future surveys using Fishers-exact tests.

The ability to manipulate survey effort is restricted because: (1) spatial variation in levels of bat activity meant that the number of monitoring sites in each area could not be increased, and (2) there are logistical limitations on the number of nights sampled at each site. However, given the serious consequences of failing to detect a decline if one is occurring (Type II error) power estimates obtained using one- and two-tailed tests at the conventional significance level of $\alpha = 0.05$ and the less stringent level of $\alpha = 0.10$, were compared.

Results

The mean number of bat passes per night and variability was greater at Huia than at Cascades (Table 1). Overall, the mean coefficient of variation (all sites and seasons pooled) was 121.6. Precision and therefore power was not increased by only including sites, seasons and temperature ranges with a high mean number of bat passes (J. Alexander, unpubl. data). This is because the standard deviation generally increased in proportion to the mean (Table 1-2). Power was increased by only including data from nights when variability was reduced (Figure 1). During winter and spring at Huia bat activity increased with increasing minimum overnight temperature category. In contrast to Cascades, the minimum overnight temperature during different seasons had little influence on the variability of bat activity. As the proportion of nights with very high and low levels of activity was greater at Huia than Cascades, almost twice as many nights need to be sampled at Huia to ensure reasonable levels of precision in estimates of activity (Table 3-6).

Table 1: Summary of seasonal bat activity recorded at Huia, Cascades and Opanuku.

Site	Season	Number of nights	Mean number of bat passes per night	1 standard deviation (SD)	Coefficient of Variation (CV)
Huia	Summer	5	25.6	21.7	84.6
	Autumn	7	57.6	101.4	176.1
	Winter	12	92.7	126.3	136.3
	Spring	20	32.3	57.9	179.4
	All seasons	44	52.0	88.1	169.5
	Cascades	Summer	30	42.3	47.4
Autumn		5	0	0	N/A
Winter		5	2.4	0.9	37.3
Spring		25	2.7	2.3	84.6
All seasons		65	20.8	37.8	181.8
Opanuku		Autumn	6	13.4	7.3

Table 2: The level and variability of bat activity at Huia and Cascades during different seasons and on nights with different minimum overnight temperature.

Season	Temperature category (°C)	Mean number of bat passes per night	1 Standard deviation (SD)	Coefficient of variation (CV)
Huia				
Summer	15-20	31.0	20.9	66.9
Autumn	5-10	131.7	128.2	97.3
Winter	0-5	55.8	70.9	126.9
	5-10	108.0	147.1	136.2
	10-15	140.3	192.5	137.3
Spring	5-10	8.2	11.5	139.9
	10-15	57.1	74.7	130.7
Cascades				
Summer	5-10	11.3	6.9	62.2
	10-15	43.0	56.4	131.1
	15-20	52.3	39.2	74.3
Winter	15-20	3.0	1.4	47.1
Spring	0-5	0.3	0.5	200.0
	5-10	2.7	2.4	88.1
	10-15	3.8	1.9	49.1

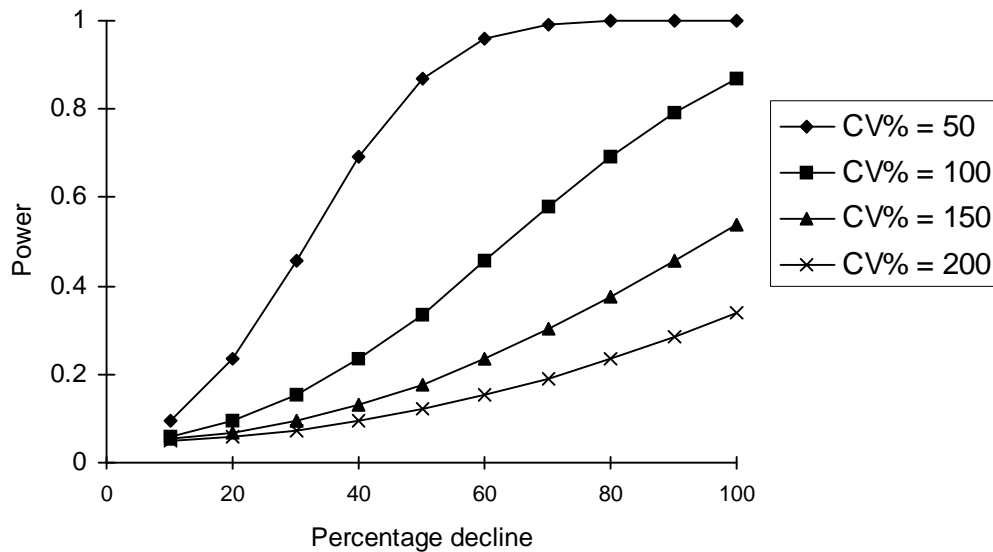


Figure 1: Influence of variability in count data (CV%) on power to detect a decline with a single future survey using Mann-Whitney *U*-tests (calculated using PASS).

A power analysis using Monitor indicated that the statistical power to detect a 10 % annual decline in bat activity during winter at Huia after ten years is only 0.40 using annual surveys (Figure 2). At Cascades, statistical power is adequate (0.80; Cohen, 1988) to detect a 10% annual decline in bat activity after eight years if only nights with high minimum overnight temperatures (between 15-20°C) are included (Figure 3). Using summer counts only, power may also be adequate (0.80) to detect an annual decline of 5% at Cascades after 10 years, if the less stringent significance level of $\alpha = 0.10$ is used with a one-tailed test (Figure 4). A power analysis using PASS shows that there is low power to detect changes in activity level between any two surveys, even if sacrifices are made in terms of statistical rigor. Before and after surveys only have adequate power to detect declines greater than 60% (Figure 5). By re-surveying the same 92 sites at some point in the future, power to detect a decline in the proportion of sites with bats compared with the results of this study is adequate only if the magnitude of the decline is 50% or greater (Figure 6). Power was increased by re-sampling only the 32 sites where bats were present, or even a subset of 20 of the 32 sites where bats were present. If 20 sites with bats are resurveyed, the study would have adequate power to detect declines of $\geq 30\%$ in the number of sites with bats (i.e. bats are no longer present at six or more

of the sites) (Figure 6). By including 10 sites where bats were not detected in the original survey (20 sites where bats were present and 10 sites where bats were absent) the option of being able to detect increases in the proportion of sites with bats is preserved. However, by designing a survey that includes the option to detect increases, there is only adequate power to detect declines of 50% or greater (Figure 7).

Table 3: Percentage of 100 random samples with the mean number of bat passes per night within 10-50% of the mean for the entire dataset collected at Huia ($n = 44$) (after Hayes, 1997).

Number of nights in subsample	Percentage deviation from the mean				
	≤ 10	≤ 20	≤ 30	≤ 40	≤ 50
2	1	7	10	13	19
3	3	12	20	25	34
4	15	22	28	38	43
5	8	22	30	32	46
6	9	25	32	46	61
7	11	18	27	45	56
8	10	27	40	46	58
9	16	27	41	47	54
10	11	21	40	56	67
11	17	35	50	61	76
12	19	34	52	63	73
13	15	27	37	56	65
14	22	32	48	60	72
15	13	28	43	62	74
16	15	31	45	63	75
17	20	41	57	69	84
18	22	40	54	69	73
19	20	37	59	73	78
20	22	40	57	71	83

Table 4: Percentage of 100 random samples with the mean number of bat passes per night within 10-50% of the mean for the Cascades summer dataset ($n = 30$) (after Hayes, 1997).

Number of nights in subsample	Percentage deviation from the mean				
	≤ 10	≤ 20	≤ 30	≤ 40	≤ 50
2	8	10	18	32	48
3	7	14	23	31	47
4	9	22	33	44	58
5	15	27	34	50	64
6	22	37	47	58	70
7	23	44	59	75	85
8	15	43	58	71	84
9	17	37	58	72	86
10	21	45	65	76	88
11	25	44	63	76	85
12	21	51	71	78	91

Table 5: Percentage of 100 random samples with the mean number of bat passes per night within 10-50% of the mean for the Cascades spring dataset ($n = 25$) (after Hayes, 1997).

Number of nights in subsample	Percentage deviation from the mean				
	≤ 10	≤ 20	≤ 30	≤ 40	≤ 50
2	10	17	35	46	59
3	13	34	44	56	66
4	21	47	59	74	78
5	16	43	54	74	82
6	23	44	59	75	85
7	25	44	57	76	86
8	28	51	73	87	92
9	32	58	68	81	91
10	22	58	80	92	98
11	37	61	79	94	100
12	35	63	79	94	97

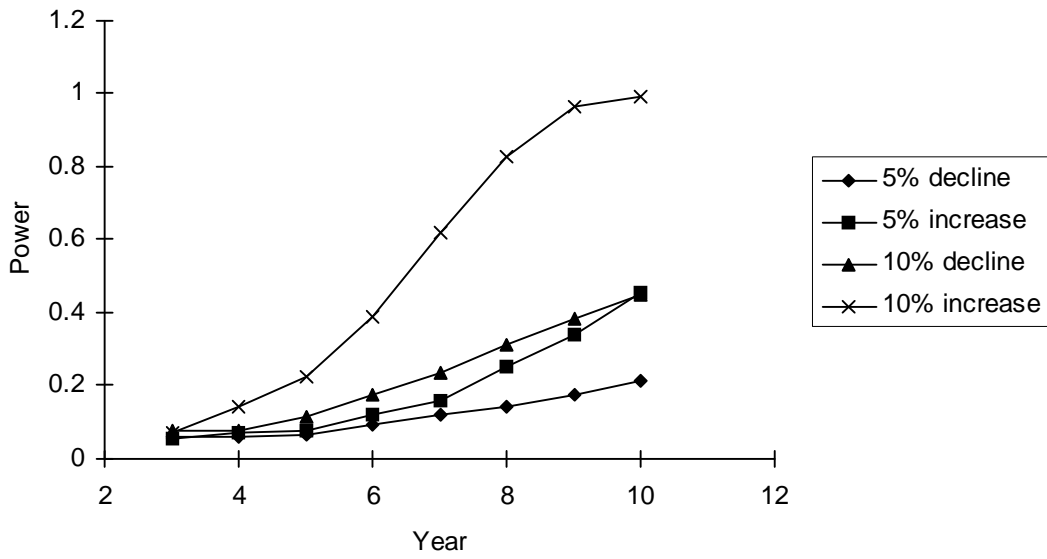


Figure 2: Power to detect changes in bat activity at Huia during winter with annual surveys ($n = 11$; $\alpha = 0.05$, two-tailed test).

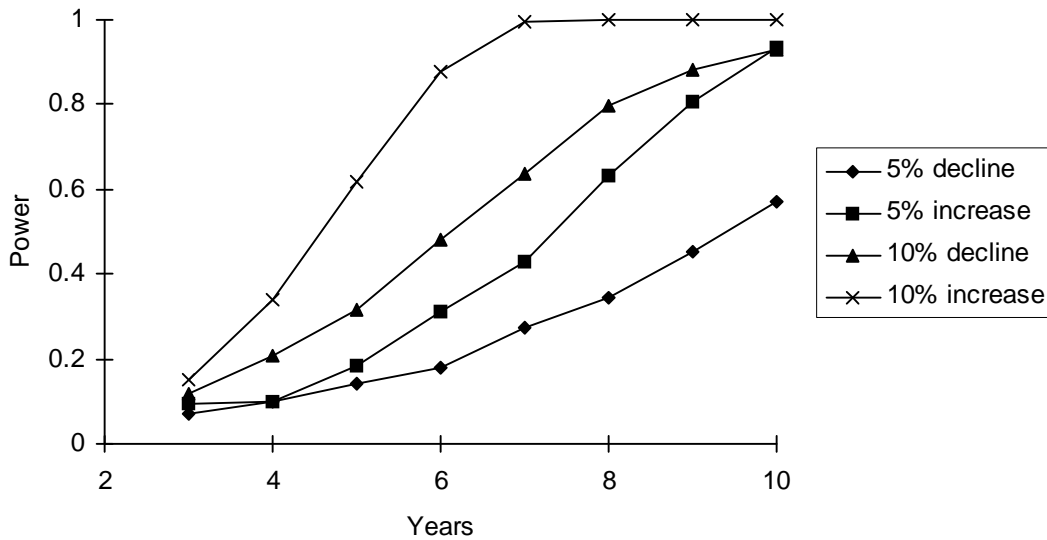


Figure 3: Power to detect changes in bat activity at Cascades with annual surveys during summer and only including monitoring data when overnight minimum temperatures are between 15-20°C ($n = 11$; $\alpha = 0.05$, two-tailed test).

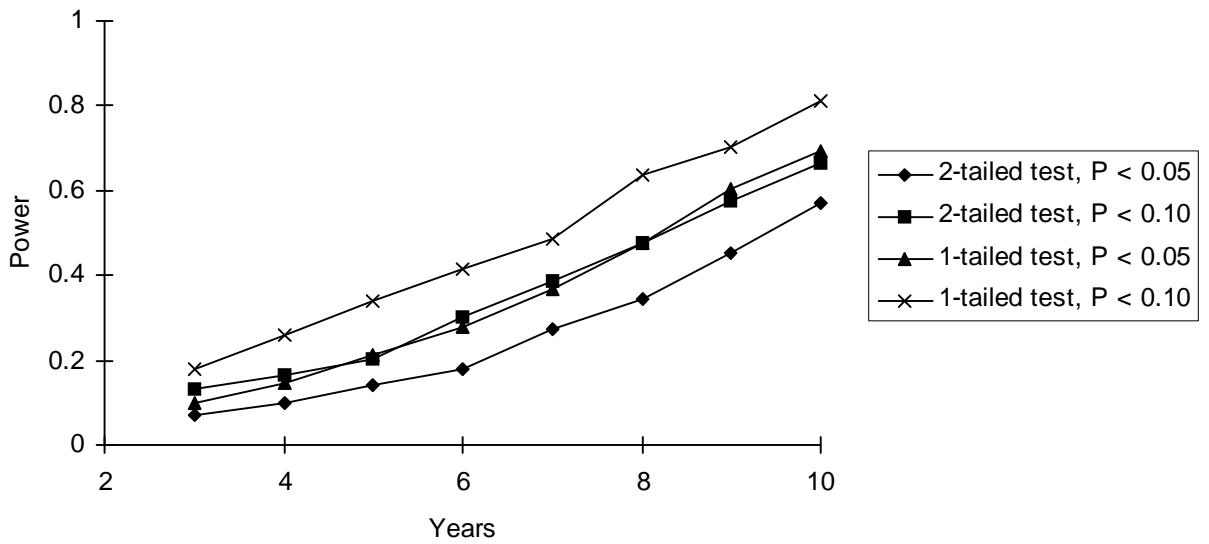


Figure 4: Power to detect a 5 % annual decline in bat activity during summer at Cascades using one- and two-tailed tests at significance levels of $\alpha = 0.05$ and $\alpha = 0.10$.

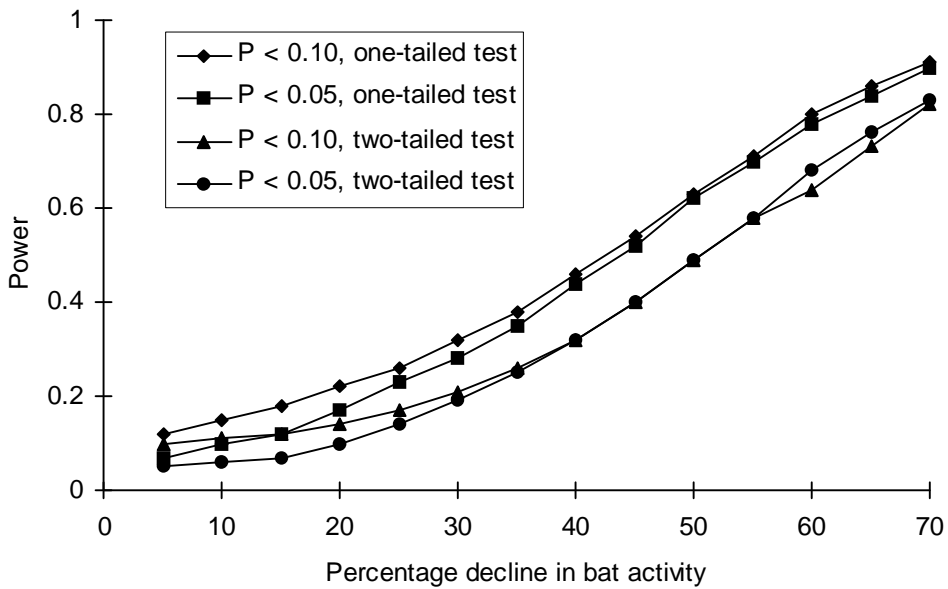


Figure 5: Power to detect declines in bat activity at Cascades monitoring for 20 nights using one- or two-tailed Mann-Whitney U -tests at significance levels of $\alpha = 0.05$ and $\alpha = 0.10$.

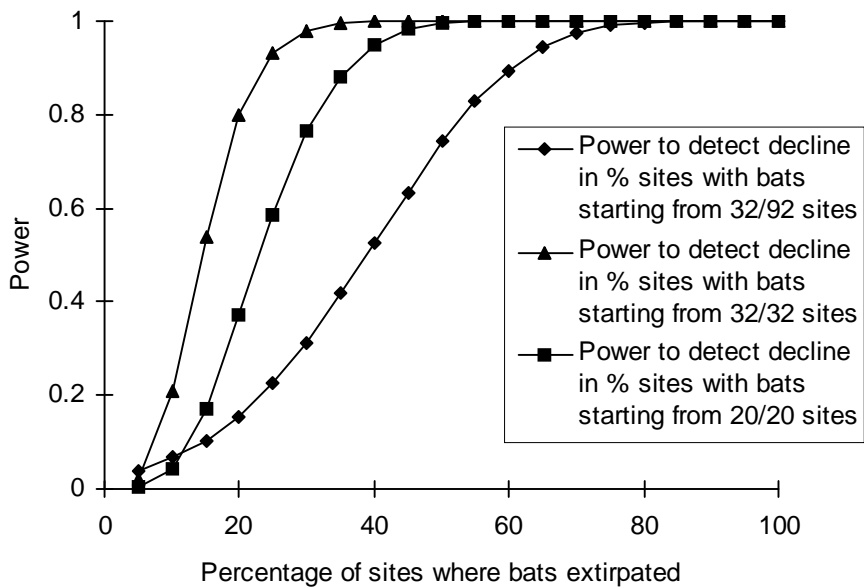


Figure 6: Power to detect annual declines in the proportion of sites with and without bats, comparing results from this study with a single future presence/absence survey using Fishers exact test.

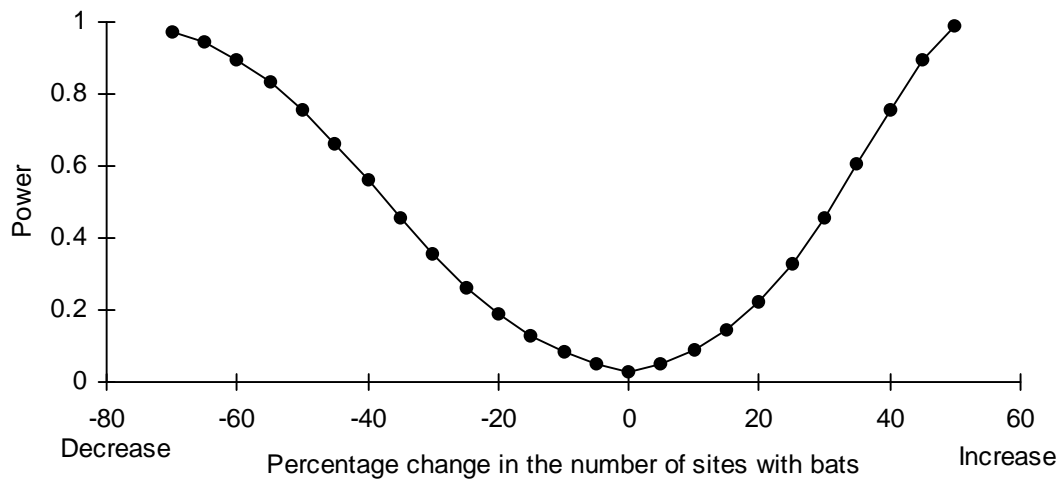


Figure 7: Power to detect changes in the proportion of sites with and without bats, comparing results from this study with a single future survey using Fisher exact test.

Discussion

The key factor that reduces the power of a sampling study to detect declines or increases in bat activity is the high degree of variability in the data. High variability between nights increases the number of nights necessary to obtain data that give an accurate and precise estimate of activity levels. Biased estimates of bat activity occurs if true bat activity is under or over estimated for a given sampling period (Hayes, 1997). Bias is more likely to occur if not enough nights are sampled. Because the precision of the estimates are also affected by variability, sampling will need to be more intensive for those sites that have greater nightly variation. However, despite statistical requirements, the number of nights that can be sampled in any one season or year is restricted by logistical, time and cost considerations.

If a site is monitored for twenty nights annually, the power to detect a 10% annual decline does not reach 0.8 until the eighth year, by this time the population could be half it's size as indicated by a decline in bat activity of about 54% (10% annual decline = 54% after eight years). However, if a decline of this magnitude occurred in bat activity, there would be adequate power to detect it with any single future survey of activity at the same site, without the expense of annual surveys. Therefore, the costs and benefits of annual monitoring versus less frequent monitoring should be explored. The costs involved will vary from site to site depending on factors such as who undertakes the monitoring (e.g., volunteers or paid researchers) and site access.

Biological significance and statistical significance are not always synonymous. Studies on threatened species are, by their nature, characterized by small sample sizes and high sampling variation (Thomas, 1997). If sample sizes are small and variation is high, statistically significant population changes are not likely to be found (Johnson, 1995). Clearly, any population decline, regardless of its rate, if it persists unabated will be biologically significant (Reed and Blaustein, 1997). However, a common situation that exists in conservation management is that actions are not taken until there is proof that populations are in a state of decline, uncertainty in the current state of the population is often used as a rationale for not taking action (Taylor *et al.*, 2000). This is the case with long-tailed bats as management of

long-tailed bat populations will not be initiated until population trends have been assessed (Molloy, 1995).

Assessing population trends will be expensive and time consuming (e.g., O'Donnell, 1999) and the ability to detect even moderately large declines is poor. If declines are occurring, bat populations are unlikely to be able to recover quickly even if threats are reduced because like most bats, long-tailed bats have low reproductive capacity. Most females begin reproducing when they are two years old (O'Donnell, 2001a), giving birth to a single young once a year (Daniel and Williams, 1984) for at least nine years (O'Donnell, 2001a). The low reproductive output means that bat populations are particularly vulnerable to pressures that result in reduced adult survival and reproductive output (Findley, 1993). Particularly, as survival may not be similar in all age and sex classes. Females may be more vulnerable to predation because when pregnant or carrying young they are likely to be less manoeuvrable (Aldridge and Brigham, 1988) and thus less able to avoid predators. Furthermore, reproductive females dominant colonies where as males are more likely to roost solitary (O'Donnell and Sedgeley, 1999). Compared to bats roosting solitarily, bat colonies may be more detectable by predators (Molloy, 1995). If a roost is destroyed (e.g., by logging or windthrow) while a colony is present then a significant proportion of females may be lost from the population at one time.

Effective population size is primarily reflected in the number of reproductive females (Gilpin and Soule, 1986), and will be less than the total number of bats present (O'Donnell, 1999). A small population decline may indicate a larger, and biologically important, reduction in effective population size. This demonstrates the importance of taking a precautionary approach when assessing population trends. This would involve placing a greater emphasis on the value of historical and anecdotal evidence to influence management priorities.

A monitoring programme using automatic bat detectors to detect changes in activity may have greater power than the results of this study indicate. This is because the relationship between the level of bat activity recorded and abundance is not known. For example, if a population is small, a population decline could be reflected in the recorded activity levels in one or more of the following scenarios: (1) activity declines or disappears from a subset of sites; (2) activity

declines at all sites; (3) activity levels don't change. The third scenario is unlikely because if the population declines, activity will probably decline at one or more sites. It is more likely that bat activity will decline at only some sites, these are likely to be sites on the periphery of the bats collective foraging range. Declines are less likely to be detected near roosts or at sites that have high invertebrate activity. This is because long-tailed bats have similar movement patterns each night, returning to optimal foraging areas (Griffiths, 1996; O'Donnell, 2001b) and individual bats space themselves to minimize competition for food and allow lactating females to use resources close to maternity roosts (O'Donnell, 2001b). If these prediction are correct, intensive presence - absence surveys may have considerable utility.

In this study, bat activity was more variable at Huia than at Cascades. This may be a result of habitat differences between the two sites. It also indicates that monitoring programmes using bat detectors may have more scope to detect trends at certain sites than others. As the number of bat passes per night increased so too did variability. Therefore, data that are obtained during seasons and temperature ranges in which bats are typically more active may not be the best sites for detecting trends or changes. Sites chosen for monitoring should be those where variability is low in relation to the number of bat passes (i.e., where CV% is low). The results suggest that at present it is unwise to rely on monitoring with bat detectors to make sensible management recommendations. Currently, the most reliable method to detect changes in long-tailed bat populations is mark-recapture studies. Bat activity should be monitored concurrently with demographic studies to determine how population changes are reflected in the levels and patterns of bat activity.

References

- Aldridge, H.D.J.N., Brigham, R.M. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% 'rule' of radio-telemetry. *Journal of Mammalogy* 69: 379-382.
- Blaustein, A. R., Wake, D.B., Sousa, W.P. 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. *Conservation Biology* 8: 60-71.
- Borkin, K. 1999. *Long-tailed bat distribution in the Waikato Conservancy*. Unpublished Diploma of Wildlife Management Report. University of Otago, Dunedin.

- Cohen, J. 1988. *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum, Hillsdale, New Jersey, USA.
- Daniel, M.J., Williams, G.R. 1984. A survey of the distribution, seasonal activity and roost sites of New Zealand bats. *New Zealand Journal of Ecology* 7: 9-25.
- Denyer, K.; Cutting, M.; Campbell, G.; Green, C.; Hilton, M. 1993. *Waitakere ecological district: survey report for the protected natural areas programme*. Auckland Regional Council, Auckland.
- Esler, A.E. 1983. Forest and scrubland zones of the Waitakere Range, Auckland. *Tane* 29: 109-118.
- Findley, J.S. 1993. *Bats: a community perspective*. Cambridge University Press, Cambridge.
- Furlonger, C.L., Dewar, H.J., Fenton, M.B. 1987. Habitat use by foraging insectivorous bats. *Canadian Journal of Zoology* 65: 284-288.
- Gannon, M.R., Willig, M.R. 1998. Long-term monitoring protocol for bats: lessons from the Luquillo experimental forest of Puerto Rico. *Man and the Biosphere* 21: 271-291.
- Gibbs, J.B. 1995. *Overview of Monitor (version 6.2) Software*. Department of Biology, Yale University.
- Gillingham, N. 1996. *The behaviour and ecology of long-tailed bats in the central North Island*. Unpublished M.Sc. Thesis. Massey University, Palmerston North.
- Gilpin, M., Soulé, M. 1986. Minimum viable populations: the processes of population extinction. In *Conservation biology: the science of scarcity and diversity*, pp13-34, Soulé, M (Ed). Sinauer Associates, Sunderland.
- Grace, A. 1992. *Waitakere Ranges regional parkland management plan*. Auckland Regional Council, Auckland. 140p.
- Griffiths, R. 1996. *Aspects of the ecology of a long-tailed bat, Chalinolobus tuberculatus, population in a highly fragmented habitat*. Unpublished M.Sc. Thesis. Lincoln University, Canterbury.
- Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation monitoring studies. *Journal of Mammalogy* 78(2): 514-524.
- Johnson, D.H. 1995. Statistical sirens: the allure of nonparametrics. *Ecology* 76: 1998-2000

- Lawrence, B., Palmer, D. 2000. Detecting critical changes in mohua (*Mohoua ochrocephala*) populations. *Conservation Advisory Science Notes No. 316*, Department of Conservation, Wellington.
- New Zealand Meteorological Service. 1980. *Summaries of climatological observations to 1980*. New Zealand Meteorological Service Miscellaneous Publication 177.
- O'Donnell, C.F.J. 1999. The ecology, spatial organisation and conservation of long-tailed bats *Chalinolobus tuberculatus*. Unpublished PhD thesis. University of Otago, Dunedin.
- O'Donnell, C.F.J. 2000a. Conservation status and causes of decline of the threatened New Zealand Long-tailed bat. *Mammal Review* 30(2): 89-106.
- O'Donnell, C.F.J. 2000b. Influence of season, habitat, temperature, and invertebrate availability on nocturnal activity of the New Zealand long-tailed bat. *New Zealand Journal of Zoology* 27: 207-221.
- O'Donnell, C.F.J. 2001a. Advances in New Zealand mammalogy 1990-2000: long-tailed bat. *Journal of the Royal Society of New Zealand* 31(1): 43-57.
- O'Donnell, C.F.J. 2001b. Home range and use of space by *Chalinolobus tuberculatus*, a temperate rainforest bat from New Zealand. *The Journal of Zoology London*: 253: 253-264.
- O'Donnell, C., Sedgeley, J.A. 1994. An automatic monitoring system for recording bat activity. *Department of Conservation Technical Series No.5*. Department of Conservation, Wellington.
- O'Donnell, C.F.J. and Sedgeley, J.A., 1999. Use of roosts by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate rainforest in New Zealand. *Journal of Mammalogy* 80(3): 913-923.
- Molloy, J. 1995. *Bat (pekapeka) recovery plan*. Department of Conservation, Wellington.
- Reed, J.M., Blaustein, A.R. 1997. Biologically significant population declines and statistical power. *Conservation Biology* 11(1): 281-282.
- Taylor, B.L. and Gerrodette, T. 1993. The use of statistical power in conservation biology: the vaquita and northern spotted owl. *Conservation biology* 7: 489-500.
- Taylor, B.L., Wade, P.R., De Master, D.P., Barlow, J. 2000. Incorporating uncertainty into management models for marine mammals. *Conservation Biology* 14(5): 1243-1252.
- Thomas, L. 1997. Retrospective power analysis. *Conservation Biology* 11(1): 276-280.

Thomas, L. and Krebs, C. 1997. A review of statistical power analysis software. *Bulletin of the Ecological Society of America* 78:

Winnington, A. 1999. Ecology, genetics and taxonomy of pekapeka (Chiroptera: *Mystacina tuberculata* and *Chalinolobus tuberculatus*). PhD Thesis. University of Otago, Dunedin.

Zielinski, W.J. and Stauffer, H.B. 1996. Monitoring Martes populations in California: survey design and power analysis. *Ecological Applications* 6(4): 1254-1267.

Chapter 5: General Discussion

Relevance of this study

The aim of this study was to provide information on the ecology of long-tailed bats in the Waitakere Ranges which would assist in the development of a long-term monitoring programme. To achieve this aim, habitat use and nocturnal activity patterns were examined and a power analysis was conducted to determine if automatic bat detectors could be used to detect potentially significant changes in bat activity. A study of the Waitakere Ranges long-tailed bat population was significant because:

1. The Waitakere Ranges is the northern most location at which long-tailed bats have been researched.
2. The study was the first to be conducted on a long-tailed bat population that persisted in kauri *Agathis australis* dominated forest remnants.
3. The long-tailed bat population in the Waitakere Ranges is the only known extant population in close proximity to a major urban area.
4. There is a diverse range of habitat types potentially available to bats in the Waitakere Ranges.
5. Factors that are attributed to long-tailed bat population declines (i.e., forest clearance, predation and urbanisation; O'Donnell, 2000) have all had a major impact on other species in the Waitakere Ranges.

Importance of kauri

As bats had the opportunity to use a wide range of habitats, it is significant that bat activity and roost sites were concentrated in and near areas of mature kauri forest. Results from recent surveys with automatic bat detectors suggest that most records of long-tailed bats in Northland (S. McManus pers. comm.), and on the Coromandel Peninsula (S. Chapman pers. comm.), are also associated with remnants of kauri forest. Bats may preferentially roost in mature kauri for several reasons. Mature kauri trees possess physiological and morphological characteristics that could make them ideal for long-tailed bat roosts. For example, where it occurs it is usually the tallest tree in the landscape and there are often large numbers of cavities within the crowns of mature kauri. As the long-tailed bat is an edge-forager (O'Donnell, 1999), the open structure of

mature kauri forest may enable more within-forest foraging compared with many other forest types.

An alternative hypothesis to explain apparent, preference for kauri trees is that in areas where predation pressure is or was intense, long-tailed bats may be largely restricted to kauri forest due to selective pressure from introduced predators. A combination of introduced mammalian predators and the availability of secure roosting sites are probably why long-tailed bats in the Waitakere Ranges were mainly roosting in mature kauri trees. Griffiths (1996) concluded that the same factors limited long-tailed bats in South Canterbury, although a vastly different habitat to the Waitakere Ranges. Bats were confined to roosting in small crevices in vertical limestone cliff faces because they were inaccessible to predators.

The most likely causes for long-tailed bat population declines are predation and the loss of roosting trees following forest clearance (O'Donnell, 2000a). If bat roosts are now restricted to sites that are inaccessible to mammalian predators, then direct predation by mammalian predators may now be rare. Large-scale forest clearance has also ceased. However, the indirect effects of predation and forest clearance may be ongoing. For example, once a population has been reduced to a small size and its roosting area reduced, factors such as predation by the morepork *Ninox novaeseelandiae* may have a significant impact on population viability. Particularly, if juveniles and females are more vulnerable to predation than adult males. This may occur because colonial long-tailed bat roosts are dominated by reproductive females (O'Donnell, 2001). Given that there are probably greater levels of bat activity, noise and odour at colonial roosts than solitary roosts, they may be easily located by predators (Molloy, 1995), this would have greater impact if bats are cycling around a small pool of roosts. Pregnant females and newly volant young are probably also more vulnerable to predation because they are less maneuverable than male bats (Alridge and Brigham, 1988).

In the Waitakere Ranges, it appeared that long-tailed bats had higher rates of roost reuse than in the Eglinton Valley, Geraldine or Hawkes Bay (Sedgeley and O'Donnell 1999a; Gillingham, 1996; Griffiths, 1996). The reasons for this are unclear. Either suitable roosts are limited or they are of such high quality that it is not necessary to switch roosts as often. The later is

unlikely because while roost cavity characteristics were not measured, there is no reason to expect that roost cavities in kauri forest are of superior quality to cavities in podocarp (Gillingham, 1996) or *Nothofagus* dominated forest (Sedgeley and O'Donnell, 1999b). However, it is extremely unlikely that roosts in the Waitakere Ranges would be more limited than in Geraldine, the most modified and fragmented habitat in which the long-tailed bat has been studied. Therefore, there may be another factor involved in the higher than expected roost reuse.

Use of urban areas

As in other studies, in the Waitakere Ranges long-tailed bats utilised linear landscape features such as streams and roads (e.g., O'Donnell, 1999). These features appeared to assist bats movement into semi-urban areas and very near to urban environments. Long-tailed bats also foraged around houses set in a forested landscape. These observations suggest that if roosting habitats are secure then long-tailed bats may be able to persist in close proximity to urban areas.

Value of automatic bat detectors for monitoring population trends

Bat detectors provide valuable information on bat distribution, activity patterns and habitat use (O'Donnell and Sedgeley, 1994). Several authors have implied that bat populations could be monitored with bat detectors (e.g., Hayes, 1997; Griffiths, 1999; O'Donnell, 1999). However, the results of this study indicate that more research is required before bat detectors could be used to detect trends in bat populations. It is possible that bat detectors may never be an effective tool for tracking population changes. However, their low cost makes exploring their potential for monitoring worthwhile. Particularly, as a network of national monitoring sites is required and intensive demographic studies are probably not feasible for using nationwide.

Automatic bat detectors are used in two ways: 1) presence / absence surveys, or 2) recording bat activity at a site or a network of sites over time. It is not known if and how population changes will be reflected in data collected using automatic bat detectors. If a population declines, bat activity may only decline at a subset of sites around the periphery of the groups collective range or at the least preferred foraging grounds. To clarify the relationship between

population changes and changes in activity, bat detector studies (both presence / absence surveys and monitoring of activity) should be undertaken concurrently with trapping-banding studies at a network of sites. Such studies should be undertaken in areas where population changes might be expected and where factors implicated in the decline of long-tailed bat populations are intense. This research should be carefully designed and a BACT design used (Before-After-Control-Treatment; e.g., Norton, 1996). As trapping-banding studies are expensive, study sites should be selected carefully. Another method to determine how population changes are reflected in bat activity might be to monitor bat activity before and after the population is temporarily reduced by removing one or more bats caught at or near monitoring sites for all or part of the night (e.g., the first or second half of the night).

The results of the power analysis performed in this study suggest that even if bat activity is found to be an index of population size, the high level of variability in pass rates will mean that monitoring programmes will only have sufficient power to detect declines in bat activity of greater than fifty percent. However, if bat activity declines sharply at some sites, bat detectors may be a very useful tool of indicating population declines. It is important to select monitoring sites with low coefficient of variability (i.e., sites where variability in pass rates is low, in proportion to the mean pass rate), rather than simply selecting sites with the most activity.

Until the relationship between actual population changes and indices of bat activity is clarified I recommend that if the primary aim is to monitor population trends then intensive presence - absence surveys (c.f., broad scale distribution surveys) should be undertaken. This is because the results of the power analysis indicate that presence-absence surveys are potentially useful in monitoring population trends and it is probably more important to gather baseline data at a range of sites rather than focusing effort on a few sites. Three nights of recording without wind or rain (bats forage under these conditions but such conditions reduce the effectiveness of automatic detectors) are, in most cases, sufficient to confirm the presence of bats at a site. If bats are not recorded within this time they cannot be considered to be absent from the site. Rather, their presence is not confirmed.

This study showed that activity patterns differed between Huia and Cascades. At Huia, activity patterns did not differ between assumed periods of pregnancy and lactation as they did at Cascades. Possibly this could have been a result of habitat differences between the two areas. However, of 16 captures of 10 long-tailed bats at Huia, no males were captured (S. Chapman pers. comm.). While the sample size was small, the results are significant because in all other long-tailed bat trapping studies, more females than males were captured and the overall sex ratio of adults was 1.8 females:1 male (O'Donnell, 2001). A greater understanding of activity patterns and the influence reproduction has on activity patterns recorded with bat detectors may be of use in determining whether there are reproductive females present. The potential of comparing activity during reproductive stages as a monitoring technique warrants further investigation.

Alternative monitoring methods

If automatic bat detectors provide little or no information on population status or trends, then alternative techniques for identifying conservation needs must be developed. Mark-recapture demographic studies may be useful for monitoring larger populations but by the time changes in survival and fecundity are detected in small populations remedial action may be prohibitively expensive or no longer possible (Williams, 2000). Therefore it is vital that better monitoring techniques are developed and criteria are developed that are capable of predicting which populations are likely to be declining, given environmental changes in the area.

Fluctuating asymmetry may provide an alternative means of determining whether a population is suffering genetic or environmental stress (Williams, 2000). When individuals are under stress, small directionally random changes from perfect symmetry may occur (Palmer and Strobeck, 1986). In some species fluctuating asymmetry has been shown to increase with increasing population stress (Sommer, 1996). Therefore, by investigating and comparing symmetry between different populations, or over time in a single population, it may be possible to assess population health and identify if population declines are occurring.

Future research

The Waitakere Ranges long-tailed bat population

The Waitakere Ranges long-tailed bat population should be targeted for further research and management. The factors thought to be involved in the decline of long-tailed bats all occur in the Waitakere Ranges at an equal or greater intensity than other areas except perhaps Geraldine. With increasing population growth in Auckland and ongoing development in the Waitakere Ranges pressures on the local long-tailed bats are likely to intensify (e.g., conversion of present foraging areas such as farmland and orchards to housing estates). This study provides baseline data which future research should build upon. Priority should be directed towards establishing a long-term demographic study and a population viability analysis. Of critical importance is determining if the Huia population is breeding. A presence - absence survey should be continued and survey effort should be focused on semi-urban areas. Other potential monitoring methods such as measuring fluctuating asymmetry (Williams, 2000) should be trialled in the Waitakere Ranges.

Other long-tailed bat populations

A primary focus of future long-tailed bat research must be to identify the main factors limiting their populations. The primary aim of developing effective monitoring techniques is to identify which populations are declining so that management can be initiated (O'Donnell, 2000a). However, the main threats to long-tailed bats have not been identified so restoration efforts are not likely to be successful (O'Donnell, 2000). Before managers can begin to treat population declines it is critical that their causes be diagnosed. There are two main methods that may be used to do this:

- a) Sites with a range of population trends are selected to undertake experiments (adaptive management) that manipulate apparent agents of decline and a population viability analysis is then performed to assess the populations response (O'Donnell, 1999). Adaptive management has been successfully used to determine the causes of population decline and to simultaneously recovery populations of threatened species (e.g., kokako *Callaeas cinerea wilsoni*; Innes *et al.*, 1999).

- b) Characteristics of long-tailed bat populations (e.g., abundance and trends, sex ratio, occurrence of reproduction, roost size and use) are compared in a range of areas that have been subjected to different degrees of forest clearance and predator impacts.

Isolating the factors that may cause long-tailed bat population declines may prove difficult. This is because it is necessary to identify the current and historical threats, the probability of exposure to these, and the likely population response (Harwood, 2000). However, it may be possible to isolate these factors if long-tailed bat populations are studied in areas where kauri forest is present because:

- 1) Vegetation type may potentially confound explanations of differences in roost size and roost fidelity. Therefore, it may not be possible to compare factors such as roost size and use between populations in different vegetation types.
- 2) Areas where mature unmodified kauri persists are well mapped and many stand characteristics are described in detail.
- 3) Kauri forest often persists in discrete patches surrounded by other vegetation.
- 4) Logging intensity has been well documented, especially in areas such as Omahuta, Herekino and Puketi where logging has occurred during the last 50 years (New Zealand Forest Service, 1983). Therefore it is possible to compare the impact of a range of logging regimes within the same general location (e.g., in unlogged, selectively logged or clearfelled forests) on long-tailed bat populations.
- 5) By identifying the presence or absence of species that are sensitive to different predator species and densities it may be possible to infer predator history and examine characteristics of long-tailed bat populations in relation to the presence and abundance of potential predators.

Concluding Remarks

The Waitakere bat population is perhaps one of the most accessible and its close proximity to New Zealand's largest city means that it can potentially play a vital role in bat advocacy. Many of New Zealand indigenous species are now extinct in the Waitakere Ranges. Even species such as Bellbirds *Anthornis melanura* that have survived in other cities have disappeared from the Ranges. I strongly endorse Slaven's (1989) sentiments that it is our duty to ensure that the

depauperate wildlife of the Waitakere Ranges declines no further. If we do not meet this challenge, the Waitakere long-tailed bat population could be yet another species that future generations will not have the pleasure of experiencing in their own environment. The enormous interest in this project and the many people volunteering their assistance demonstrates that the wider community is committed to conserving long-tailed bats. I urge the relevant management agencies to invest the necessary resources to ensure that the Waitakere Ranges long-tailed bats are able to flourish.

References

- Aldridge, H.D.J.N., Brigham, R.M. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% 'rule' of radio-telemetry. *Journal of Mammalogy*
- Gillingham, N. 1996. *The behaviour and ecology of long-tailed bats in the central North Island*. Unpublished M.Sc. Thesis. Massey University, Palmerston North.
- Griffiths, R. 1996. Aspects of the ecology of a long-tailed bat, *Chalinolobus tuberculatus*, population in a highly fragmented habitat. Unpublished M.Sc. Thesis. Lincoln University, Canterbury.
- Harwood, J. 2000. Risk assessment and decision analysis in conservation. *Biological Conservation* 95(2): 219-226.
- Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation monitoring studies. *Journal of Mammalogy* 78(2): 514-524.
- Innes, J., Hay, R., Flux, I., Bradfield, P., Speed, H., Jansen, P. 1999. Successful recovery of North Island kokako *Callaeas cinerea wilsoni* populations, by adaptive management. *Biological Conservation* 87: 201-214.
- Molloy, J. 1995. *Bat (pekapeka) recovery plan*. Department of Conservation, Wellington.
- New Zealand Forest Service. 1983. *Kauri forest management review*. 90p.
- Norton, D.A. 1996. Monitoring biodiversity in New Zealand's terrestrial ecosystems. In McFadgen, B and Simpson, P (Ed.). *Papers from a seminar on biodiversity*. Department of Conservation, Wellington.
- O'Donnell, C.F.J. 1999. The ecology, spatial organisation and conservation of long-tailed bats *Chalinolobus tuberculatus*. Unpublished PhD thesis. University of Otago, Dunedin.

- O'Donnell, C.F.J. 2000. Conservation status and causes of decline of the threatened New Zealand Long-tailed bat. *Mammal Review* 30(2): 89-106.
- O'Donnell, C.F.J. 2001. Advances in New Zealand mammalogy 1990-2000: long-tailed bat. *Journal of the Royal Society of New Zealand* 31(1): 43-57.
- O'Donnell, C.F.J. and Sedgeley, J.A. 1994. An automatic monitoring system for recording bat activity. *Department of Conservation Technical Series No.5*. Department of Conservation, Wellington.
- Palmer, A.R., Strobeck, C. 1986. Fluctuating asymmetry: measurement, analysis, patterns. *Annual Review of Ecology and Systematics* 17: 391-421.
- Sedgeley, J.A. and O'Donnell, C.F.J. 1999a. Roost selection by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate New Zealand rainforest and its implications for the conservation of bats in managed forests. *Biological Conservation* 88: 261-276.
- Sedgeley, J.A. and O'Donnell, C.F.J. 1999b. Factors influencing the selection of roost cavities by a temperate rainforest bat (Vespertilionidae: *Chalinolobus tuberculatus*) in New Zealand. *Journal of Zoology London* 249: 437-446.
- Slaven, O.C. 1989. Wildlife report for the protected natural areas programme. Unpublished report. Auckland Regional Council.
- Sommer, C. 1996. Ecotoxicology and developmental stability as an in situ monitor of adaptation. *Ambio* 25: 374-376.
- Williams, M. 2000. Monitoring with callipers: the potential value of fluctuating asymmetry measurement in conservation monitoring, management and research. *Ecological Management* 8: 47-61