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Hamilton City Bat Survey 2011-2012

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Hamilton City Council
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Department of Conservation
Te Papa Atawhai

WAIKATO TREE TRUST

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Document Ref: \\server files\Hamilton City Council\Bat survey city wide\city wide survey report_240512

Summary

Reduced biodiversity in urban ecosystems is often attributed to the loss and fragmentation of suitable habitat for wildlife. To date, few studies have investigated if and how New Zealand bat species use urban environments. Only two bat species – long-tailed bats (*Chalinolobus tuberculatus*) and lesser short-tailed (*Mystacina tuberculata*) bats – are found in New Zealand, both of which are endemic and classified as nationally threatened by the Department of Conservation (DOC).

We used bat detectors to conducted presence/absence surveys at 62 'green space' habitats (0.7-92 ha) to better understand bat distribution and habitat use patterns in Hamilton City. Long-tailed bat activity was confirmed at 16 sites (25.8%), all of which were restricted to the most southern urban-rural fringe of the city. Although 14 of these habitats (87.5%) were classified as 'riparian margins' or 'major gullies' situated 0-100 m from the Waikato River (a major linear landscape feature), significantly higher pass rates were recorded at a rural indigenous forest remnant (Whewell's Bush). Only six sites (<10%) showed any evidence of foraging activity and nightly activity patterns to suggest possible or likely roosting by bats.

Habitat connectivity or distance to the Waikato River/major gullies emerged as the single most significant explanatory variable in our statistical model, highlighting the importance between habitat type and distance to the river/gullies for bats. Overall, bat activity significantly increased with: 1) decreasing distances from well-connected habitats and linear landscape features (gullies and river); and 2) increasing distances from the city centre and levels of human activity. Pass rates were consistently highest at habitats where houses, roads and street lights were lowest. Even slight increases in the number of roads and street lights resulted in decreases in pass rates of 86% and 70%, respectively.

Riparian margins, with dense native and exotic trees and shrubs associated with riverine and gully landscapes, appear to be critical habitat, as bats depend on access to key resources associated with these environments. In particular these habitats provide:

1) mature exotic and native vegetation for roosting purposes;
2) emergent aquatic insect prey (e.g. mosquitoes) for foraging;
3) freshwater for drinking; and
4) linear landscape corridors for movement and navigation.

Our results show the importance of maintaining, restoring and perpetuating these well connected, less developed habitats for long-tailed bats in Hamilton City. Habitat restoration and bat conservation efforts should thus strategically focus on preserving existing foraging and roosting habitats and improving habitat connectivity by reducing the effects of human activity (e.g. low light regimes).

Future major growth cells for Hamilton city are currently focused on the southern urban-rural interface with several major roading and housing developments proposed. This study underscores the importance of making the urban landscape (both present and future) more permeable to long-tailed bats as well as protecting and enhancing existing well-connected bat habitats. If long-tailed bats are to be retained within Hamilton City in the face of ongoing urban expansion, major collective conservation decision-making by key stakeholders, as well as the implementation of multiple adaptive management strategies, will be required.

1 Introduction

Better understanding how species, especially cryptic threatened populations, are distributed within the urban landscape and affected by human activities can guide decision-making by conservationists, wildlife managers, planners and developers. Bats are a challenging group of animals to monitor and manage due to their nocturnal and mobile nature (Fenton, 2003). In human-dominated environments bat management and conservation efforts remain absent or misguided due to a lack of knowledge about how bats use these ecosystems (O' Shea *et al.,* 2003).

Few studies have investigated if and how New Zealand bat species use human-dominated environments like major cities (Dekrout, 2009; Le Roux, 2010). It is often assumed that threatened species are not found in urban ecosystems, which is often the case, however, for cryptic species such as bats this may not always be true. Only two bat species are found in New Zealand, long-tailed bats (*Chalinolobus tuberculatus*) and lesser short-tailed bats (*Mystacina tuberculata*), which form the entirety of New Zealand's native terrestrial mammal fauna (O'Donnell, 2005).

Long-tailed bats are a nationally threatened species classified as 'Nationally Vulnerable' in the North Island (O' Donnell *et al*., 2010) with ongoing population declines attributed to the loss and fragmentation of habitats and pest animal (e.g. cats and ship rats) predation and competition. Long-tailed bats are strict aerial insectivores that rely on 40 kHz frequency-modulated echolocation calls for navigation and foraging on the wing (Parsons *et al*., 1997). Individuals roost in hollows and under split bark typically associated with mature and dead native and exotic trees (O' Donnell, 2001; Borkin & Parsons, 2011).

Hamilton City (North Island, New Zealand) is one of the only known cities in New Zealand to still support bats within the City's urban boundaries (Dekrout, 2009; Le Roux, 2010). This is despite the Hamilton Ecological District being one of the most degraded in New Zealand with c. 1.6% of the original native vegetation remaining (Clarkson & McQueen, 2004). To date, there has been no single city-wide survey to catalogue bat distribution and identify the factors which may influence this.

The objectives of this study were to: 1) obtain a comprehensive understanding of bat distribution and habitat use patterns in and around Hamilton City; 2) develop a comprehensive, publicly accessible online bat distribution map and database; 3) determine which landscape features (i.e. habitat type and connectivity) and anthropogenic variables (i.e. housing, roading and street lighting) best explain bat distribution and habitat use patterns; and 4) provide strategic management recommendations for the ongoing conservation of bats in Hamilton City.

2 Methods & Materials

2.1 Site descriptions

Hamilton City (37°47'S, 175°17'E) is New Zealand's fourth largest city with a total area of 9,800 ha that supports a population of c.150,000 people. We completed long-tailed bat presence/absence surveys at 62 sites in and around Hamilton City during austral spring and summer months (between September 2011 and January 2012), when bat activity is highest (Le Roux, 2010). Selected survey sites included both rural (*N* = 6; situated within 4 km of the city but outside of designated city boundaries) and urban (*N* = 56; within designated city boundaries) 'green space' habitats with features that had the highest potential of supporting roosting and/or foraging bats (i.e. mature native and exotic vegetation, proximity to water bodies and/or edge habitat). Sites were situated at varying distances (0-4,700 m) from the Waikato River – a major linear landscape feature bisecting the city. Four major gully systems are situated throughout the city. The Mangakotukutuku and Mangaonua gullies situated along the southern urban-rural interface of Hamilton City are the largest of the four gullies and together with Waikato River form the single largest and most continuous ecotone in Hamilton. Conversely, the Kirikiriroa and Waitawhiriwhiri gullies (where no bat activity was detected in this survey) are situated within the urban matrix in highly developed areas in the northern part of the city.

All sites were categorized into four major habitat types found throughout Hamilton. Habitats included:

1) *Major gullies* - well vegetated native and/or exotic corridor systems >50m from the banks of the Waikato River connecting habitats such as forest fragments with riparian margins;
2) *Riparian margins* - native and/or exotic vegetation immediately flanking (0-50m) the banks of the Waikato River;
3) *Urban parklands* - designated public recreational areas within the city's boundaries dominated by large open grassy space, mature native and exotic vegetation, and/or artificial or natural waterbodies (e.g. lakes); and
4) *Native forest remnants* - urban and rural forest fragments <12ha in size dominated by mature native emergent vegetation (e.g. kahikatea (*Dacrycarpus dacryiodes*) and totara (*Podocarpus totara*)).

3.2 Monitoring design and equipment

Automated heterodyne bat detectors were used to remotely and passively record bat echolocation pulses (manufactured by DOC; Lloyd, 2009). Detectors are made with similar sensitivities and for the purposes of this study it was assumed that each detector had an equal chance of detecting echolocation pulses, although this may in fact vary with microhabitat and detector location (Le Roux, 2010). Detectors were calibrated to have the same time and date settings (NZST) and were pre-set to start monitoring 30 minutes before sunset until 30 minutes after sunrise. On average 15-20 detectors were available for use at one time, which limited the number of sites that could be concurrently surveyed. Each site was surveyed once for five consecutive nights, irrespective of weather conditions. The order in which sites were monitored was randomised. At each site, the distance between detector locations was at least 25 m apart to increase the chance of independent bat monitoring. All detectors were secured on trees and orientated upward at 30-45°C from the horizon.

The number of detectors allocated to each site was dependent on the size of the habitat. Surveyed areas ranged in size from 0.7 to 92 ha. On average, for sites < 1 ha we allocated one detector (range 1-2); for sites between 1 and 10 ha three detectors were allocated (range 1-9); for sites > 10 ha, seven detectors were deployed (range 2-10). Equipment failure, theft and limited availability of detectors meant that detector allocation per area was not always kept consistent. As a result bat activity measures were standardised and calculated per unit effort (i.e. passes/detector/night).

3.3 Data collection and classification

Recorded bat echolocation files were sorted by visual and auditory inspection of waveforms using Bat Search 1.02 Software ® (DOC, 2008, New Zealand; Lloyd, 2009). Individual sound files were sorted into: 1) echolocation passes, defined as a series of two or more high frequency echolocation pulses emitted in sequence by flying bats (Parsons *et al.*, 1997); and 2) non-bat sounds (i.e. wind, rain or insect generated noise) that were discarded. All passes were classified into one of two echolocation categories: 1) search phase pulses with low pulse repetition rates (mean inter-pulse interval of c. 104 ms) likely used for commuting and/or locating prey; and 2) feeding buzzes consisting of a series of rapidly emitted pulses (mean inter-pulse durations of c. 4.5 ms) used to determine the range of prey prior to capture (Parsons *et al.*, 1997). If a file contained one or more feeding buzzes, it was classified as a single feeding buzz only. All echolocation pulses were recorded with a date (day/month/year) and time (hour/minute/second) stamp.

By assessing the amount, type and temporal peaks in nightly echolocation activity we were able to distinguish between three different ways in which bats were using habitats. Habitat use included:

a) *Commuting* - sites with no feeding buzzes and ≤ 0.2 pass/detector/night.

b) *Foraging and possible periodic roosting* - sites with feeding buzzes and ≥ 1 pass/detector/night with activity peaks recorded within the first hour after sunset and again before sunrise indicative of roost emergence and return.

c) *Foraging and likely regular roosting* - sites with feeding buzzes and ≥ 20 passes/detector/night with clear bimodal peaks in activity after sunset and before sunrise indicative of roost emergence and return.

3.4 Statistical analyses

For each site with confirmed bat activity (N =16) we calculated the mean number of search phase pulses and feeding buzzes/detector/night. By pooling data across these sites, we were able to calculate the mean number of passes for each hour after official sunset for: commuting habitats; foraging and possible periodic roosting habitats; and foraging and likely regular roosting habitats.

To test the null hypotheses that bat activity (passes/detector/night) is not influenced by 1) habitat type; 2) habitat connectivity; and 3) anthropogenic variables, we used a bootstrap Generalised Linear Model (GLM) that incorporated both categorical (e.g. habitat type) and continuous variables (e.g. distance) into the analyses. This involved rank transforming pass rates to minimize the effect of extreme random spikes; calculating F-values in a GLM; and subsequently generating null F distributions using a bootstrap GLM to calculate P-values.

To account for habitat connectivity and landscape features we measured both the distance of each site to the city centre and the distance of each site to the Waikato River or a major gully system. To account for the influence of anthropogenic variables, we estimated the density of three predominant variables according to the number/hectare and/or type of each variable for each surveyed site using a combination of aerial map inspections and physical counts (Table 1). The number of houses and streetlights/hectare was calculated from counts made within 50 m around the perimeter of each site. We also counted and classified roads within 50 m around the perimeter of each site. We ranked density values and allocated a score between 1 (lowest) and 5 (highest) for housing, roading, and street lighting for all sites. Because these three anthropogenic variables are interconnected and influence each other within the urban landscape (i.e. sites with high housing typical also have high roading and thus street lighting and vice versa), we needed to account for this issue as these data suffer from multicolinearity. To do this we calculated a single combined mean ‘human activity’ score which assimilated all three independent variables at each site. We thus tested the significance of all anthropogenic variables collectively in the GLM.

Habitat type for all 62 sites was also incorporated as a variable in the GLM, however we also completed an additional analysis to determine if there were any differences in rank transformed pass rates across the four habitat types for sites with confirmed bat activity only. A bootstrap one-way ANOVA was used to do this.

All statistical analyses were completed using bootstrap macros written in MINITAB® 13.30 (Minitab Inc. 2000). Bootstrap iterations run for each analysis were kept constant at 2000. The significance threshold was held at $P < 0.05$, although weak ($P < 0.1$) significant results/interactions were also considered. Means are presented with ± SEM. Untransformed data are displayed in all figures.

Table 1 Scores between 1 (lowest) and 5 (highest) for the three anthropogenic variables characterising the urban landscape with corresponding ranges in the density and/or type of each variable (X = density for each site)

Score	# houses/ha	# and type of roads	# street lights/ha
1	0 ≤ X < 1	Few (1-3) rural roads	0 ≤ X < 1
2	1 ≤ X < 5	Few (1-3) residential roads	1 ≤ X < 5
3	5 ≤ X < 10	Main road OR surrounded by residential roads	5 ≤ X < 10
4	10 ≤ X < 20	Main road AND surrounded by residential roads	10 ≤ X < 20
5	20 ≤ X	Major state highway	20 ≤ X

3 Results

4.1 Presence/absence

In total, bats were monitored at 254 fixed locations for 600 hours over 75 survey nights. This resulted in a combined surveyed area of 628.4 ha or c. 70% of the available 'green spaces' in and around Hamilton City.

No lesser short-tailed bats were detected.

Of the 62 sites surveyed 16 (25.8%) had confirmed long-tailed bat activity. See Figure 1, Appendix I, and the following URL address for the online public distribution map:

http://maps.google.co.nz/maps/ms?vps=2&hl=en&ie=UTF8&oe=UTF8&msa=0&msid=209683510036776183064.0004b8677777cd753a43f

4.2 Habitat type

All 16 bat habitats are restricted to the southern most urban-rural interface of the city and are situated within the same continuous ecotone (i.e. along the banks of the Waikato River and within or in close proximity to the two largest gully systems – Mangakotukutuku and Mangaonua; see Figures 1 and 2). Furthermore, 14 (87.5%) of the confirmed bat habitats were classified as 'riparian margins' (7 sites; 43.75%) or 'major gullies' (i.e. situated between 0-100 m from the Waikato River or a major gully which feeds into the Waikato River; Table 2). The only urban parkland (Resthills Park), and indigenous forest remnant (Whewell's Bush[1]) with any bat activity were both 450 m from the nearest gully system.

Bootstrap one-way ANOVA analysis was carried out using bat activity only and comparing and between habitat types. This revealed that pass rates were significantly higher (P = 0.02; F = 3.7) for Whelwell's Bush compared with all other habitat types. This is despite native forest remnants being the most poorly

[1] A 11.5 ha mature kahikatea dominated Scientific Reserve managed by the Department of Conservation

represented habitat type in the urban landscape and thus our data set. Major gullies (0.658 ±0.35) and urban parklands (0.086 ± 0.06) had the lowest pass rates (passes/detector/night) when compared to other habitat types. However, when 'habitat type' was incorporated into the more realistic bootstrap GLM it did not emerge as a significant explanatory variable ($P = 0.11$, $F = 2.13$).

4.3 Habitat use

A total of 1,898 echolocation passes were recorded, 94% of which were identified as search phase passes (6% feeding buzzes). Only 40 detectors recorded echolocation passes, 70% of which recorded a total of ≤10 passes over five nights while just 15% of detectors recorded a total of ≥50 passes over a five night period.

Of the 16 sites with bat activity, a majority (N =10; 62.5%) were identified as commuting habitats with low nightly activity (0.02 ± 0.009 mean passes/hour/night). This was characterised by search phase activity only, normally with one or two passes recorded randomly between the 2^{nd} and 8^{th} hours after sunset (Figure 4). The number of sites (N = 3) identified as foraging and possible periodic roosting habitats accounted for 18.7% of the bat habitats. At these sites activity was characterised by a relatively small series of nightly peaks in search phase passes (0.1 ± 0.08 mean passes/hour/night) and feeding buzzes (0.01 ± 0.008) occurring between the 1^{st} and 11^{th} hours after sunset. Similarly, the number of sites (N = 3) identified as foraging and likely regular roosting habitats accounted for 18.7% of the bat habitats or just 3% of the total sites surveyed. Nightly activity patterns at these three sites were the highest overall and were characterised by distinct bimodal peaks in search phase (2.35 ± 1.35 mean passes/hour/night) and feeding activity (0.53 ± 0.38) occurring between the 1^{st} and 3^{rd} hours after sunset and again between the 7^{th} and 11^{th} hours after sunset.

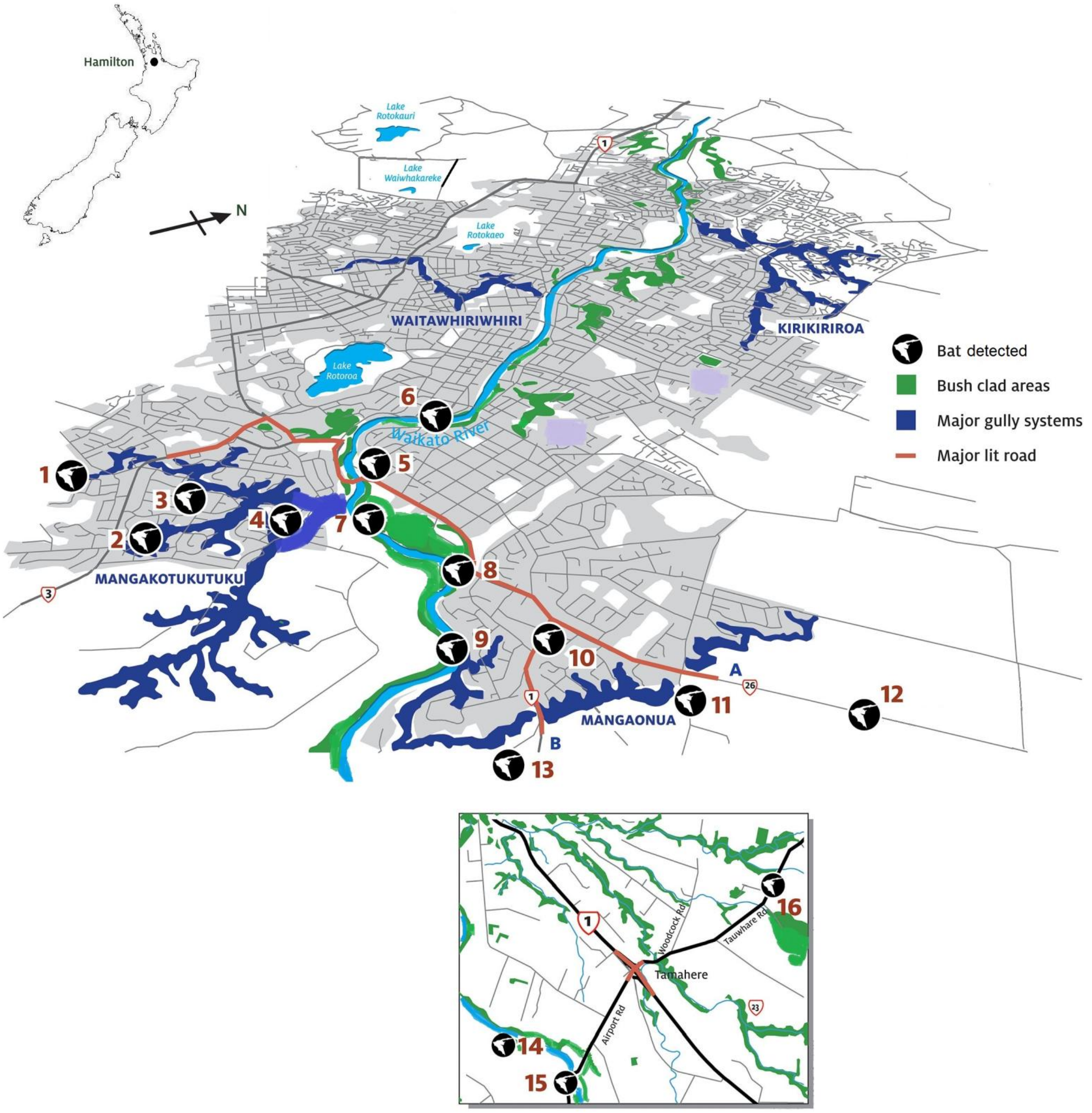

Figure 1 Long-tailed bat distribution map for Hamilton City, highlighting major landscape and anthropogenic features as well as all 16 habitat locations with confirmed bat activity

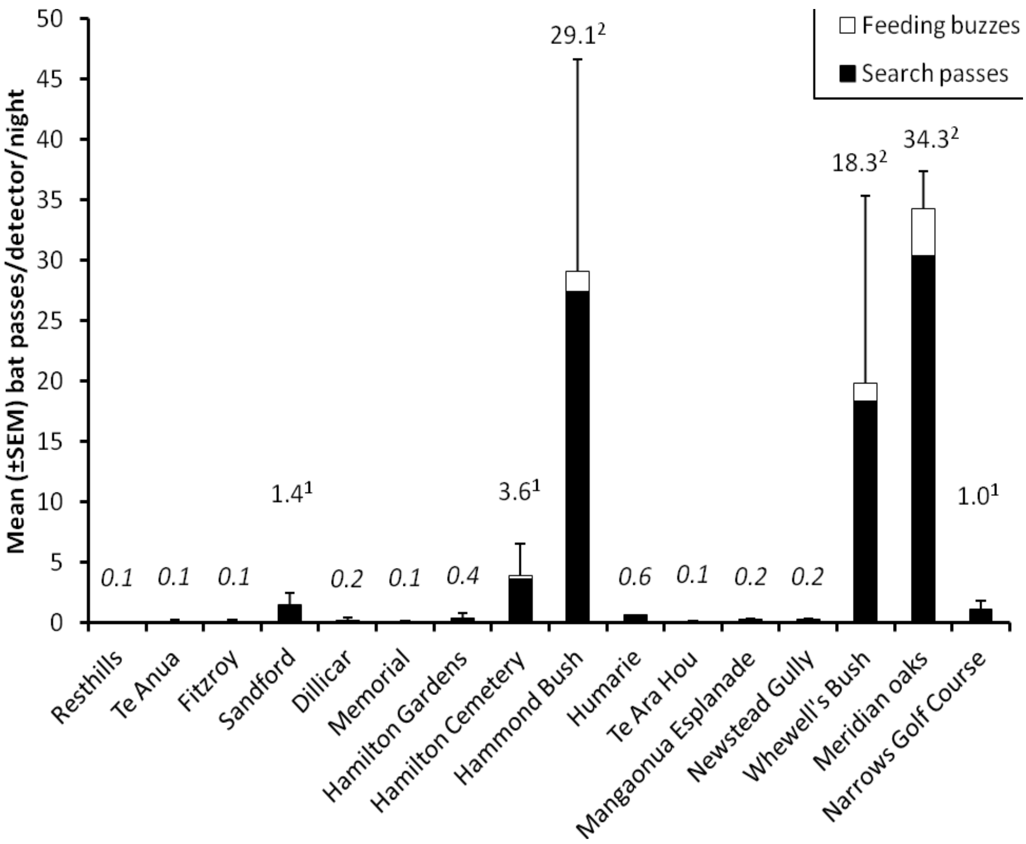

Figure 2 **Mean passes (± SEM) /detector/night for search passes and feeding buzzes recorded at all 16 sites with bat activity (site names from left to right correspond to site numbers 1-16 in Figure 1). Combined mean values (feeding and search) for each site are displayed above error bars and superscript numbers 1 and 2 correspond to habitats categorized as 'foraging and possible periodic roosting' and 'foraging and likely regular roosting', respectively, while values italised number correspond to 'commuting' habitats (see Figure 4).**

4.4 Landscape and anthropogenic variables

Bat activity significantly ($P < 0.001$; $F = 10.4$) increased with a decreased distance to the Waikato River and/or major gully systems (Figure 3). This relationship was highly significant, but not necessarily linear in nature, as illustrated by the peaks in Figure 3. The only major exception to this trend was the high levels of pass rates recorded at the native forest remnant (Whewell's Bush). Conversely, bat activity significantly ($P = 0.02$; $F = 5.62$) increased with an increase in distance from the city centre (Figure 3). Invariably, this meant that bat activity was highest at rural habitats (13.17 ± 7.57) compared with urban habitats (3.028 ± 2.39), despite an overall higher number of urban sites with bat activity (Figure 3). Pass rates more than doubled at sites > 9 km from the city centre compared with sites < 9 km from the city centre.

Overall, bat activity was highest at habitats that were allocated the lowest scores (1) for roading, street lighting and housing density (Figure 5). For roading in particular, pass rates dramatically decreased by 86% with a slight increase in variable score (i.e. from 1 to 2; Figure 5). A similar trend was observed for street lighting and housing with decreases of 70% and 42% between scores of 1 and 2, respectively. Tested in isolation in the bootstrap GLM, roading ($P = 0.05$, $F = 4.02$), street lighting ($P = 0.98$, $F = 0.0$) and housing ($P = 0.33$, $F = 0.96$) all emerged as weakly significant variables, however, as previously discussed these variables are inextricably interconnected and therefore these data suffer from multicollinearity. To overcome this we incorporated a more robust combined mean 'human activity' score accounting for these interactions. 'Human activity' was a significant ($P = 0.01$; $F = 6.3$)

explanatory variable of bat activity in this model, with increasing human activity resulting in reduced bat activity. There were no significant interactions between habitat type and distance from the city centre (*P* = 0.34) but there were weak significant interactions between 'habitat type' and mean 'human activity' (*P* = 0.09) and 'habitat type' and 'habitat connectivity' / distance to the Waikato River or major gully (*P* = 0.07).

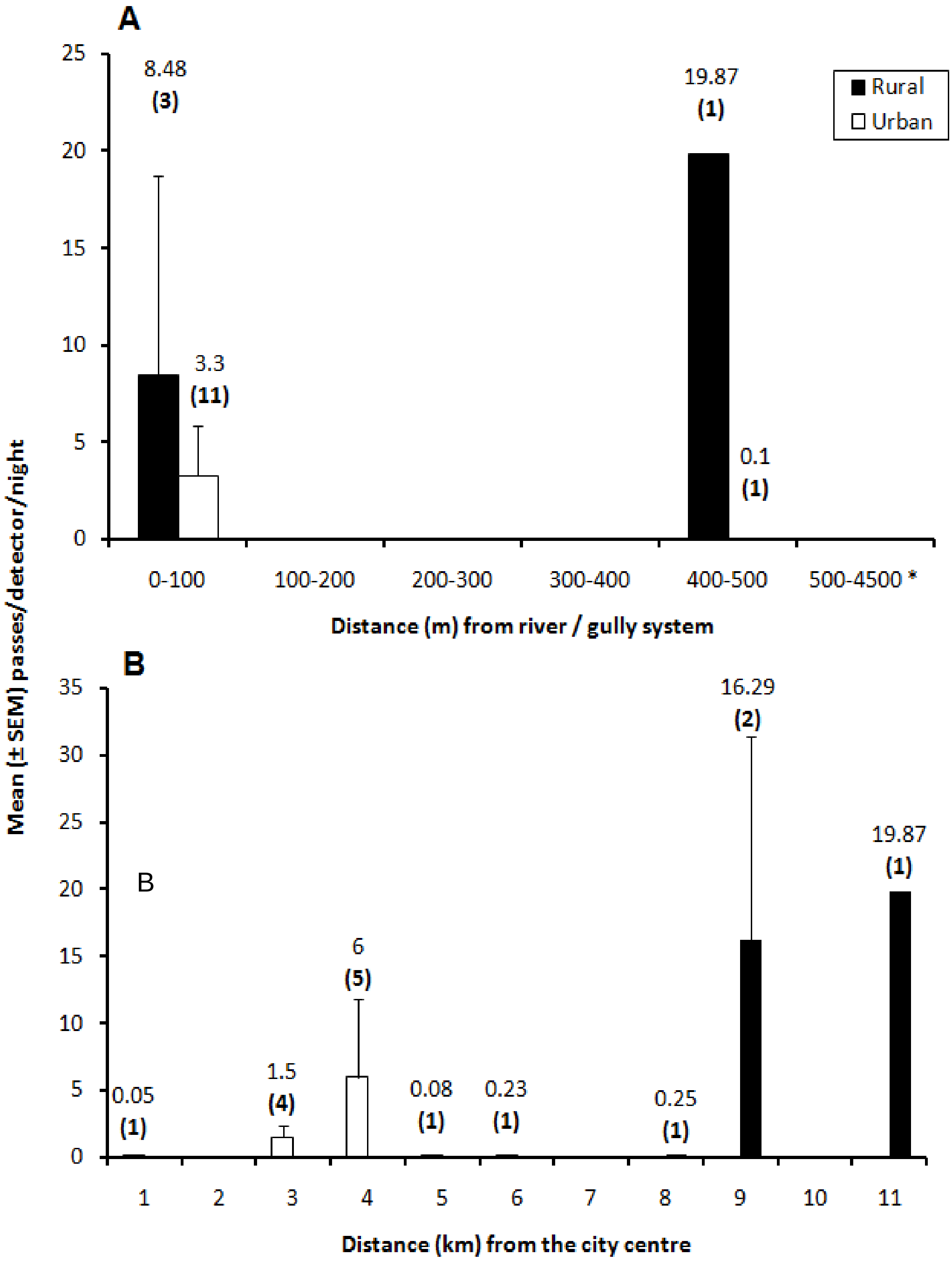

Figure 3 **Mean passes (± SEM) /detector/night for rural and urban habitats with confirmed bat activity considering the distance (m) of sites to the Waikato River or the nearest major gully system (A) and the distance (km) of sites to the city centre (B). Mean values for each site are displayed above error bars and the number of sites at each distance is presented in brackets (note: * on x-axis in Figure 3A indicates a change in scale, as bats were not detected at >500m).**

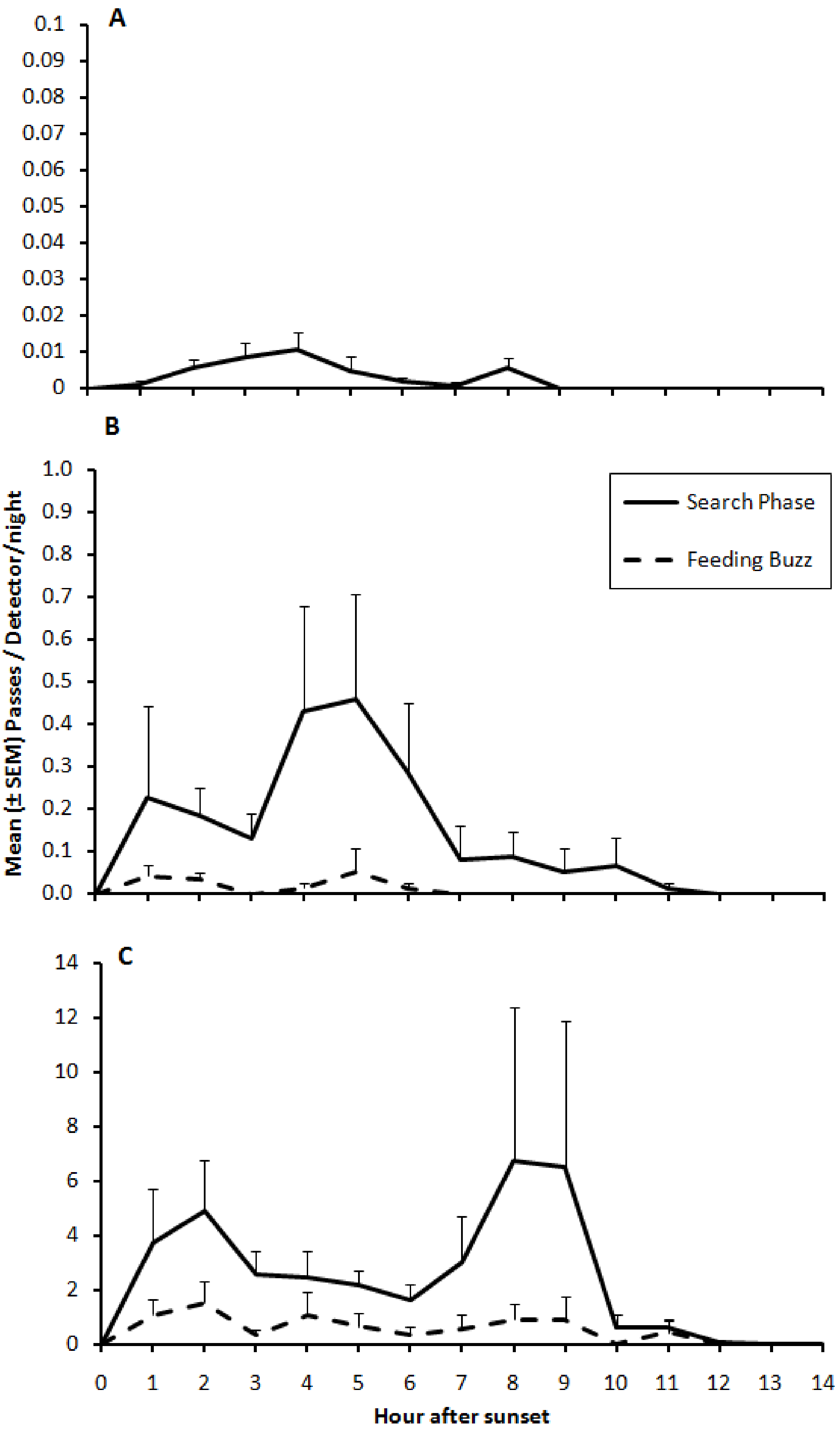

Figure 4 **Mean passes (± SEM) /detector /night for each hour after sunset for habitats categorised as commuting (A), foraging and possible periodic roosting (B); and foraging and likely regular roosting (C; note: y-axes scales vary)**

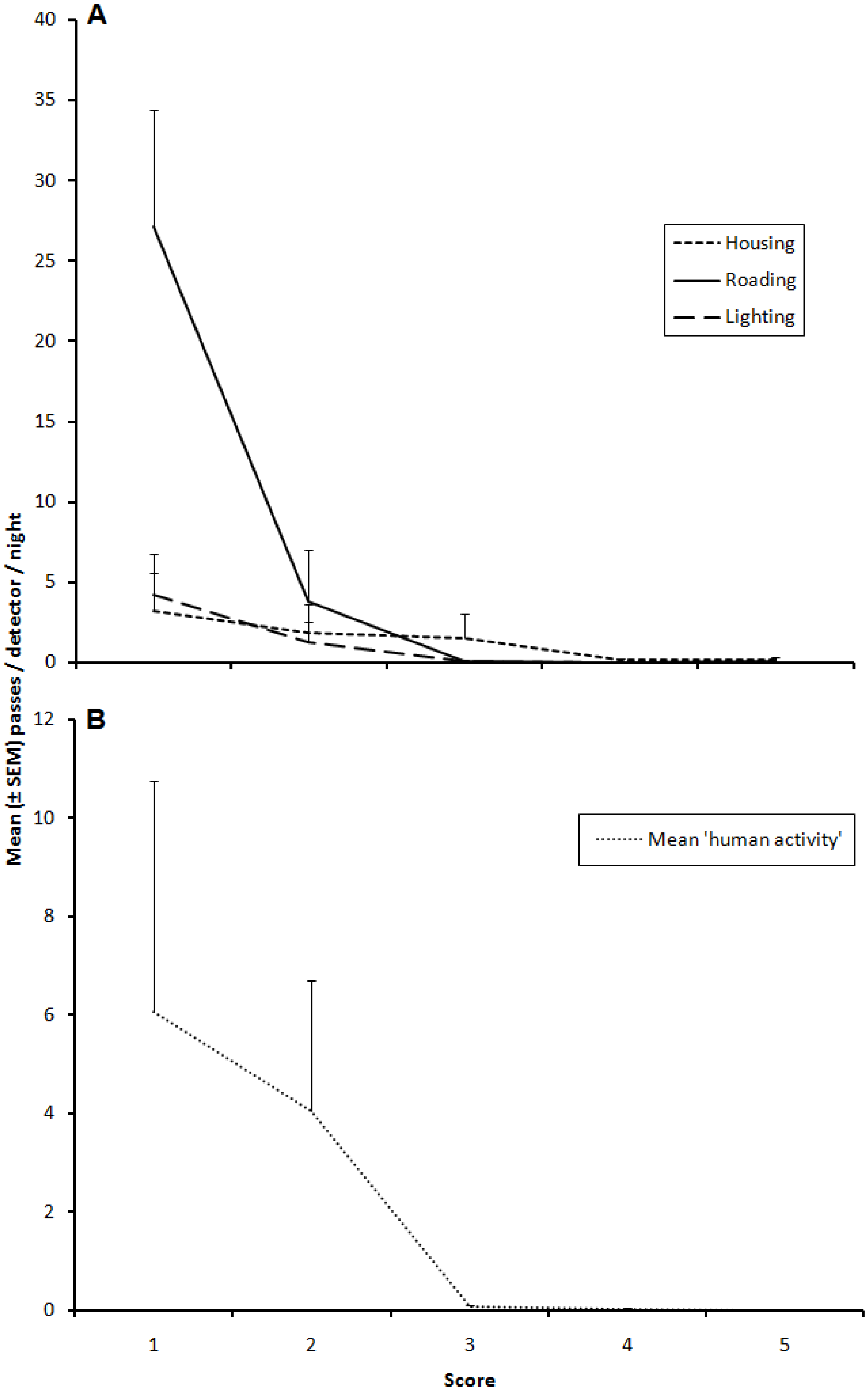

Figure 5 **Mean passes (± SEM) /detector /night for each score (1-5) allocated for all three anthropogenic variables (A) as well as the mean 'human activity' score (B). All 62 surveyed sites are considered.**

Table 2 **Summary of the survey effort allocated to the four major habitat types along with corresponding mean passes/detector/night and rank means (bootstrap one-way ANOVA) for sites with bats. Habitat types with the same superscript letter above rank means do not have significantly (*P* > 0.05) different levels of bat activity.**

Habitat type	# sites surveyed (% total)	Area (ha) surveyed (% total)	# detectors allocated (% total)	# sites with bats (% totals)	Mean (±SEM) passes/detector /night (rank means ± StDev)*
Major gullies	16 (25.81%)	114.1 (18.17%)	77 (30.31%)	7 (43.75%)	0.66 ± 0.35 (6.72 ± 3.37) [a]
Riparian margins	19 (30.64%)	184.1 (29.28%)	72 (28.35%)	7 (43.75%)	10.92 ± 5.09 (7.79 ± 4.33) [a]
Urban parklands	24 (38.71%)	311 (49.51%)	94 (37.01%)	1 (6.25%)	0.09 ± 0.06 (4.83 ± 2.48) [a]
Native forest remnants	3 (4.84%)	19.1 (3.04%)	11 (4.33%)	1 (6.25%)	19.67 ± 14.99 (12.97± 0.93) [b]
Total	**62**	**628.41**	**254**	**16**	

4 Discussion, Conclusions & Management Recommendations

As far as we are aware this is the most comprehensive acoustic bat survey undertaken to date in any New Zealand city. Presence/absence survey results revealed that the lesser short-tailed bat was not detected at any of the 62 sites surveyed in this study. This supports the assumption that this species is locally extinct in Hamilton City. This was anticipated as this species is critically endangered with a current known distribution limited only to a few managed mature indigenous forest reserves and predator free offshore islands (O' Donnell *et al.*, 2010).

Long-tailed bats, the more widespread of the two native bat species found in New Zealand, were confirmed at 16 of the 62 sites surveyed. Long-tailed bat activity is thus confined to a relatively small number of sites with a distribution pattern restricted to the southern most urban-rural fringe of the city. This result is consistent with previous studies (Dekrout, 2009; Le Roux, 2010). The distribution pattern of bats in Hamilton City is likely to be partially explained by the presence of the most well connected ecotone in the southern urban-rural landscape, which is made up of the two largest gully systems (Mangaonua and Mangakotukutuku) that feed into the Waikato River and its associated riparian margins. Indeed, 14 (87.5%) of the confirmed bat habitats were classified as riparian margins or major gullies (7 sites or 43.75% for each) within 0-100 m of the Waikato River. The Waikato River is a major habitat connecting landscape feature which long-tailed bats are known to use as a corridor to move between habitats (Dekrout, 2009). This explains why habitat connectivity or distance to the Waikato River/major gullies emerged as the single most significant explanatory variable in our statistical model. This also explains the interaction between habitat type and distance to the river/gullies. Riparian margins, with dense native and exotic trees and shrubs associated with riverine and gully landscapes appear to be critical habitat, as individuals depend on access to key resources associated with these environments. In particular these habitats provide:

1) mature exotic and native vegetation for roosting purposes;

2) emergent aquatic insect prey (e.g. mosquitoes) for foraging;

3) freshwater for drinking; and

4) linear landscape corridors for movement and navigation, are most important to tree-dwelling aerial insectivorous species (Verboom *et al.*, 1999; Fukui *et al.*, 2006; Borkin & Parsons, 2011).

Access to key resources (e.g. roosting sites) by bats in a highly modified landscape may be further constrained by human activities (Borkin & Parsons, 2011; Threlfall *et al.*, 2012). Our results highlighted this, as bat activity significantly decreased with increasing distances to the city centre and habitats with the lowest scores for roading, housing and street lighting density had the highest bat activity. The effect of anthropogenic variables on bat activity is the most plausible explanation for why long-tailed bats do not utilise available foraging (Waikato River margins) and potential urban indigenous forest roosting habitats (e.g. Jubilee Park/Te papa Nui - also known as Claudelands Bush) extending north into the city. This is despite individuals being renowned for maintaining large home ranges and capable of sophisticated navigation (O' Donnell, 2005). In fact, just 3 passes, or 0.1%, of bat activity were recorded downstream of Cobham Bridge – the first major well lit road crossing along the Waikato River corridor. These findings are consistent with a previous hand-held detector survey undertaken throughout Hamilton City in 2006-7 (Dekrout, 2009) and explains our statistical interactions between 'habitat type' and 'human activity'. This conclusion is also supported by previous radio-tracking undertaken in Hamilton, which showed that although some individuals maintained large home ranges extending out into the rural landscape (mean 338 ha; range 0.8 to 7.3 km), most of their activity was concentrated within small core areas, with high roost fidelity (Dekrout, 2009). This is in contrast to bat use of unmodified native forests where long-tailed bat home ranges may be 1000's of hectares in size with roost switching occurring on average every 1.8 days (O' Donnell, 2001). It is not surprising then that individuals would concentrate their nightly activity, and thus optimise energetic expenditure, at a few core habitats where key resources are abundant and disturbance variables are lowest. This is common behaviour for many insectivorous bat species, particularly females that have higher thermoregulatory demands overall (e.g. Borkin & Parsons, 2011; Sedgeley, 2001; Safi *et al.*, 2007).

Recent research findings have highlighted the sensitivity of some echolocating bat species to anthropogenic variables. Stone *et al.*, (2008) experimentally demonstrated that lesser horseshoe bats (*Rhinolophus hipposideros*) in the UK significantly reduced their commuting activity during high-light treatments compared with controls with no evidence of habituation. Kerth and Melber (2008) showed that Bechstein's bats (*Myotis bechsteinii*) were reluctant to cross a major state highway in Germany and Schaub *et al.*, (2008) demonstrated that greater mouse-eared bats (*Myotis myotis*) avoided foraging in high vehicle noise environments. Our results suggest that the restricted use of the urban landscape by long-tailed bats is partly explained by 'barrier effects' due to anthropogenic factors including roads, bridges and artificial lights. Across all habitats bat activity was highest at those sites with the lowest levels of street lighting, roading and housing density. Even slight increases in the number of roads and street lights in particular, resulted in considerable decreases in bat pass rates. Once again this is consistent with results from a previous study that found a significant negative correlation between long-tailed bat activity in Hamilton and housing ($P = -0.863$) and streetlight density ($P = -0.961$; Dekrout, 2009). Studies further afield have also found similar trends for urban sensitive insectivorous bat species (e.g. Threfall *et al.*, 2012).

A majority of the sites (62.5%) with bat activity in this study had very low pass rates with infrequent nightly use. Most of these sites included riparian margins and gully systems. Only six (37.5%) sites had any foraging activity at all. These same six sites (Whewell's Bush, Hammond Bush[2], Meridian 37 oaks, Hamilton Cemetery, Sandford Park, and The Narrow's Golf Course) also had corresponding nightly activity patterns (i.e. bimodal peaks in activity) indicative of possible and likely roosting behaviour and likely support either singular and/or communal roosts. Sites with the most pronounced patterns of biomodality and the highest pass rates included just three habitats or only 3% of the total sites surveyed. All three of these habitats (Whewell's Bush, Hammond Bush, Meridian 37 oaks) also support the highest concentrations of mature native and/or exotic vegetation which long-tailed bats are known to depend on for diurnal and nocturnal roosting, rearing young and breeding. Only two of these six sites are situated

[2] The Hamilton City Council reserve formally known as Hammond Park

within the city's boundaries, highlighting that bat roosting and foraging behaviour is more concentrated in rural environments rather than within the city's boundaries.

Bat activity was consistently highest at a low number of rural sites compared with much lower activity recorded at a higher number of urban sites. The fact that more habitats with bats were found within the city is likely an artefact of our sampling effort as we concentrated surveys at urban 'green spaces' within the city boundaries. Moreover, a vast majority of these sites had extremely low activity. Significantly higher levels of activity were recorded at Whewell's Bush compared with all other habitat types. It is not surprising that the bat pass rate was highest at this site as this is the single largest (11.4 ha) mature native forest remnant within at least an 11 km radius of the city. This habitat also likely supports the highest concentration of hollow-bearing trees and thus roosting opportunities. Whewell's Bush also differs from other sites in that it is further (450 m) from the Waikato River and major gullies. It is inevitable that rural habitats situated further from the city centre have fewer anthropogenic variables, which in turn likely makes the rural landscape more permeable to bat movement. This would allow individuals to occupy rural habitats like Whewell's Bush, despite it being located further from core foraging and/or commuting linear landscape elements (e.g. Waikato River and gullies). It is becoming increasingly apparent that with more bat monitoring undertaken in the wider rural landscape, more rural indigenous forest fragments (exotic and native) are being identified as long-tailed bat habitats (e.g. Pukemokemoke Reserve, Maungatautari Reserve, Pirongia Forest Park).

It is important to note that a failure to detect bats at a site does not necessarily mean that bats are entirely absent from that site or that they will remain absent going into the future. Ongoing bat monitoring and future city-wide surveys will invariably continue to improve our understanding of long-tailed bat distribution and habitat use patterns in Hamilton. Results from this survey should be used as a baseline data set to compare changes in bat distribution and habitat use patterns over longer time periods. Further experimental research is also needed to better elucidate the effect of light and roads on bat behaviour, which will enable more targeted mitigation and management measures to be formulated.

Given that long-tailed bat populations are likely under additional pressure due to predation (Pryde *et al.*, 2005) and competition by introduced species for roost sites (O'Donnell, 2000), further restriction of access to core habitats and disturbance/destruction of roosts through urban expansion is likely to exacerbate population declines.

Results from this study have allowed us to develop three key strategic bat management and conservation recommendations for Hamilton. These recommendations should better inform and guide conservation planning and impact assessment and should not be viewed as being mutually exclusive (i.e. all recommendations and actions should be considered equally and collectively). They are:

1) Maintaining and perpetuating habitat connectivity: Our results emphasise the importance of well-connected habitat corridors and linear landscape features for long-tailed bats, with bat activity concentrated at sites 0-100 m from the Waikato River and major gullies along the southern urban-rural interface only. Enhancing and restoring habitat connections will likely facilitate bat movement into adjacent habitats and maintain existing habitat usage and commuting corridors. This might involve the following actions:

- Ongoing gully restoration and enhancement;
- Ongoing riparian restoration and enhancement;
- Establishing appropriate buffer zones to retain gully and riparian values; and
- Maintain linear landscape features and vegetation complexity (e.g. hedgerows and vegetation diversity)

2) Protecting existing bat habitats: The restricted site occupancy of bats in Hamilton underscores the importance of protecting habitats currently used by bats, particularly those supporting foraging and roosting resources. This might involve the following actions at existing bat habitats:

- Long-term legal protection (e.g. Reserve Act or QEII open space covenants) of existing habitats;
- Mature native and exotic vegetation retention (possible existing bat roosts);

- Young native and exotic vegetation retention (possible future bat roosts);
- Active re-vegetation initiatives;
- Pest management;
- Artificial roost provision (bat boxes);
- Bat monitoring incorporated as part of land use and subdivision consent conditions, in order to measure long-term and cumulative effects of developments and the effectiveness of associated mitigation measures; and
- Offsets required if identified on-site threats to long-tailed bats cannot be avoided or sufficiently mitigated.

3) Reducing the effect of anthropogenic factors: Human variables, such as roads and artificial lighting, likely contribute to the restricted use of the urban landscape by long-tailed bats. Although this species is somewhat tolerant of human disturbances, given that it is found within the city's boundaries, our results suggest that long-tailed bats remain relatively sensitive to human activities. We would argue that a complacent approach to urban development could result in further bat distribution and habitat use restrictions, particularly if subdivision and roading infrastructure development increases within the peri-urban and residential rural landscape south of Hamilton. Instead we urge that a 'green infrastructure' approach be incorporated in urban planning that focuses on reducing 'barrier effects' by making the urban landscape more permeable to bat movement. This might involve the following actions:

- Bridge and major arterial roading locations should be carefully considered and reviewed, following further research on bat disturbance, to prevent barriers to bat movement and habitat use;
- Low impact residential lighting regimes (e.g. installing fewer more directional lights);
- Low impact road and bridge lighting regimes;
- Retain and enhance residential and roadside tree cover; and
- Enhance vegetation connections between riparian/gully habitats and urban 'green spaces' (e.g. parklands).

Major growth cells for Hamilton city are currently focused on the southern urban-rural interface with several major roading and housing developments proposed for the short to mid-term future (e.g. Floyd & Dekrout, 2009). This study underscores the importance of making the urban landscape (both present and future) more permeable to long-tailed bats as well as protecting and enhancing existing, well-connected bat habitats. Major collective conservation decision-making by key stakeholders, as well as the implementation of multiple adaptive management strategies, is likely needed if long-tailed bats are to be retained in Hamilton City in the face of urban expansion.

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6 Acknowledgments

We especially wish to thank the Kessels & Associates team – notably, Derek Christie, Hannah Mueller, Ryan Clark, Britta Deichmann, Mahuru Robb and Gerry Kessels for field assistance, equipment provision, review and statistical analyses. We thank Gerard Kelly of the Waikato Tree Trust for assistance with funding applications and in-kind logistical services. We also thank The Department of Conservation, Waikato Regional Council and the Hamilton City Council for generously lending automated bat detectors and other essential resources. For review of the report and of the survey methods we thank Associate Professor Stuart Parsons of Auckland University.

This research was funded by the Hamilton City Council (Enviro Fund, Waikato Tree Trust), Waikato Regional Council, Trust Waikato, Waikato University (CBER) and Kessels & Associates, Ltd.

7 Appendix I

Table 3 Summary table detailing key characteristics of all the 62 'green spaces' surveyed.

Site name	Habitat	R/U	Area	Time	Use	Bats?	# ABM	Active ABM	House	Road	Light	Connectivity	City Centre	Search	Feed	Calls	Calls/ABM/night
Hamilton Gardens	R	U	17.2	Sept	C	Y	5	1	1	2	1	0-100	3000	10	0.00	10.0	0.4
Hamilton Cemetery	R	U	17.2	Sept	FPR	Y	5	4	1	2	1	0-100	3000	92	7.00	99.0	4.0
Hammond Bush	R	U	11.0	Sept	FRR	Y	9	6	3	2	1	0-100	4400	1234	76.00	1310.0	29.1
Humare Park	G	U	0.6	Sept	C	Y	1	1	5	2	3	0-100	4600	3	0.00	3.0	0.6
Mystery Creek Golf	R	R	30.0	Sept	FPR	Y	7	5	1	3	1	0-100	8900	36	5.00	41.0	1.2
Meridian 37	R	R	1.2	Jan	FRR	Y	2	2	2	1	2	0-100	8000	305	39.00	344.0	34.4
Whewells Bush	N	R	11.4	Sept	FRR	Y	3	3	1	1	1	400-500	10000	272	23.00	298.0	19.9
Fitzroy Park	G	U	5.4	Oct	C	Y	5	1	4	3	2	0-100	3800	3	0.00	3.0	0.1
Memorial Park	R	U	3.0	Nov	C	Y	4	1	2	3	2	0-100	800	1	0.00	1.0	0.1
Te Anua Park	G	U	5.8	Oct	C	Y	9	2	4	3	2	0-100	4200	5	0.00	5.0	0.1
Dillicar Park	R	U	1.6	Sept	C	Y	2	1	4	4	3	0-100	2400	2	0.00	2.0	0.2
Ta Ara Hou	G	U	2.0	Dec	C	Y	4	1	3	5	4	0-100	4800	1	0.00	1.0	0.1
Sandford Park	G	U	10.0	Nov	FPR	Y	9	5	4	3	2	0-100	3200	62	2.00	64.0	1.4
Resthills Park	P	U	16.0	Dec	C	Y	8	2	2	2	2	400-500	4800	3	0.00	3.0	0.1
Newstead School	G	R	2.0	Dec	C	Y	4	2	2	5	2	0-100	7100	4	1.00	5.0	0.3
Mangaonua Esp.	G	U	20.0	Dec	C	Y	8	5	2	4	1	0-100	5100	9	0.00	9.0	0.2
Hamilton Zoo	P	R	30.0	Sept	NA	N	10	0	1	2	1	4200-4300	6000	NA	NA	NA	NA
Chartwell Park	P	U	3.1	Sept	NA	N	3	0	4	4	3	300-400	4000	NA	NA	NA	NA
Claudeland's Bush	N	U	5.1	Sept	NA	N	6	0	3	4	3	1000-1100	1600	NA	NA	NA	NA
Hillary Park	G	U	2.2	Oct	NA	N	3	0	3	3	2	300-400	4000	NA	NA	NA	NA
Grosvenor Park	P	U	3.1	Oct	NA	N	1	0	5	4	3	1800-1900	6100	NA	NA	NA	NA
Eden Park	P	U	0.7	Oct	NA	N	1	0	5	3	5	1800-1900	6600	NA	NA	NA	NA
Lake Domain	P	U	92.0	Oct	NA	N	10	0	2	4	1	600-700	1600	NA	NA	NA	NA
Jesmond Park	R	U	1.3	Nov	NA	N	3	0	3	4	3	0-100	400	NA	NA	NA	NA
Pirana Park	R	U	1.5	Nov	NA	N	1	0	4	3	3	0-100	600	NA	NA	NA	NA
Soldiers Park	R	U	1.7	Nov	NA	N	2	0	2	3	3	0-100	1000	NA	NA	NA	NA
Hayes Paddock	R	U	2.7	Nov	NA	N	2	0	2	2	2	0-100	1400	NA	NA	NA	NA
Chelmsford Park	G	U	2.0	Nov	NA	N	3	0	3	2	3	2500-2600	4600	NA	NA	NA	NA
Hillcrest Park	P	U	6.5	Nov	NA	N	3	0	4	4	2	1000-1100	3800	NA	NA	NA	NA
Jansen Park	P	U	10.0	Nov	NA	N	2	0	3	5	2	1200-1300	4300	NA	NA	NA	NA
Waikato Museum	R	U	0.7	Nov	NA	N	2	0	3	3	4	0-100	700	NA	NA	NA	NA
Totara Park	N	U	2.6	Nov	NA	N	2	0	4	4	4	400-500	5000	NA	NA	NA	NA

Table 3 (continued) **Summary table detailing key characteristics of all the 62 'green spaces' surveyed.**

Site name	Habitat	R/U	Area	Time	Use	Bats?	# ABM	Active ABM	House	Road	Light	Connectivity	City Centre	Search	Feed	Calls	Calls/ABM/night
Steele Park	P	U	3.7	Dec	NA	N	2	0	4	4	3	200-300	1600	NA	NA	NA	NA
Melville Park	P	U	5.2	Nov	NA	N	2	0	2	4	3	100-200	2200	NA	NA	NA	NA
Yendell's Park	R	U	7.8	Nov	NA	N	3	0	1	5	2	0-100	2000	NA	NA	NA	NA
Grahams Park	P	U	4.2	Nov	NA	N	4	0	2	5	3	100-200	1800	NA	NA	NA	NA
Galloway Park	P	U	6.0	Nov	NA	N	2	0	3	4	2	1100-1200	2300	NA	NA	NA	NA
Flynn Park	P	U	5.9	Nov	NA	N	2	0	3	4	2	400-500	3000	NA	NA	NA	NA
Onukatara Park	G	U	5.4	Oct	NA	N	3	0	2	4	2	1400-1500	4500	NA	NA	NA	NA
Tauhara Park	G	U	20.0	Oct	NA	N	6	0	2	3	2	500-600	4900	NA	NA	NA	NA
Edgecumbe gully	G	U	3.8	Dec	NA	N	7	0	4	4	3	200-300	1900	NA	NA	NA	NA
Waikato University	P	U	19.0	Nov	NA	N	8	0	3	4	2	2200-2300	3200	NA	NA	NA	NA
Clyde Park	P	U	6.0	Nov	NA	N	2	0	2	4	2	1400-1500	2400	NA	NA	NA	NA
Hillcrest Stadium	P	U	10.0	Nov	NA	N	2	0	2	4	2	900-1000	2700	NA	NA	NA	NA
Lugton Park	P	U	4.3	Nov	NA	N	2	0	3	4	3	1300-1400	2300	NA	NA	NA	NA
Marist Park	P	U	6.0	Nov	NA	N	1	0	1	3	2	1500-1600	2100	NA	NA	NA	NA
Ruakura	P	U	20.0	Jan	NA	N	10	0	2	3	1	2300-2400	2800	NA	NA	NA	NA
Glenview Park	P	U	4.1	Nov	NA	N	2	0	3	3	3	1300-1400	2300	NA	NA	NA	NA
Mahoe Park	P	U	6.0	Dec	NA	N	3	0	3	3	2	2000-2100	3300	NA	NA	NA	NA
Flagstaff Park	P	U	4.8	Dec	NA	N	5	0	4	3	2	800-900	6000	NA	NA	NA	NA
Discovery Park	P	U	4.5	Dec	NA	N	3	0	4	3	2	800-900	6700	NA	NA	NA	NA
Miropiko Park	R	U	0.7	Oct	NA	N	1	0	5	3	5	0-100	900	NA	NA	NA	NA
Days Park	R	U	11.0	Oct	NA	N	4	0	2	3	2	0-100	3200	NA	NA	NA	NA
Donny Park	G	U	9.1	Oct	NA	N	2	0	3	3	1	600-700	3300	NA	NA	NA	NA
Fairfield Esp.	R	U	0.7	Jan	NA	N	1	0	3	3	4	0-100	1000	NA	NA	NA	NA
Sylvestor Esp.	R	U	2.1	Jan	NA	N	1	0	3	3	3	0-100	6400	NA	NA	NA	NA
Braithwaite Park	R	U	7.7	Jan	NA	N	4	0	2	2	2	0-100	5800	NA	NA	NA	NA
Forest Lake	P	U	40.0	Jan	NA	N	6	0	2	5	1	1700-1800	3300	NA	NA	NA	NA
Beetham Park	G	U	11.0	Dec	NA	N	2	0	3	4	2	600-700	1900	NA	NA	NA	NA
Magaiti Gully	G	U	10.0	Dec	NA	N	8	0	4	4	2	2100-2200	5600	NA	NA	NA	NA
A. J. Seeley gully	G	U	4.8	Jan	NA	N	3	0	3	3	2	600-700	1100	NA	NA	NA	NA
Horsham Downs Golf	R	R	25.0	Jan	NA	N	6	0	1	3	1	0-100	10000	NA	NA	NA	NA
St Andrews Golf	R	U	40.0	Jan	NA	N	8	0	2	3	1	0-100	4200	NA	NA	NA	NA

Possible nightly use:	**Habitat type:**
C = Commuting	**N** = Native
FPR = Foraging and possible periodic roosting	**R** = Riparian
FRR = Foraging and likely regular roosting	**G** = Gully
Area = hectare	**P** = Parkland
R/U = Rural / Urban	
Connectivity = Distance (m) from gully system or Waikato River	
City centre = Distance (m) from city centre	

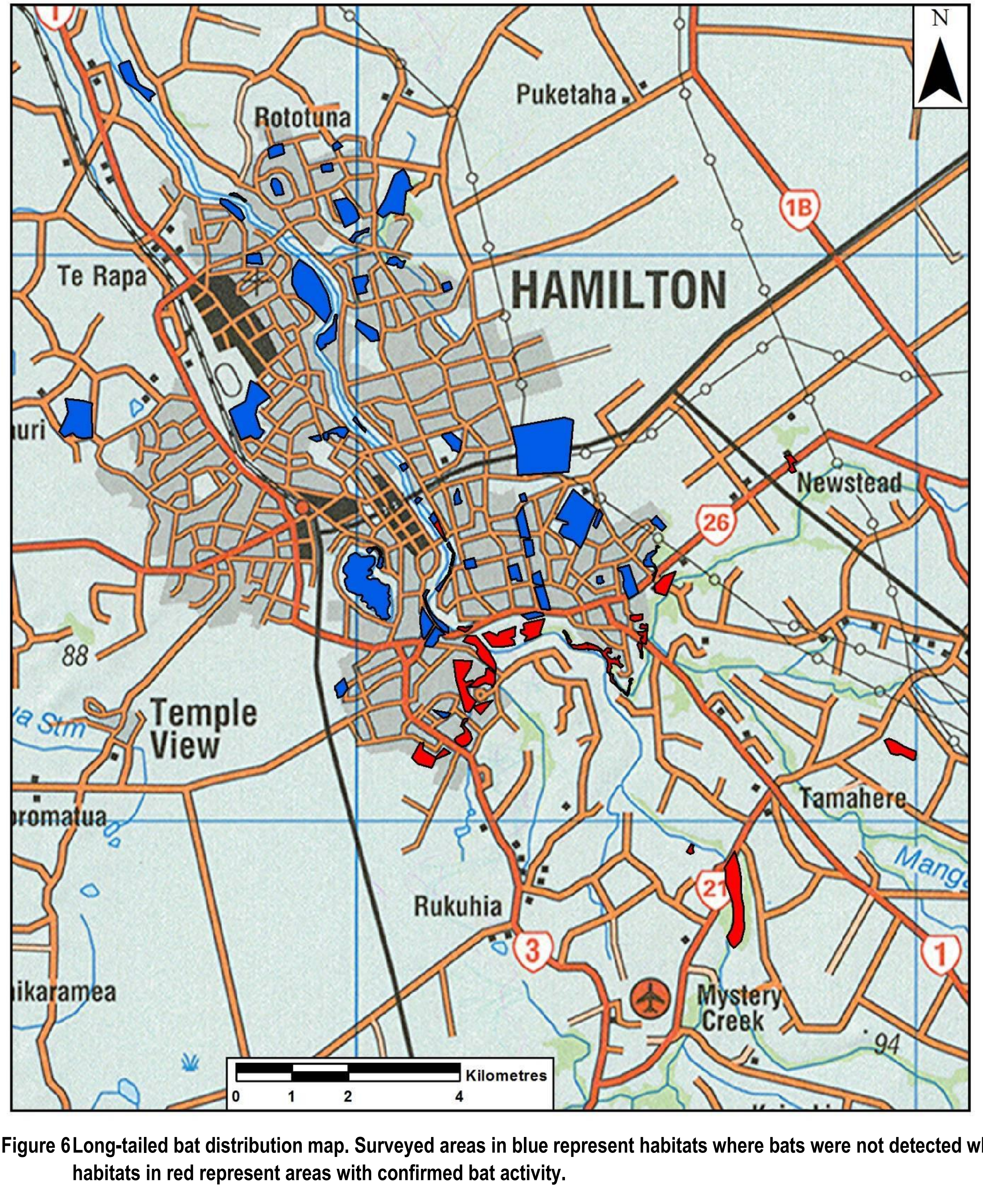
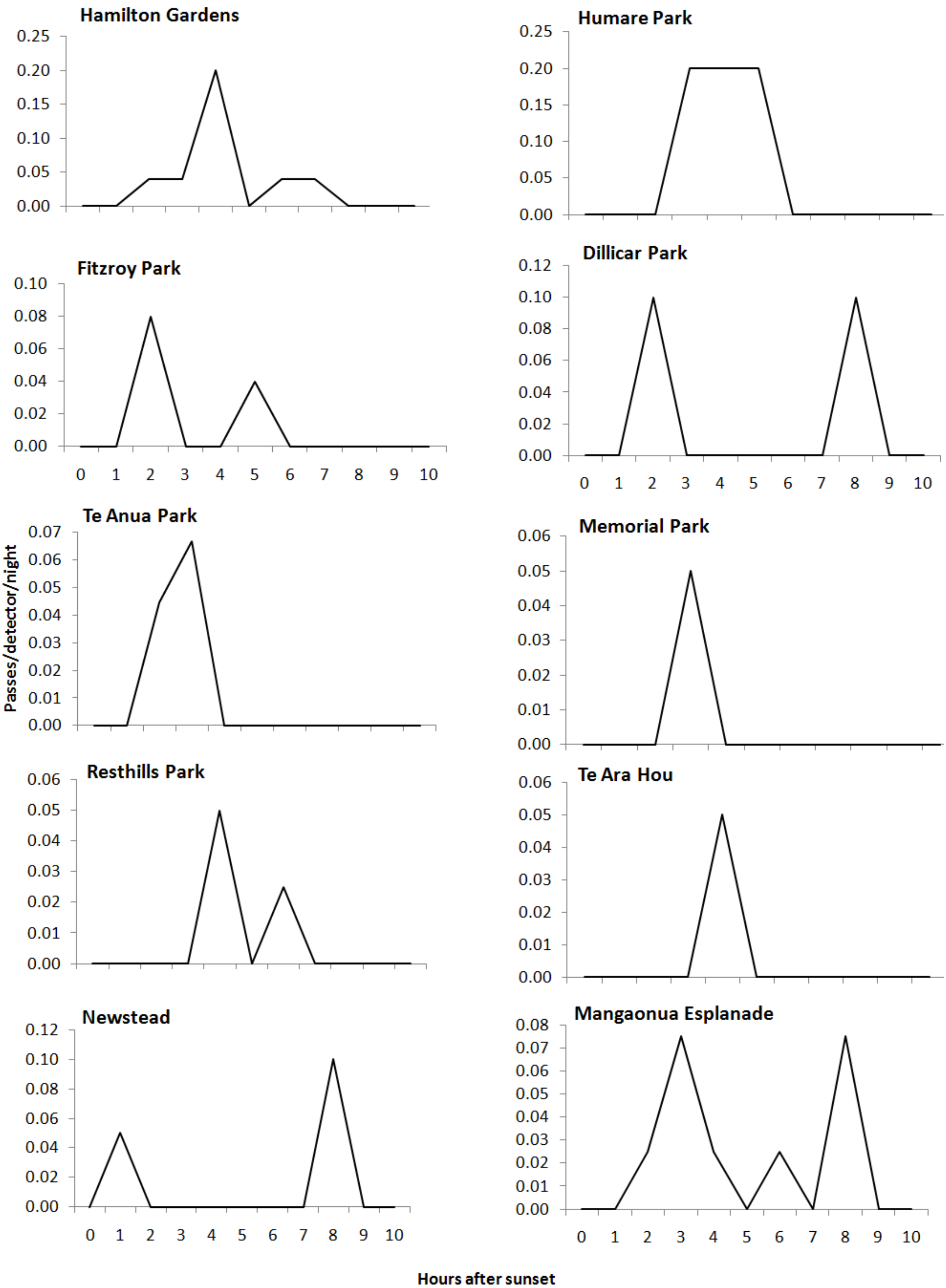


Figure 6 **Long-tailed bat distribution map. Surveyed areas in blue represent habitats where bats were not detected while habitats in red represent areas with confirmed bat activity.**


Hamilton Gardens
Humare Park
Fitzroy Park
Dillicar Park
Te Anua Park
Memorial Park
Resthills Park
Te Ara Hou
Newstead
Mangaonua Esplanade
Passes/detector/night
Hours after sunset

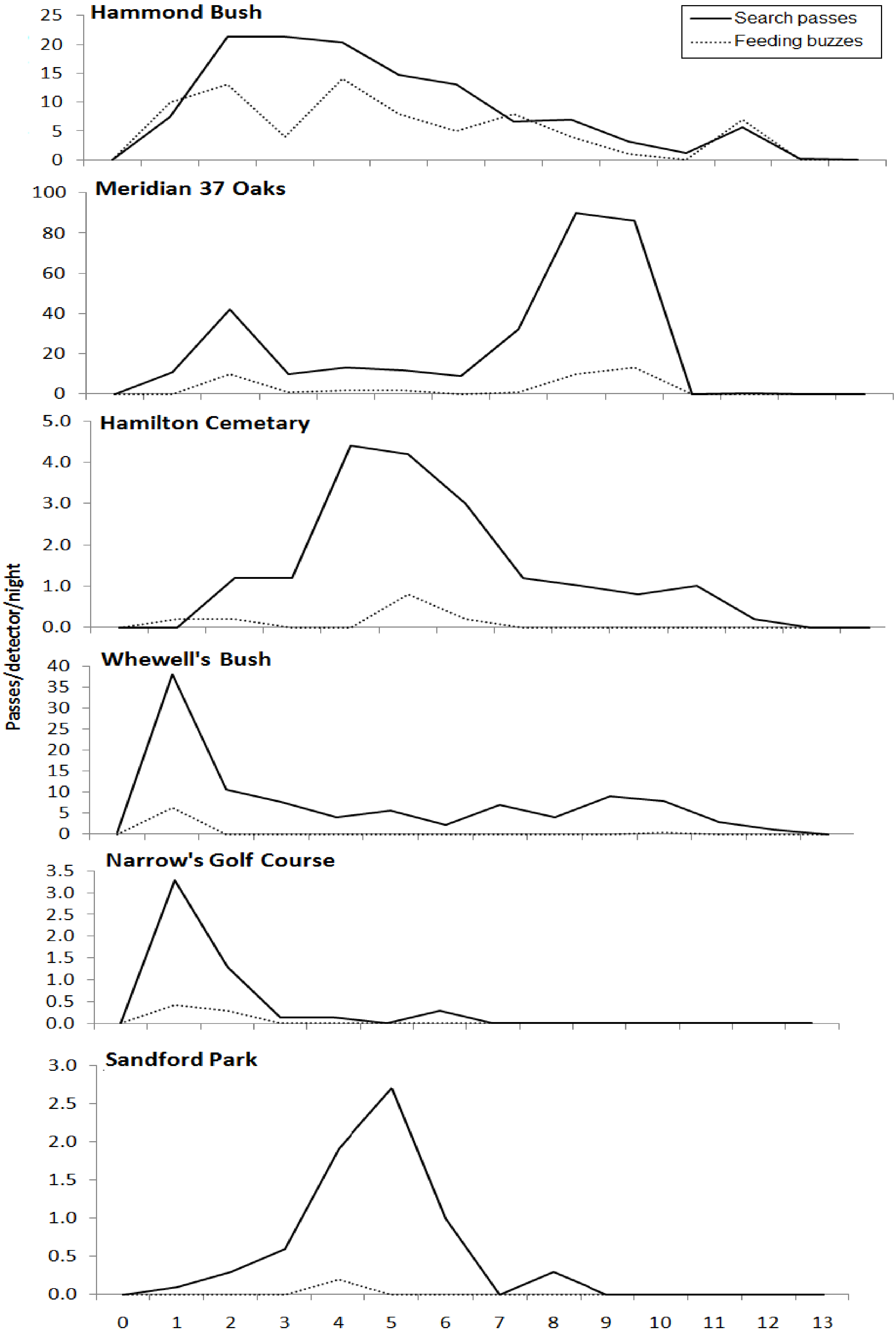


Figure 7 **Individual nightly activity patterns for all 16 sites with confirmed bat activity.**