

# **Chapter three – The home range, roost use and nocturnal activity of urban *Chalinolobus tuberculatus* in Hamilton New Zealand**

Landscape transformations through human expansions, such as urbanisation, progressively reduce bat habitats. Anthropogenic habitat fragmentation physically reduces natural habitats through processes such as deforestation, but also presents biota with aversive stimuli that are the by-products of high-density human settlement (Savard et al. 2000). Development often divides natural areas into isolated, disjointed patches or “islands” of habitat. While this is generally considered to have a negative effect on fauna, cities are sometimes able to provide habitats for populations of sensitive animal and plant species, even if they are becoming increasingly rare in the wider environment (Mazerolle and Villard 1999, Niemela 1999).

In the case of bats, it has been suggested that, due to the continued reduction of wild spaces, encouraging bats to use urban habitats has the potential to extend their range (Kunz and Pierson 1994). This is supported by a number of studies indicating that some species of bat flourish in patchy urban landscapes (Duchamp et al. 2004). Anthropogenic changes can sometimes produce more of the bats’ preferred habitats (Hogberg et al. 2002, Gorresen and Willig 2004). For example in the USA both *Eptesicus fuscus* and *Myotis lucifugus* frequently roost in the buildings of Chicago (Gehrt and Chelsvig 2003) and *Pipistrellus pipistrellus* are extremely abundant in London, England (Mickleburgh et al. 2002).

Few studies have been conducted on the responses of specific bat species to the urban environment or how urban bats may differ from their rural counterparts. Recent research has suggested that there may be subtle differences in the basic biology of bats in urban and rural areas. For example, Kervyn and Libois 2008 found the diet of urban *Eptesicus serotinus* was seasonally different from rural animals. No studies have compared home range, roost selection or nightly activity between urban and

non-urban bats. However, bat home ranges and activity generally have been found to strongly reflect ground-level habitat features (Meyer et al. 2005, Rhodes and Carferall 2008) and it is thus likely that urban bats would differ in their use of space and resources and in their behaviour from non-urban bats.

In New Zealand the long-tailed bat (*Chalinolobus tuberculatus*), is considered to be in decline (O'Donnell 2000) and listed as a “category B” threatened species (New Zealand Department of Conservation’s classification scheme). However, *C. tuberculatus* has been shown to exploit anthropogenically modified habitats such as rural agricultural areas, plantation pine forests (Borkin 1999, Sedgeley and O'Donnell 2004, Griffiths 2007) and, as documented in Chapter two of this thesis, they are present in Hammond bush and the southern river areas of Hamilton. Urban *C. tuberculatus* have not previously been studied, but differences have been found between the roost use and home ranges in *C. tuberculatus* which inhabit agricultural areas and those that inhabit less modified habitats (Sedgeley and O'Donnell 2004, Griffiths 2007). For example, *C. tuberculatus* in modified areas will often roost in exotic trees such as willows (*Salix fragilis*), macrocarpas (*Cupressus macrocarpa*) and pine trees (*Pinus radiata*) (Sedgeley and O'Donnell 2004, Griffiths 2007), while in the beech (*Nothofagus fusca* and *N. menziesii*, *N. solandri*) dominated forests of Fiordland, *C. tuberculatus* are closely associated only with native trees upwards of 100 years old (Department of Conservation 1997, O'Donnell and Sedgeley 1999). *C. tuberculatus* in modified areas also appear to have smaller home ranges, a maximum of 642 ha has been reported for *C. tuberculatus* in rural Canterbury habitats (Griffiths 2007), while home ranges upwards of 1589 ha are recorded for Fiordland bats (O'Donnell 2001). In Canterbury *C. tuberculatus* also have a stronger association with water habitats than that documented for *C. tuberculatus* in less modified areas (Sedgeley and O'Donnell 2004, Griffiths 2007). Internationally, urban bats such as *Tadarida australis* in metropolitan Brisbane, Australia, have also been found to be strongly associated with water or riparian habitats (Rhodes and Carferall 2008). This has largely been attributed to the presence of relic habitats with productive foraging sites and old growth trees, in these areas (Lloyd et al. 2006).

Nationally in New Zealand, habitat loss has been identified as the main cause of the decline in *C. tuberculatus* populations (King 2005). For this reason, all habitats where

*C. tuberculatus* persist can be considered important and should be managed for conservation. If *C. tuberculatus* are to be conserved within the urban habitats of Hamilton, information about their nightly activities and urban resource use is needed. In particular, day roosts, foraging areas and commuting corridors need to be identified to allow these critical habitat elements to be protected or even extended across the city. Further, elucidation of individual bats' time budgets, home ranges and use of space is necessary for predicting the potential effects of any developments on urban *C. tuberculatus*. The aim of this study was to use radio-telemetry to document the roost sites, home range and core areas of *C. tuberculatus* in Hamilton. It also aimed to describe the bats' nightly time budgets and to compare the results with those documented for *C. tuberculatus* in non-urban habitats.

## **Methods**

### **Study area**

The city of Hamilton is situated in the centre of the highly modified Hamilton Ecological District (159 376 ha) in the North Island of New Zealand (37° 48'S, 175° 18'E) (Clarkson and McQueen 2004). The city has a population of 122 000 and a land area of 9 400 ha (Hamilton City Council 2002). Within Hamilton's city limits the most extensive green spaces include a several gully systems, small lakes and the Waikato River which flows through the length of the city (total: 810 ha, including the river area) (Clarkson et al. 2002). Hamilton also contains a network of parks and playing fields dominated by exotic flora (8.6 ha).

One of Hamilton's most important remnant habitats is Hammond Bush, a 1 ha bush reserve found near the southern limits of the city (37° 48' 34.5"S, 175° 19' 19.5"E) (Figure 3.1). The park is botanically rich, supporting approximately 145 native plant species (DeLange 1996) and is home to a variety of native bird and insect species (Clarkson and McQueen 2004). The study described in Chapter two showed that Hammond Bush also represents the area with the most consistent records of *C. tuberculatus* in Hamilton. Thus, Hamilton's southern area and the surrounding agricultural lands up to 10 km from the city limits were the focus of this study. The limits of the study area were ultimately set by the ranges of the urban bats tracked in

this study. Areas inside the official city limits are considered within Hamilton and areas outside the official city limits are described as the surrounding rural areas.

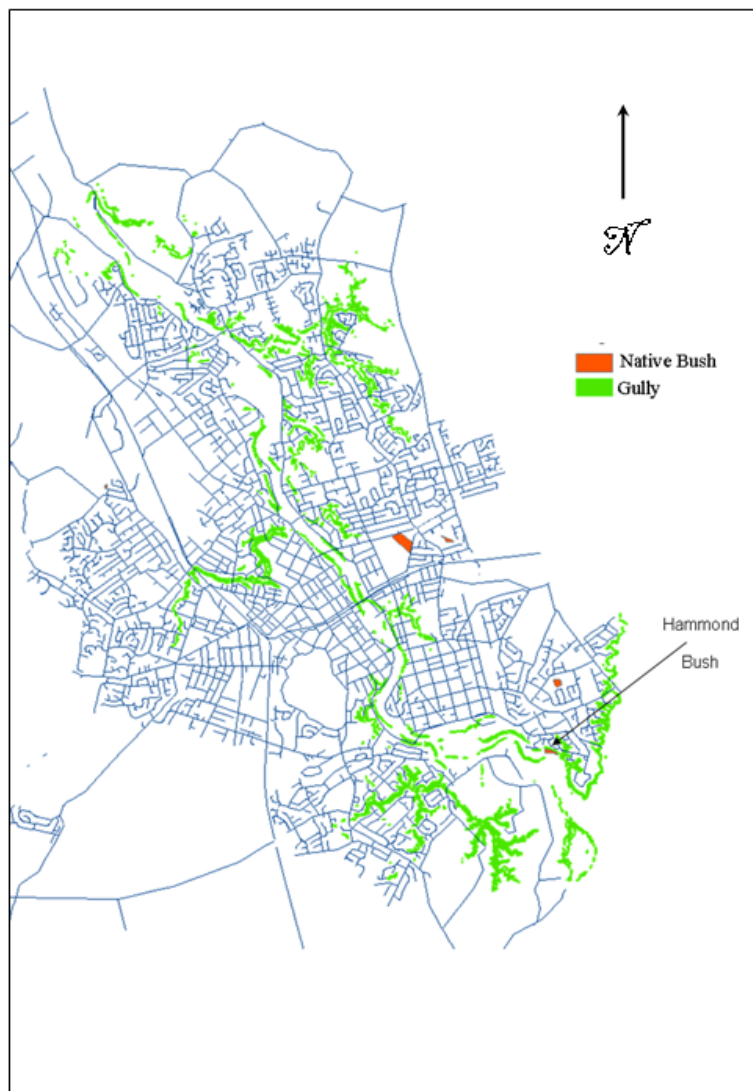


Figure 3.1 Map of Hamilton showing the location of Hammond Bush at the southern extreme of the city. See Figure 2.6 for major habitat types and city features.

### **Bat capture**

The radio-telemetry methods used in this study closely follow those used in other studies of *C. tuberculatus* (Sedgeley and O'Donnell 2004).

Bat trapping was conducted during the summer and autumn (November-May) between November 2004 and May 2007. Harp traps (Faunatec, USA) and/or stacked nylon mist nets (Faunatec, USA) were assembled in areas of Hammond Bush where

ultra-sound surveys suggested high levels of bat activity (Chapter two). Up to two harp traps (1.5 m wide by 3 m high) and three stacked mist nets (total area: 15 m long by 9 m high) were erected in any one area of high bat activity, including across paths and along bush edges. Trapping was conducted every dry night until a bat was caught.

On first capture, each bat had fitted a 2.8 mm, individually numbered, forearm band (The Mammal Society, UK). A number of morphometric and physical measurements were taken from captured bats including sex, mass, right forearm length and a qualitative ectoparasite score on a scale from 0 (no ectoparasites) to 5 (heavy infestation). The ectoparasite score was assigned by visually assessing the density of all ectoparasites on the bats' wings and body. The same observer assigned the ectoparasite score for all bats. The bats' reproductive status was also recorded and was assigned based on criteria used by O'Donnell 2002a. Reproductive females were defined as animals with large bare nipples and reproductive males were defined as animals with white, distended epididimides. Females without visible nipples and males with regressed epididimides were classed as non-reproductive.

### ***Radio-telemetry***

Animals of no less than 8 g were selected for radio-telemetry. Ados F-2 contact adhesive (3M, USA) was used to attach a radio-transmitter (Holohil Systems, Canada, LB-2, 0.48 g) to bats selected for telemetry. A small patch of hair was removed from the back of the bats, between the scapulas, to allow the transmitters to be fixed in place with the adhesive. The transmitter and adhesive together accounted for less than 6.5% of the body weight of the bats (8.25–12.00 g). An ATS scanning receiver (Model R2100, Advanced Telemetry Systems, Minnesota, USA) connected to a three element, hand-held, yagi antenna was used to track the bats. Individual bats were tracked one at a time such that a continuous tracking program could be adopted. Each bat was constantly tracked from the time of its release, until the signal was lost, the transmitter failed or approximately five nights of activity had been recorded and/or the home range was considered to be fully elucidated (where a plot of home range size vs. the number of recorded fixes had reached an asymptote). Plots of home range size vs. the number recorded points always reached an asymptote by the fifth track night. Each bat was only tracked once.

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*Range, habitat and roost use*

Pilot studies with stationary transmitters ( $n = 3$ ) were conducted to estimate the accuracy of radio-tracking fixes and to determine the correlation between signal strength and transmitter distance.

Each bat's location ( $\pm 15$  m) was recorded every 15 minutes to allow for the calculation of home ranges, core areas and habitat selection and the discovery of roost sites. Fixes were acquired using a "homing in" method (O'Donnell 2001): the observer approached a tagged bat as closely as possible and when the signal was very strong, a compass bearing and distance (based on signal strength) were recorded. However, if the bat was stationary (roosting), its exact location ( $\pm 3$  m) was recorded using a hand-held GPS unit (Garmin Etrex, Garmin International Ltd).

All the tracked bats' day roosts were identified and fully described. The tree species, height (measured with a clinometer) and breast height diameter (measured with a diameter tape) were recorded. The area immediately around the roost site was described with regard to habitat type (gully, forest or specimen trees in an open area), canopy cover (estimated % based on visual assessment), slope (measured with a clinometer), distance from the Waikato River and distance from built structures and roads (as calculated from a S14 New Zealand topographical map at the 1:250 scale, Land Information New Zealand). The dominant plant species in the canopy, sub-canopy and under story were also recorded. Large bushes and trees were identified to species and the under story was classified as either predominantly native ferns or broad leaf exotics. The specific roost cavities were identified and their height (measured with a clinometer) and cavity type (knot hole, hollow trunk, split bark or peeling bark) were described. Roosts were inspected visually at times when bats were exiting to determine if they were solitary or communal roosts.

*Activity*

The second type of data recorded was focal animal behaviour data. Recorded behaviours included commuting, foraging, night-roosting and day-roosting. These categories were similar to those used by O'Donnell (2001) with the exception that O'Donnell considered commuting and foraging as a single category. Commuting was considered to be rapid uni-directional movements between two areas. If a bat was

found to be flying in multiple directions within a restricted area it was considered to be foraging and when the bat was stationary it was considered to be roosting (either day-roosting or night-roosting). Commuting, foraging and roosting times were recorded continuously, from the time of first day roost exit to the final day roost entrance, for each bat for at least one complete night to calculate the bats' time budgets.

## ***Analysis***

### ***Home-range, core area and overlap***

Home-range and habitat selection was analysed for each bat using the Ranges VI software (Kenward et al. 2003). Total home-ranges were described by plotting the 95%, 99% and 100% minimum convex polygons (MCPs) calculated using the bats' quarter-hourly positions (O'Donnell 2001, Griffiths 2007). Only 95% MPCs were used in analyses as 95%, 99% and 100% were the same to within 0.01 m<sup>2</sup>. Core use areas were identified using the kernel polygon method. The 50% isopleths were used to describe the core area for all bats (Griffiths 2007). These were calculated using a fixed reference smoothing parameter (hRef) of 0.33. The hRef of 0.33 was identified as the optimal hRef by taking the mean of the hRefs calculated for each bat by least squares cross validation (Worton 1989). Quarter-hourly positions were also used to calculate the bats' flight speeds based on net interlocation displacement.

Ranges VI was used to calculate the spatial overlap in the ranges of individual bats. Overlap was calculated for MCPs and core areas. Additionally, for pairs of bats who's core areas overlapped, Jacob's cohesion index (Jacobs 1974) was calculated (using locations recorded at the same time with respect to sunset) to determine if there was any temporal segregation between bats. Jacobs's cohesion index ranges from 1.00 to -1.00, rising towards +1 if animals are often together and falling towards -1 if animals avoid each other. It is zero if animals are randomly associated.

Kolmogorov-Smirnov and Shapiro-Wilk's W test were used to test for normality and Spearman's correlation coefficient was used to describe the relationships between flight speed, roost locations and core area locations.

### *Habitat use*

The habitat types and their relative proportions (measured as % of total land area) present in the total study area and the bats' MCPs and core areas, were identified using the Geographic Information Systems (GIS) program Arcview 9, (ESRI, USA) with data provided by LandSat images and data sourced from Land Information New Zealand (LINZ, New Zealand Government database, New Zealand), Land Environments of New Zealand (LENZ, New Zealand Government database, New Zealand) and Land On Line (LOL, New Zealand Government database, New Zealand) data bases and Eagle Orthophotos (USA). In all cases the New Zealand S14 topographical map area was used. Six habitat types were identified. These included: built up areas (those whose area was primarily covered by housing or large buildings), urban parks, gullies (often containing or associated with small forest fragments), orchards/rotation crop land, pasture land and the river. The proportion of the study area represented by each habitat type was calculated as were the proportion of each habitat in the MCPs and core areas of each bat.

Kolmogorov-Smirnov and Shapiro-Wilk's W test were used to test for normality. Chi-squared was used to assess habitat selection and Wilcoxon matched pairs (Z) was used to compare between habitat proportions in MPCs and core areas.

### *Activity*

The bats' nightly time budgets were calculated based on a single, complete, track night for each bat, so as not to bias the results towards bats that were tracked for longer periods than others and because the locations were temporally dependant (White and Garrott 1990). Total time budgets were calculated as the total minutes allocated to commuting, foraging and night-roosting. Additionally, the number of occurrences of each behaviour (bouts) and the length of each behavioural bout was calculated. Finally, to determine how the bats allocated their time budgets over the course of each night, a 10 h period calculated from sunset was divided into 2-hour intervals and the total time allocated to each behaviour during the five intervals was calculated. Kolmogorov-Smirnov and Shapiro-Wilk's W test were used to test for normality and one-way ANOVA was used to compare the time allocated to each behaviour between the 2-hour intervals. Statistica (Statsoft, USA) was used for all analysis.



## **Results**

### ***Bat capture***

There were a total of 33 captures of 24 individual bats. Nine bats were recaptured once; no bats were recaptured more than once. There was a large capture bias towards males ( $n = 22$ ) and only one individual (male) was a juvenile. Only one male and one female bat were considered to be reproductively active at capture. On average, bats had very low ectoparasite scores and no bats were found to be highly infested. A total of 17 bats were fitted with radio transmitters. Of these, 6 bats were lost on the first night or the transmitters failed. Eleven bats were tracked successfully, 10 males (mean 7 nights per bat, range 5 – 19 nights) and one female (3 nights). Table 3.1 shows the capture date, sex, age class, reproductive status, weight, right forearm length, parasite load and radio-tracking record for each bat.

Table 3.1 Capture details and physical characteristics for captured *C. tuberculatus*.

Bat ID	Date dd.mm.yy	Sex (M/F)	Age Class (A/J)	Breeding (Y/N)	Weight (g)	Forearm (mm)	parasite index (1- 5)	tracked (Y/N)
1	01.11.04	M	A	N	12.20	39.90	0	Y
2	01.11.04	M	A	N	10.00	38.50	0	Y
3	08.02.05	M	A	N	8.60	38.80	2	Y
4	08.02.05	M	A	N	8.90	38.30	3	Y
5	01.03.05	M	J	N	6.75	39.80	3	N
6	01.03.05	M	A	Y	9.75	37.80	0	Y
7	18.04.05	M	A	N	8.25	38.00	2	Y
8	10.12.05	M	A	N	9.00	39.00	1	Y
9	11.12.05	M	A	N	8.50	38.14	0	Y
10	11.12.05	M	A	N	9.00	38.70	1	N
11	27.12.05	M	A	N	9.25	39.58	0	Y
12	10.01.06	M	A	N	9.00	38.45	3	Y
13	07.02.06	M	A	N	8.25	38.14	2	Y
14	17.02.06	M	A	N	9.00	38.70	1	N
15	03.11.06	F	A	Y	9.00	38.90	0.	Y
16	07.12.06	M	A	N	8.50	39.40	1	Y
17	07.12.06	M	A	N	9.00	38.50	0	N
18	12.12.06	M	A	N	9.50	39.30	0	N
19	15.12.06	M	A	N	9.00	36.46	1	N
20	24.01.07	M	A	N	9.75	38.26	2	N
21	24.01.07	M	A	N	9.50	40.08	0	N
22	25.01.07	M	A	N	10.00	39.64	0	N
23	05.02.07	M	A	N	9.00	38.06	0	Y
24	06.03.07	F	A	N	8.75	38.08	0	Y
Mean ± SE					9.10 ±0.19	38.69 ±0.17	0 0-3	Median range

### Day roosts

Day roosts were found in small forest groves within pasture and gully habitats (Tables 3.2 and 3.3). All bats showed a high fidelity for a limited number of day roosts. Nine bats used only one day roost over the tracking period (5 – 19 days). The remaining two bats used a secondary roost for one night only. Roost trees included eucalypts (*Eucalyptus spp.*), kahikatea (*Dacrycarpus dacrydioides*), pine (*Pinus radiata*),

grey willow (*Salix cinerea*), oak (*Quercus spp*), birch (*Betula spp*) and acacia (*Acacia spp*) trees. Day roosts were variable with respect to tree features, cavity features and habitat features. However, many roosts were found in dead trees or dead limbs (Table 3.3). Some roost trees were located within the city limits while others were located in small forest patches in the surrounding rural areas. All roosts found within the city limits appeared to be solitary, based on visual bat detection at exit times, though this may have underestimated the bat present (Chapter five). Three of the roosts in rural areas were found to be communal. Each of these trees had one radio tracked bat and between 12 and 30 additional bats that were seen at exit times. They were found in small, rural, old growth forest groves.

**Table 3.2 Site names and GPS locations, in New Zealand map grid, for 12 *C. tuberculatus* day roosts in the Hamilton area.**

Tree number	Site name	Easting	Northing
1	Balfour Crescent - Hammond Bush	2714887	6374531
2	Tamahere	2720540	6372547
3	Balfour Crescent - Hammond Bush	2714887	6374531
4	Hammond Bush	2714953	6374215
5	Tamahere	2720540	6372547
6	Trentham Rd orchard - Matangi	2719213	6377742
7	Gainsford Rd	2714198	6370036
8	Sandford Park river side	2712391	6374656
9	CTC aviation oaks	2715951	6371253
10	CTC aviation oaks	2715951	6371253
11	Sandford Park gully side	2712261	6374264
12	Narrows Bridge motor lodge	2716859	6370717

Table 3.3 Day roost trees, roosts cavities and surrounding landscape features. Roosts marked in bold were within the city those with \* were communal. Site numbers are based on the tree number. Note that roost trees include both native and exotic species but that most roosts are located in dead trees or limbs.

Tree number	Tree species	Common name	Tree condition	Tree height (m)	Breast height diameter (cm)	Trunk surface area (m <sup>2</sup> )	Trunk height (m)	Limb number	Cavity type	Cavity height (m)
1	Eucalyptus spp.	Gum tree	dead	7.1	18.5	4.1	6.0	4.0	peeled bark	5.9
2*	Dacrycarpus dacrydioides	Kahikatea	dead	12.2	34.0	13.0	12.2	0.0	hollow trunk	12.2
3	Eucalyptus spp.	Gum tree	dead	6.7	18.5	3.9	6.0	7.0	peeled bark	5.3
4	Pinus radiata	Pine	dead	7.5	26.5	6.2	7.5	6.0	peeled bark	4.7
5	Salix cinerea	Grey willow	dead	5.0	60.0	9.4	2.0	25.0	hollow trunk	2.0
6	Dacrycarpus dacrydioides	Kahikatea	dead	11.4	30.0	10.7	11.4	0.0	hollow trunk	11.4
7	Eucalyptus spp.	Gum tree	live/dead limb	11.6	34.5	12.6	6.0	19.0	peeled bark/dead limb	4.7
8*	Quercus spp.	Oak	live/dead limb	14.4	54.0	24.4	10.0	6.0	split bark/dead limb	8.8
9*	Quercus spp.	Oak	live	24.1	56.0	42.4	10.5	35.0	knot hole	17.4
10	Betula spp.	Birch	dead	6.4	15.5	3.1	6.4	0.0	peeled bark	4.4
11	Acacia spp.	Acacia	live	21.5	52.0	35.1	9.3	7.0	split bark	15.1
Mean ± SE				11.7 ± 1.7	36.1 ± 4.5	14.8 ± 3.6	8.2 ± 0.9	9.1 ± 3.3		8.7 ± 1.4
Roost site number	Site type	Ground slope (degrees)	canopy cover (%)	canopy species	sub-canopy	under-story	distance from housing (m)	distance from road (m)	distance from southern city (m)	distance from river (m)
1	gully edge	15	50	Gum tree	none	broad leaf exotics	30	50	0 (within city)	100
2	small forest grove	0	80	Kahikatea	none	none	15000	200	5900	6000
3	gully edge	15	50	Gum tree	none	broad leaf exotics	30	50	0 (within city)	100
4	gully edge	35	80	Pine/Gum	lemonwood	native ferns	30	20	0 (within city)	100
5	gully edge	30	60	Grey willow	none	native ferns	15000	200	5700	5500
6	small forest grove	0	80	Kahikatea	none	none	5000	500	4300	4000
7	gully edge	5	70	Gum tree	none	broad leaf exotics	60	50	0 (within city)	70
8	small forest grove	15	70	Oak	none	none	6000	200	3500	100
9	small forest grove	15	70	Oak	none	none	6000	200	3500	100
10	gully bottom	5	30	Pine/Gum	none	tree ferns	100	150	0 (within city)	500
11	five specimen trees	0	0	Acacia	none	none	50	30	4000	50
Mean ± SE		11 ± 3	60 ± 7				5192 ± 1843	154 ± 38	90 ± 40	1385 ± 671

### ***Home range, core area and overlap***

In terms of residency in the city, Hamilton *C. tuberculatus* fell broadly into two categories: 1) resident bats that stayed in the city during the entire tracking period and whose home ranges, core areas and roosts were within the city and 2) those that commuted between the city where they foraged and the surrounding rural area where they roosted. *C. tuberculatus* that commuted into the city, day roosted in rural areas and had core areas within the city.

The two different strategies for exploiting the city are reflected in the high variability of MCP sizes and shapes. MCPs ranged from 25.9 ha to 871.0 ha (mean 338.9 ha  $\pm$  87.5 SEM). Home range shapes were also variable and this is reflected in the large spread of spans, ranging from 0.8 km to 7.3 km (mean 3.9 km  $\pm$  0.7 SEM) (Figure 3.2). The home ranges of bats that commute into the city include the surrounding gully systems as bats follow these into the city, this gives the home ranges a long narrow shape, while the home ranges of resident *C. tuberculatus* were more round. Core areas were much smaller than MCPs, averaging 9.7 ha  $\pm$  2.9 and representing only 3.4%  $\pm$  0.6 of the bats' MCPs. The bats had between one and five nuclei within the MCP (Figure 3.3). Each bat's most distant core nuclei was between 0.4 and 7.3 km from the its primary day roost (mean = 3.1 km  $\pm$  0.8). Spearman's ranked correlation coefficient showed that MCP size was positively correlated with the distance between roost sites and most distant core nuclei ( $R_s = 0.669$   $P < 0.05$ ).

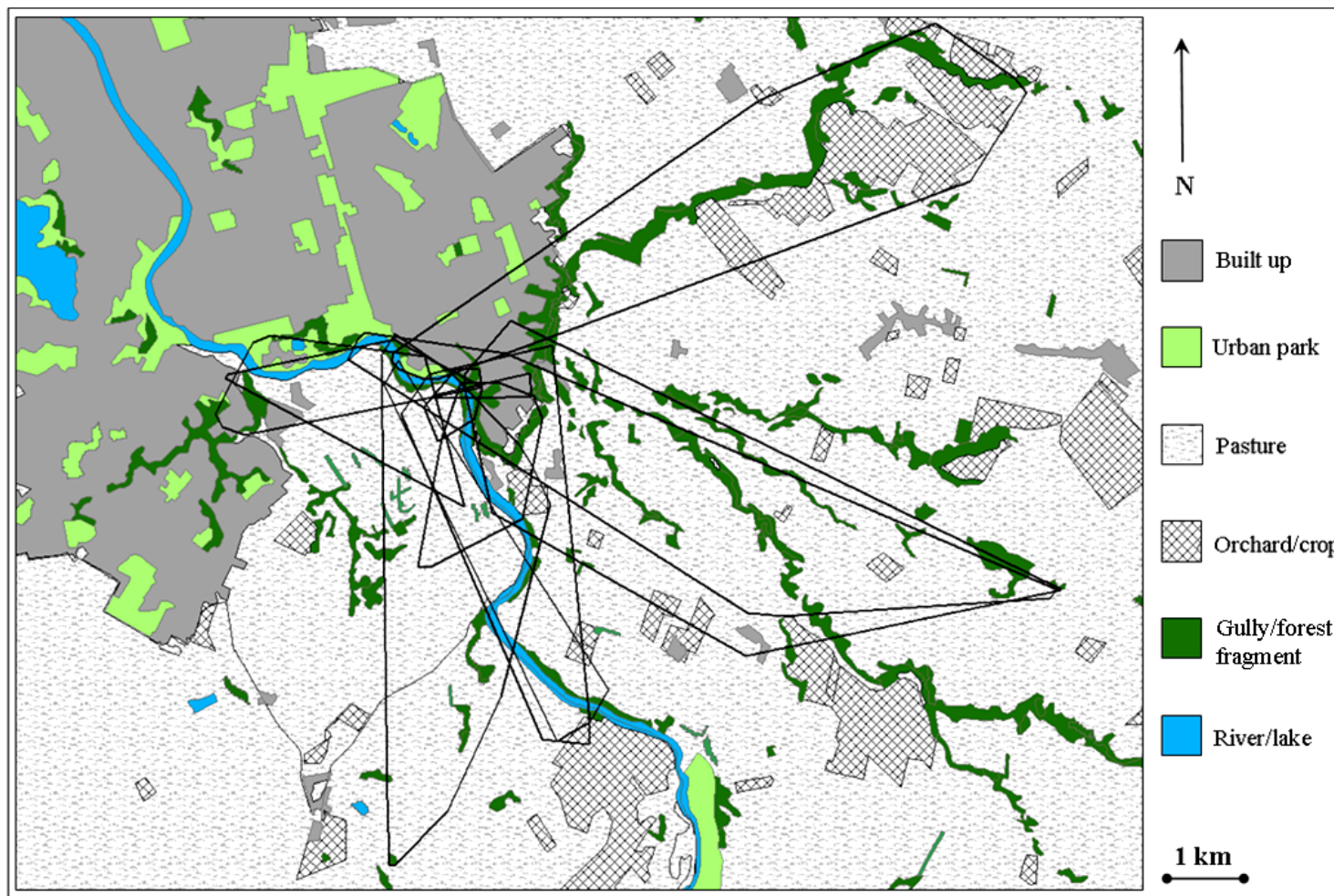


Figure 3.2 The study area and the home ranges (95% minimum convex polygons) of all eleven *C. tuberculatus* tracked. Major landscape features are indicated. The MCPs of individual bats are highly variable in shape and size and the Waikato River is present within all of the ranges.

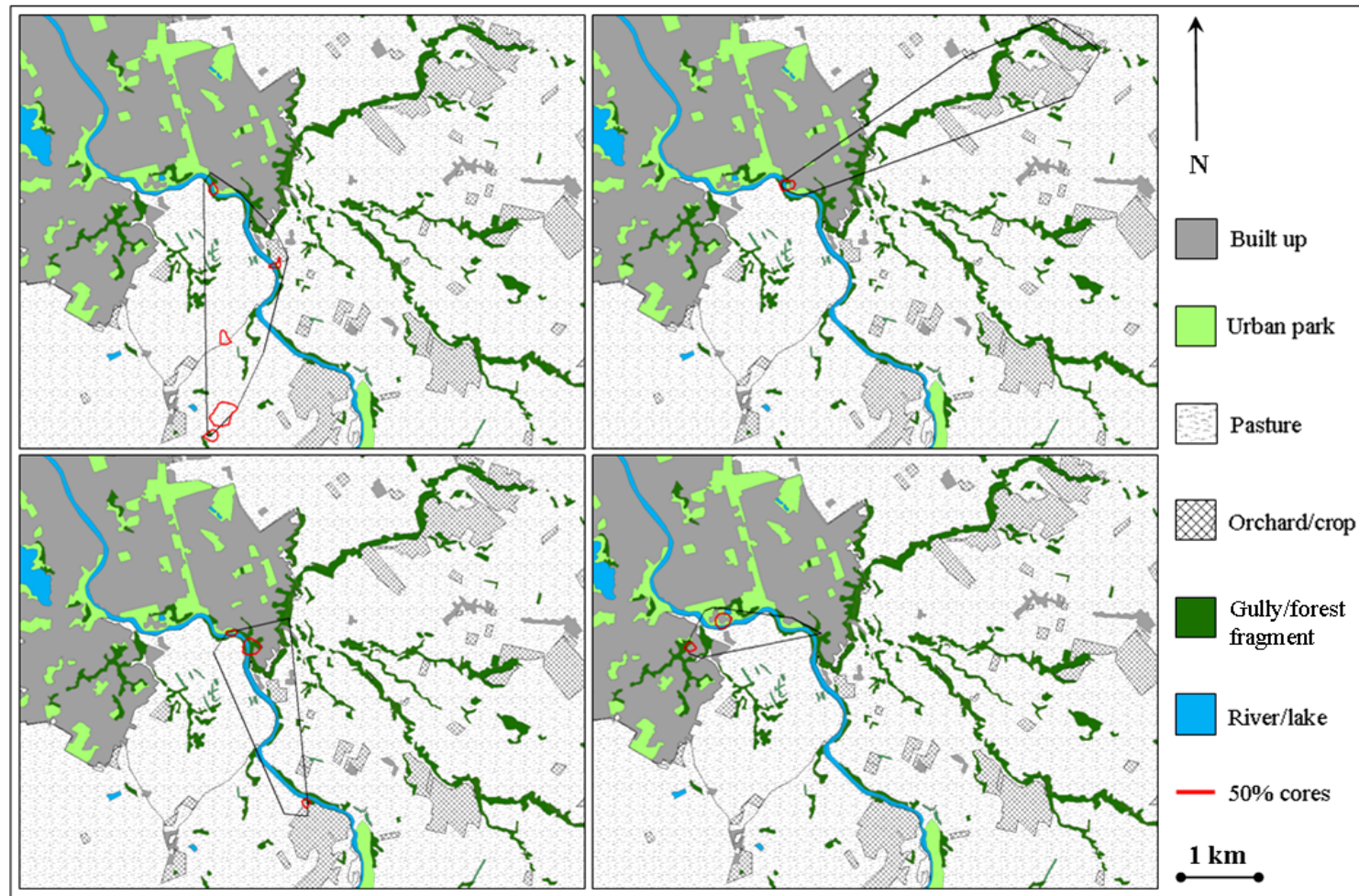


Figure 3.3 Four examples (animals 6, 8, 13 and 22) of *C. tuberculatus* home-ranges (95% minimum convex polygons) and their 50% core areas which are shown in red. Major landscape features are indicated. This figure illustrates that core areas are substantially smaller than MCPs and that some animals have multiple core nuclei while others have only one.



All individuals showed overlap in their MCPs with between 8 and 10 other individuals' MCPs. Nine bats had overlap in their core areas with between two and four other individuals. Mean MPC overlap was  $20.0 \pm 2.6\%$  and mean core area overlap was only  $6.9 \pm 1.5\%$ . However, when pairs of animals with 0% overlap were removed mean core area overlap rose to  $25.9 \pm 2.9\%$ . No significant temporal segregation could be seen between pairs of bats and associations are likely to be random (Jacob's cohesion index =  $0.00 \pm 0.01$ ).

### **Habitat use**

Chi-squared tests showed that the habitat proportions in all the bats' MCPs were different from expected proportions. Expected proportions are the available proportions of each habitat type based on the percent land area covered by each habitat type within the study site. Further, the habitat proportions in the bats' core areas were also different from expected proportions based on the habitat percentages within each bat's MCPs (Table 3.3).

Table 3.4 Chi-squared test results for observed versus expected habitat use for each tracked *C. tuberculatus* at the home range (95% minimum convex polygon) scale and within the home range at the 50% core area scale. The degree of freedom for all tests was six.

Bat ID	observe vs. expected habitat proportions in the total study area vs. MCPs		observe vs. expected habitat proportions in MCPs vs. core areas	
	$\chi^2$	<i>P</i>	$\chi^2$	<i>P</i>
5	205.42	< 0.001	125.00	< 0.001
6	50.33	< 0.001	293.57	< 0.001
7	45.93	< 0.001	353.33	< 0.001
8	21.65	< 0.001	71.67	< 0.001
9	40.08	< 0.001	205.00	< 0.001
11	440.00	< 0.001	475.00	< 0.001
12	41.18	< 0.001	242.86	< 0.001
13	51.11	< 0.001	282.81	< 0.001
15	31.82	< 0.001	567.50	< 0.001
16	50.34	< 0.001	293.57	< 0.001
24	20.13	0.002	356.67	< 0.001



Figure 3.4 shows the proportion of each habitat type available in the study area and the mean proportion of each habitat type represented in MCPs and core areas. Wilcoxon match pairs tests showed that pasture represented significantly less of the bats' core areas than in their MCPs ( $Z = 2.803$ ,  $P = 0.005$ ), while both river and gully habitats were significantly over-represented in core areas compared with MCPs ( $Z = 2.428$ ,  $P = 0.015$  and  $Z = 2.756$ ,  $P = 0.006$  respectively).

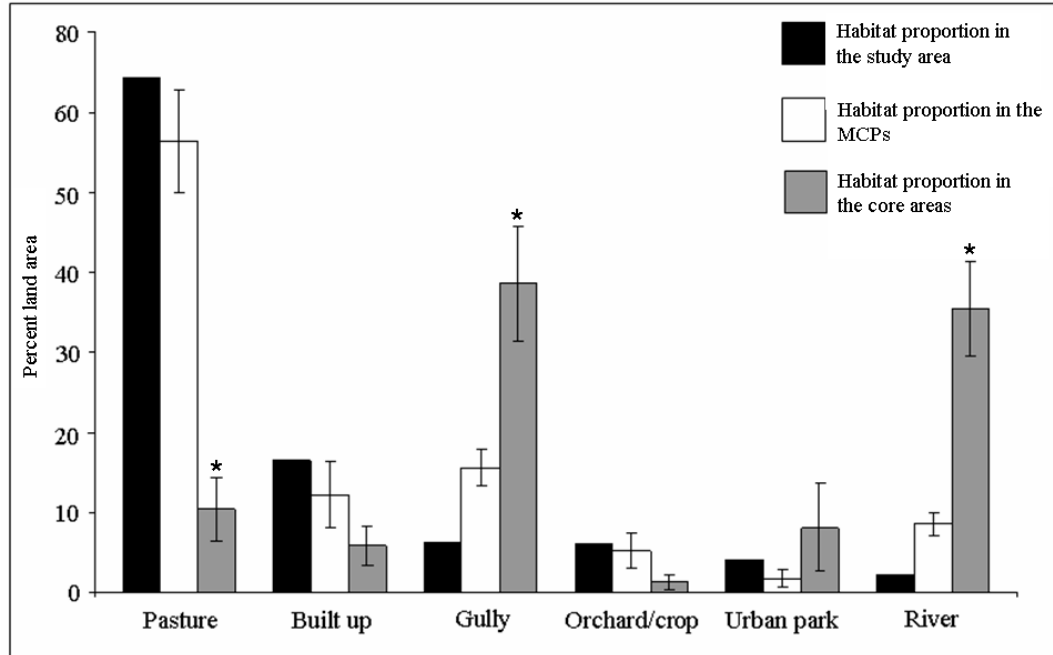


Figure 3.4 Proportions of pasture, built up, gully, orchard/crop, urban park and river habitats in the study area and their mean proportions  $\pm$  SEM in *C. tuberculatus* 95% minimum convex polygons and 50% core areas. Core area bars labelled with \* show a habitat proportion significantly different in *C. tuberculatus*' 50% cores when compared to minimum convex polygons (Wilcoxon matched pairs ( $Z$ ),  $P < 0.05$ ). Gully and river habitat are over represented in core areas and pasture habitats are under represented.

### Activity

All bats engaged in each recorded behaviour at least once during their active period. Male bats displayed comparatively regular activity patterns within and between individuals, but

the data were not normal. The female bat, however, exhibited activity patterns that were inconsistent with the male bats' activity, therefore, she is described independently and not included in any statistical analyses.

Male bats exited their day roosts on average  $50.7 \pm 5.7$  SEM min after official sunset and spent on average  $490.3 \pm 10.3$  SEM min away from the day roost before returning to it  $5.6 \pm 11.3$  SEM min before official sunrise. The female bat exited her day roost 110.0 minutes after sunset and was active for 139.00 minutes before returning to the day roost 528.0 minutes before sunrise.

Commuting was the most variable of all the recorded behaviours. Total commuting time ranged from 1 to 92 minutes over either one or two bouts (Figure 3.5). Spearman's ranked correlation coefficient showed that commuting time was not related to the distance between a male bat's day roost and its furthest core nuclei ( $R_s = 0.322$ ,  $P > 0.05$ ). Rather, some bats engaged in multiple commutes across their foraging area while others did not. However, top flight speed was correlated with distance between day roosts and furthest core nuclei ( $R_s = 0.879$ ,  $P < 0.05$ , top speed =  $14.8 \pm 2.6$  km/hour) indicating that these bats regulate their commuting time by moderating their flight speed. The high variability in commuting behaviour between male bats prevented any meaningful comparisons of commuting behaviour between intervals. The female engaged in one, 5 minutes, commuting bout and reached a top speed of 1.2 km/hour.

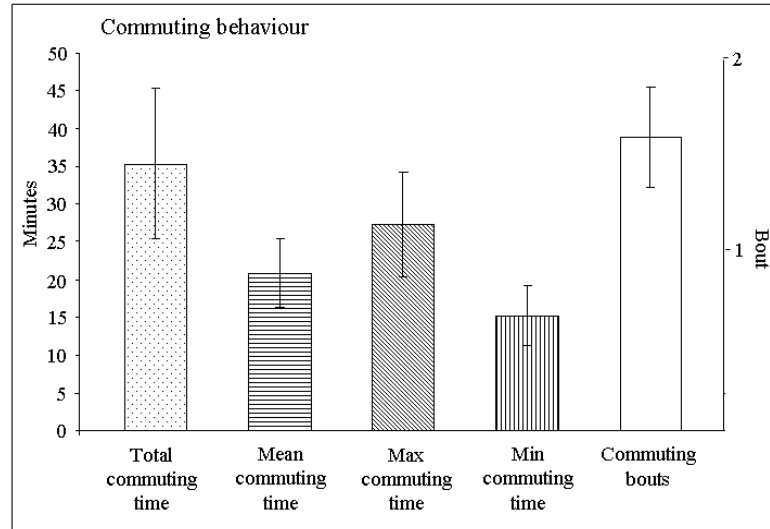


Figure 3.5 Descriptive statistics for commuting behaviour including the total time spent commuting, the mean, maximum and minimum bout time and the number of commuting bouts. All are presented  $\pm$  SEM. Commuting behaviour was highly variable between individuals.

Foraging represented the largest proportion of the bats' nightly time budgets and took place in the bats' core areas. Male bats foraged for an average of  $306.7 \pm 19.7$  SEM minutes and engaged in an average of  $6.4 \pm 1.1$  SEM foraging bouts. Foraging time reached a peak in the third interval; between four and six hours after sunset. Analysis of variance showed male bats also engaged in significantly longer foraging bouts during the third interval ( $P < 0.05$ ) (Figure 3.6A and C). The female bat foraged 124.0 minutes over three foraging bouts.

All *C. tuberculatus* night-roosted in their core areas and showed a high fidelity for a single night roost. Male bats night-roosted for, on average,  $151.1 \pm 19.8$  SEM minutes in  $5.3 \pm 0.9$  SEM bouts. Night-roosting only differed significantly between interval one and all other intervals (ANOVA,  $P < 0.05$ ). This difference is a consequence of the fact that male bats spent up to half of the first interval in their day roost (Figure 3.6, B and D). The female bat engaged in only one, 13 minute, night-roosting bout.

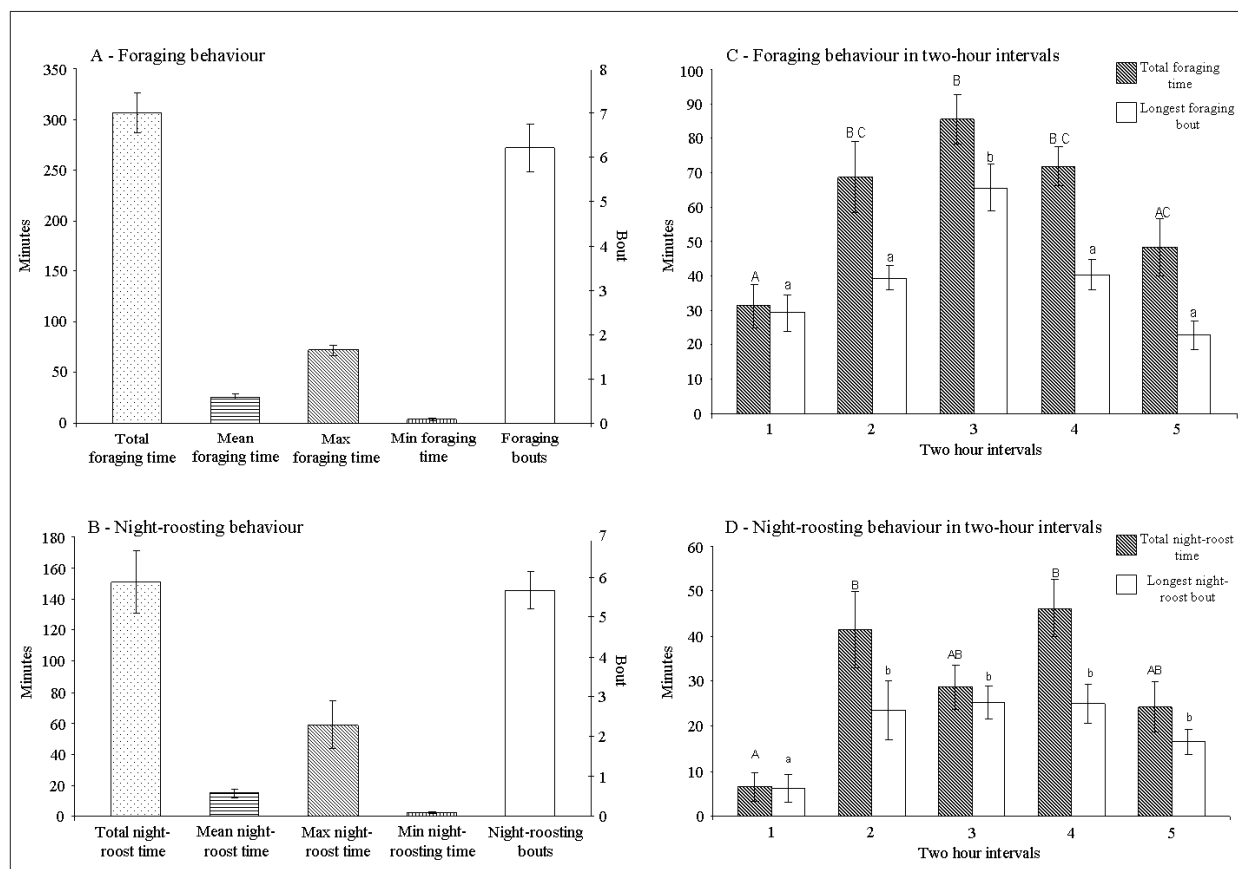


Figure 3.6 Graphs A and B show descriptive statistics for foraging and night-roosting behaviour including the total time spent in each behaviour, the mean, maximum, and minimum bout time and the number of bouts of each behaviour. Graphs C and D show total foraging and night-roosting time and the length of the longest behaviour bout in each two-hour interval, bars marked with different letters are significantly different from each other ( $P < 0.05$ ). All data are presented  $\pm$  SEM.

## Discussion

This study recorded an extreme capture bias towards male *C. tuberculatus*. Bats in the Hamilton area also showed a high fidelity for a limited number of day roosts. Home range sizes and shapes were highly variable between individuals but all *C. tuberculatus* showed a significant preference for river and gully habitats and had small core areas in these habitat types. *C. tuberculatus* engaged in all recorded activities and spent the most time foraging.

***Sex bias in urban habitats***

The capture methods used in this study are standard methods which have been employed in numerous *C. tuberculatus* studies at various sites around New Zealand including Canterbury, Fiordland, South Waikato and the Waitakere ranges (O'Donnell and Sedgeley 1999, Sedgeley and O'Donnell 1999b, Alexander 2001, O'Donnell 2002b, Sedgeley 2003, Griffiths 2007). All other studies of *C. tuberculatus* report equal capture rates or some bias towards females (O'Donnell and Sedgeley 1999, Sedgeley and O'Donnell 1999b, Alexander 2001, O'Donnell 2002b, Sedgeley 2003, Griffiths 2007). Some of these studies captured *C. tuberculatus* at or near communal roost sites (O'Donnell 2002a, Griffiths 2007) and this likely increased the probability of capturing females since they roost communally more often than males (O'Donnell and Sedgeley 1999). However, these studies were also conducted in areas within or near larger forest habitats. This study is the first to focus on *C. tuberculatus*' use of areas within city limits, and therefore the first to capture bats specifically within an urban bush remnant.

Niche segregation between demographic groups has been documented in numerous bat species (Grindal et al. 1999). Often this segregation is seasonal and associated with the times of gestation and lactation known as the nursery period (Encarnacao et al. 2005). The energy demands on females during this time are higher than baseline (Kurta et al. 1989) and the energy savings of deep torpor are not available to pregnant or lactating bats as this would inhibit foetal growth and milk production (Wilde et al. 1999). Thus, reproductive females use different strategies for economising energy use. For example, they choose nursery roosts which are warmer, located in more stable microclimates and closer to productive foraging sites (Cryan et al. 2000, Broders and Forbes 2004, Encarnacao et al. 2005). Additionally, foraging time is maximised and commuting costs are minimised by the lactating females' very small home ranges (O'Donnell 2001, Safi et al. 2007). Some authors even suggest that lactating females defend the best foraging sites

around nursery roosts, forcing male bats to forage in less desirable or more distant areas (Grindal et al. 1999, Senior et al. 2005).

Previous studies indicate that *C. tuberculatus* prefer large, old growth trees, with thick trunks, as nursery roosts (Sedgeley and O'Donnell 1999b). Thus, it is likely that Hamilton presents a limited potential for nursery roosting. Few large trees are found in the urban area or in urban bush patches (Clarkson et al. 2002). Those that do remain are generally cut off from other resources by large areas of suburban buildings, thus not providing the needed combination of roosting and foraging opportunities. This study did identify three likely nursery roosts (roosts 2, 8 and 9). However, from the city limits, the nearest of these was 3.5 km to the south. The apparent lack of nursery roosts in Hamilton, or within 3 km, is likely the primary reason for the apparent lack of females within Hamilton. This is supported by the timing of the two female bat captures. The first female was captured very early in November, before the establishment of nursery roosts and the second at the end of March, after the break up of nursery roosts (King 2005).

Conversely, when considered from the perspective of male bats, Hamilton may provide resources outside the range of females. Some studies have suggested that the monopolisation of prime local foraging areas by females may be to the detriment of male bats where resources are limited (Senior et al. 2005). However, male *C. tuberculatus* captured in this study had average body weights and low parasite loads; both are often used as indicators of good condition in other mammals (Pioz et al. 2008). The persistence of male *C. tuberculatus* in Hamilton may thus reflect productive, low competition foraging opportunities and roosting opportunities that are suitable for the deep torpor used by male bats all year round (Wilde et al. 1999). Future studies could investigate if male *C. tuberculatus* are marginalised by females.

### ***C. tuberculatus* in Hamilton**

*C. tuberculatus* in Hamilton exist within the southern city limits and the surrounding rural areas. Areas spanning the edges of city limits and the surrounding rural areas are often

referred to as the urban-rural interface (Duchamp et al. 2004). *C. tuberculatus* at Hamilton's urban-rural interface showed a high fidelity for their individual commuting paths between day roosts and foraging sites. This fidelity has been reported for *C. tuberculatus* in Canterbury (Griffiths 2007) and Fiordland (O'Donnell 2001) and has also been recorded for numerous other species of bats as is often associated with the use of patchy resources where animals return to previously productive sites by known routes (Racey and Swift 1985, Waiping and Fenton 1989, Law 1993, Wilkinson and Barclay 1997).

*C. tuberculatus* home ranges in this study were highly variable, ranging from 25.9 to 871.0 ha, and spanning on average  $3.9 \pm 0.6$  km. This is consistent with home ranges reported for five bats in fragmented Canterbury habitats (322 - 642 ha) (Griffiths 2007), but is much smaller than the ranges of bats in Fiordland where median homes range for male bats are reported to be 1589 ha with range spans as large as 19 km (O'Donnell 2001). Core areas were also smaller in Hamilton (O'Donnell 2001, Griffiths 2007). However, both the MPCs and core areas of Hamilton *C. tuberculatus* are comparable in size and variability to those reported for other microbats inhabiting urban-rural interface habitats (Sparks et al. 2005, Walters et al. 2007). For example *Myotis humeralis* at the urban-rural interface have home ranges of  $4.0 \pm 1.4$  km (Duchamp et al. 2004). Also consistent with reports for other bats at the urban-rural interface and for *C. tuberculatus* in Fiordland, is the high variability in home range size and shape between individual bats (O'Donnell 2002a, Sparks et al. 2005).

*C. tuberculatus* using the urban-rural interface fall into two broad categories: bats that reside within the city and use it for day roosting, foraging and night-roosting and non-resident bats that day roost outside the city limits and commute into the city to forage and night roost. These two strategies for exploiting the urban fringe are reflected in the variability in home range size and shape seen in Hamilton's *C. tuberculatus*. The two different strategies also explain the high variability that was seen in commuting behaviour. Bats that day roost within the city limits had foraging areas within a few

hundred meters of their day roosts and so commuted within their foraging areas but did not undertake the extended commutes that were seen in bats roosting several kilometres away. The impact of roost proximity to foraging sites on home ranges has been shown in other bats, such as *Lasiurus borealis*, whose home ranges are generally smaller when they are close to day roosts (Walters et al. 2007). This is supported by the data in this study which shows a strong regression between home range size and distance between individual bats core areas and days roosting sites.

Both resident and non-resident *C. tuberculatus* used habitats selectively and in the same way, avoiding pasture areas and seeking out river and gully habitats. River/riparian habitats have been shown to be important foraging habitat for numerous bat species internationally (Furlonger et al. 1987, Vaughan et al. 1996, 1997, Wickramasinghe et al. 2003). Preference for river/riparian areas has also been documented in *C. tuberculatus* in South Canterbury (Griffiths 2007). The Waikato River likely provides *C. tuberculatus* with a reliable water source and productive foraging opportunities. Both the amount of time that Hamilton *C. tuberculatus* spent foraging and number of foraging bouts they undertook is consistent with what has been recorded for *C. tuberculatus* in unfragmented Fiordland habitat (O'Donnell 2002a). This suggests that the river/gully areas within Hamilton may provide foraging sites of comparable productivity to more pristine forest areas. This is likely because aggregations of insects over water can be particularly productive prey for bats because these insects are often non-tympanic and have reduced flight ability compared to terrestrial insects (Brodsky 1991, Fukui et al. 2006). River/riparian zones also create aggregations of terrestrial insects where they represent eco-tones of increased vegetation cover (Clark et al. 1993, Sijpe and Holsbeek 2007). It is possible that the resulting diversity of prey produces more consistent foraging opportunities over the course of a night and that this may be reflected in the Hamilton bats' foraging patterns. Hamilton *C. tuberculatus* forage more consistently over the course of the night, slowly reaching a peak in foraging time and foraging bout length between the fourth and sixth hour after sunset. Fiordland bats peaked in bout foraging time and foraging bout length in the first hour after sunset.



In Hamilton and the surrounding area both the river/riparian zone and the gully systems provide a rare refuge for native flora (Clarkson et al. 2002). This is largely because these areas are steeply incised and wet and have thus escaped development and conversion to pasture (Clarkson et al. 2002). Estrada and Coates-Estrada 2001 found that patches of residual rainforest in rural Mexico were used by numerous species for both day and night-roosting. Similarly, the urban gullies and river zones also offer *C. tuberculatus* night-roosting opportunities as is indicated by the high proportion of these habitat types in the bats core areas and the fact that the *C. tuberculatus* night roost in their core areas. Night-roosting opportunities are likely to be especially important for the non-resident bats that need to rest at night roosts near their foraging sites. Night-roosting time and night-roosting bouts in Hamilton *C. tuberculatus* were again similar to those reported for Fiordland bats (O'Donnell 2001) suggesting that night roost availability and relative locations to foraging areas were as appropriate as those in forest habitats.

It is probable that the eco-tones created by gully systems are the reason the *C. tuberculatus* use Hamilton's urban-rural interface. At Hamilton's southern city limits, the Waikato River is met by two major gully systems, the Mangakotukutuku, and Mangaonua systems. Together these represent eco-tones of vegetation cover through the relatively homogeneous pasture habitats which dominate the rural areas around Hamilton. Bats are "funnelled" into the urban area because the connection between Mangakotukutuku, Mangaonua systems and the river is within Hamilton. Such vegetation corridors provide a buffer from wind and predators and linear cues for efficient navigation (Walsh and Harris 1996, Bach et al. 2004). Corridors in the Hamilton area are vital because the habitat types which *C. tuberculatus* select are rare in comparison with those that they do not select. Pasture lands make up over 60% of the total land area and built up areas contributes a further 15%; these areas were generally avoided by Hamilton *C. tuberculatus*. Avoidance of pasture lands is common in other vespertilionid species like *Pipistellus pipistrellus* (Racey and Swift 1985) and has also been documented in Canterbury *C. tuberculatus* (Griffiths 2007). In and around Hamilton, the gullies are the

only extensive habitat corridors between the river, urban green spaces and distant forest remnants.

Hamilton *C. tuberculatus* show a high fidelity for one or two day roosts. This is uncharacteristic for this species, which usually has extremely high roost turnover (O'Donnell and Sedgeley 1999). *C. tuberculatus* day roosting within Hamilton use old, dead or dying Gum (*Eucalyptus* spp.) trees. Urban *Myotis yumanensis* in the San Francisco Bay area of California, USA also use old trees and showed a high roost fidelity (Evelyn et al. 2004). Urban bush patches can contain small stands of old residual trees, often referred to as legacy trees (Mazurek and Zielinski 2004). Species like *Myotis volans* choose legacy trees exclusively over young specimen trees (Mazurek and Zielinski 2004). *C. tuberculatus* roost fidelity suggests that legacy trees may be highly limited within the city and it is likely that each individual old tree is important.

It is true however, that while *C. tuberculatus* do roost in legacy trees within the city, the roosts are almost exclusively solo roosts under peeling bark. These are not considered to be high quality roosts and in the published literature they are considered unsuitable for maternity roosts (Sedgeley and O'Donnell 1999a). Similar patterns of solitary roost use have been documented in other urban species such as the Mexican free tailed bat (*Tadarida brasiliensis*) (Scales and Wilkins 2007). Further, no communal roosts were found in the city and this could mean that there is limited potential for social contact. The Mangakotukutuku, and Mangaonua systems link stands of Kahikatea and Oak to Hamilton. It is in these stands that the three communal, potentially nursery roosts were found. Thus, despite the foraging and night-roosting opportunities in the city, the continued presence of *C. tuberculatus* within Hamilton likely depends on the Mangakotukutuku and Mangaonua corridor connection.

Because commuting is energetically costly (Kurta et al. 1989), bats of a given species are usually confined to habitat fragments within a set area. The non-resident bats' use of the gully connections can be seen in the shape of their home ranges which closely follow the

contours of the gullies and the river. These vegetation corridors likely extend the bats' range by providing stepping-stone resources (Estrada and Coates-Estrada 2001). Because the habitat fragmentation in the Hamilton area is extreme when compared to areas like Fiordland, it is doubtful that bats would make their way into the city without the gully connection. Further, it is likely that, the lack of connection between habitats deeper within the city limits the opportunity for *C. tuberculatus* to exploit more of the urban habitat (Chapter two). This is supported by city-wide surveys of Hamilton which showed that bats were absent from all but the southern parts of Hamilton, though the city contains some comparable river/riparian zones and vegetation cover in other areas (Chapter two).

The importance of the gullies as foraging sites and corridors for *C. tuberculatus* at Hamilton's urban-rural interface highlights the need for maintenance and protection of gully systems in the Waikato. Hamilton's urban biodiversity is closely linked with the gully systems and the Waikato River (Clarkson and McQueen 2004) and conservation management efforts should strongly focus on these habitat features. Any efforts to conserve, or potentially extend the range, of *C. tuberculatus* in Hamilton will likely be dependant on the preservation and/or extension of habitat corridors between the city's green spaces, river/riparian zones and distant habitat patches. Finally, the high roost fidelity shown by Hamilton's *C. tuberculatus* suggests that each individual urban roost is important and that careful management of individual old and dying trees are needed. Chapters four and five describe a new method for monitoring the use of urban legacy trees by *C. tuberculatus*.

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