Factors affecting urban insectivorous bat activity and implications for habitat management in the City of Adelaide, South Australia

Thesis submitted in partial fulfilment of the requirements for the Bachelor of Applied Science (Biodiversity, Environmental and Park Management) (Honours)

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Annette Therese Scanlon
Bachelor of Applied Science (Biodiversity, Environmental and Park Management)

School of Natural and Built Environments

University of South Australia

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Glossary

Aerial insectivory:	A mode of foraging where bats locate and capture insects while in flight.
Attenuate:	To become weaker, echolocation calls attenuate in the atmosphere; sounds lose momentum and the amount of information they carry in time and space.
Bat activity:	A measure of bat presence in an area recorded with a bat detector. Detectors record bat sounds and some species can be identified from their call structure, but there is no measure of abundance.
Bat call or echolocation call:	The vocalisation made by bats in a sequence of repeated units, not usually audible to human hearing.
Bright moonlight:	Referring to nights of full or almost full moon.
Civil twilight:	Evening civil twilight is the time in the evening when the centre of the sun is 6˚ below the horizon.
Clutter:	Clutter refers to the echolocation echoes returning from vegetation or other background objects of non-prey items.
Constant Frequency calls:	Echolocation calls made at one frequency or at a narrow range of frequencies. It is an efficient means for aerial prey detection by bats, and together with the Doppler Effect (see Doppler Effect) to measurement of the prey's distance and relative velocity (compare to frequency modulated).

Critical weight range (CWR):	Critical weight range defined for Australian mammals between 0.035 – 5.500 kg. CWR mammals have experienced a disproportionately high rate of extinction compared to other mammals in Australia since European settlement.
Diet strategy:	The animal behaviour and physiological attributes associated with finding and obtaining food.
Doppler Effect:	The apparent change in frequency that is perceived by observer moving relative to the source of echo.
Echolocation:	Bats emit high-frequency sounds and use their echoes to determine direction and distance in space as well as the detection and attack of prey and its relative size and texture.
Evapotranspiration:	The sum of evaporation and plant transpiration where evaporation is the movement of water to the air and transpiration is the movement of water within a plant.
Endotherm:	An animal with internal mechanisms to regulate and maintain body temperature independently of ambient temperature.
Frequency Modulated calls:	Echolocation calls using a broad range of frequencies and are used by a bat to determine information about prey (texture, size); they are often by bats in cluttered environments (compare to constant frequency).
Gleaners or gleaning:	Foraging mode where prey is captured or taken from surfaces, such as from a leaf surface.
Habitat partitioning:	Differentiation of ecological niches and microhabitats among organisms.
Insectivory:	A diet strategy where animals eat insects.

Lunar phobia:	In bats, lunar phobic behaviour is when activity is purposely suppressed during bright moon-lit nights; factors that drive this behaviour include increased predation risk and decreased prey abundance.
Malaise trap:	Designed by Malaise (1937), an insect trap with a tent-like structure made of netting, a high point at one end collects insects into bottle containing alcohol.
Torpor:	A form of hibernation in endotherms, where individuals enter a regulated state of hypothermia that may last for hours and up to a few weeks.
Universal Time (UT):	Or Greenwich Mean Time (GMT) refers to the time kept at longitude zero (along the Greenwich meridian), 9.5 hours behind central South Australian time.
Urban Heat Island (UHI):	Heat generated in metropolitan areas creating an effect not caused by prevailing weather; the area becomes warmer than its surroundings.
Wing-loading	A measurement of body mass divided by the surface area of the wing and tail membrane, which influences flight style. Generally, fast-flying bats have high wing-loading, whilst manoeuvrable, slow-flying species have low wing-loading.
Wing morphology:	Describes the shape and size of wings.

Abstract

Insectivorous bats are among the few native mammalian taxa that persist in urban environments, yet little information is available on the ecology of the bats that occur in urban areas, including Adelaide City. I used echolocation call detectors to assess bat activity among different sites in the Adelaide City parklands and in response to season, weather, moonlight, and insect activity. Malaise traps, light traps, and sticky traps were used to assess insect availability in relation to artificial lights, weather, and bat activity. I also investigated the diet of local bats via scat analysis and checked roosting resources in urban parks with an elevated platform. The potential for radio-tracking city bats was also tested from tall buildings in the central business district. From data collected with detectors, I identified at least 6 insectivorous bat species using the City's parklands. Bat activity fluctuated among site and season; rainfall and moonlight limited bat activity, and both bat activity and insect biomass increased with temperature, with a burst in activity occurring from around 12˚C. I identified invertebrate fragments of Coleoptera, Hymenoptera, and Hemiptera, as well as Lepidopteran scales in bat scats. No bats were recorded in bat boxes or potential tree roosts in Adelaide City; minimal bat activity was recorded in the first two hours after civil twilight, so bats may roost outside the City and migrate nightly into parkland areas. I found that minimal potential exists for radio-tracking with low-strength radio-transmitters from building rooftops; however, potential exists for radio-tracking medium to large arboreal and flying animals from rooftops in Adelaide City. This research shows that dark park areas were more important for bat diversity and activity in cities than were artificially lit parkland areas. I found that *C. gouldii* and *M. planiceps* were the bat species most advantaged in Adelaide's parklands and that overall low levels of activity recorded from *Vespadelus* species, *T. australis*, and *C. morio* should prioritise them for conservation by the Adelaide City Council.

Declaration

I declare that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

Signature of Author: ________________________

Annette Therese Scanlon

Date: ________________________

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CHAPTER 1: General introduction

Introduction

General background

This thesis investigates factors affecting the activity of insectivorous bats and the implications for habitat management in the City of Adelaide. The research was conducted as part of an honours degree in applied science at the University of South Australia. Project supervisors were Dr Sophie Petit and Mr Terry Reardon (co-supervisor); project collaborators include the South Australian Museum, the Royal Zoological Gardens of South Australia, Biocity: Centre for Urban Habitats, and the Adelaide City Council (ACC). The project objective was to develop a general understanding of the ecology of Adelaide's bat fauna and to provide habitat recommendations to the ACC.

The Adelaide Plains in the state of South Australia (Fig. 1.1) was a hotspot for biodiversity until human-induced changes caused degradation to the ecosystems (Adams *et al.* 1988; Oke 1997; Campain 2004; Tait *et al.* 2005). The Plains are approximately 185 000 ha and are bordered to the west by the Gulf of St Vincent, to the east and south by the Mount Lofty Ranges, and to the north by the Gawler River. Rapid urban settlement to the region occurred after World War II; the area is now completely urbanised and incorporates the metropolis of Adelaide (34˚ 52' S 138˚ 30'E), supporting approximately 1.1 million people or 73% of the state's population (Australian Bureau of Statistics 2005). Since urbanisation, the Adelaide Plains have experienced a decline in the number of native plant, mammal, and reptile species (Turner 2001; DEH 2003).

Arguably, mammals are the class of animals most detrimentally affected by European settlement in Australia (Burbridge and McKenzie 1989; Short and Smith 1994). Many extinctions have occurred among the ground-dwelling mammals within a critical weight range (CWR, approximately 0.035-5.500 kg) (Burbridge and McKenzie 1989; Short and Smith 1994). Extinctions from the Adelaide region of CWR mammals include the platypus (*Ornithorhynchus anatinus*), numbat (*Myrmecobius fasciatus*), eastern quoll (*Dasyurus viverrinus*), western barred bandicoot (*Perameles bougainville*), striped-faced dunnart (*Sminthopsis macroura*), and the greater bilby (*Macrotis lagotis*) (Turner 2001). Factors driving extinctions among Western Australian CWR mammals

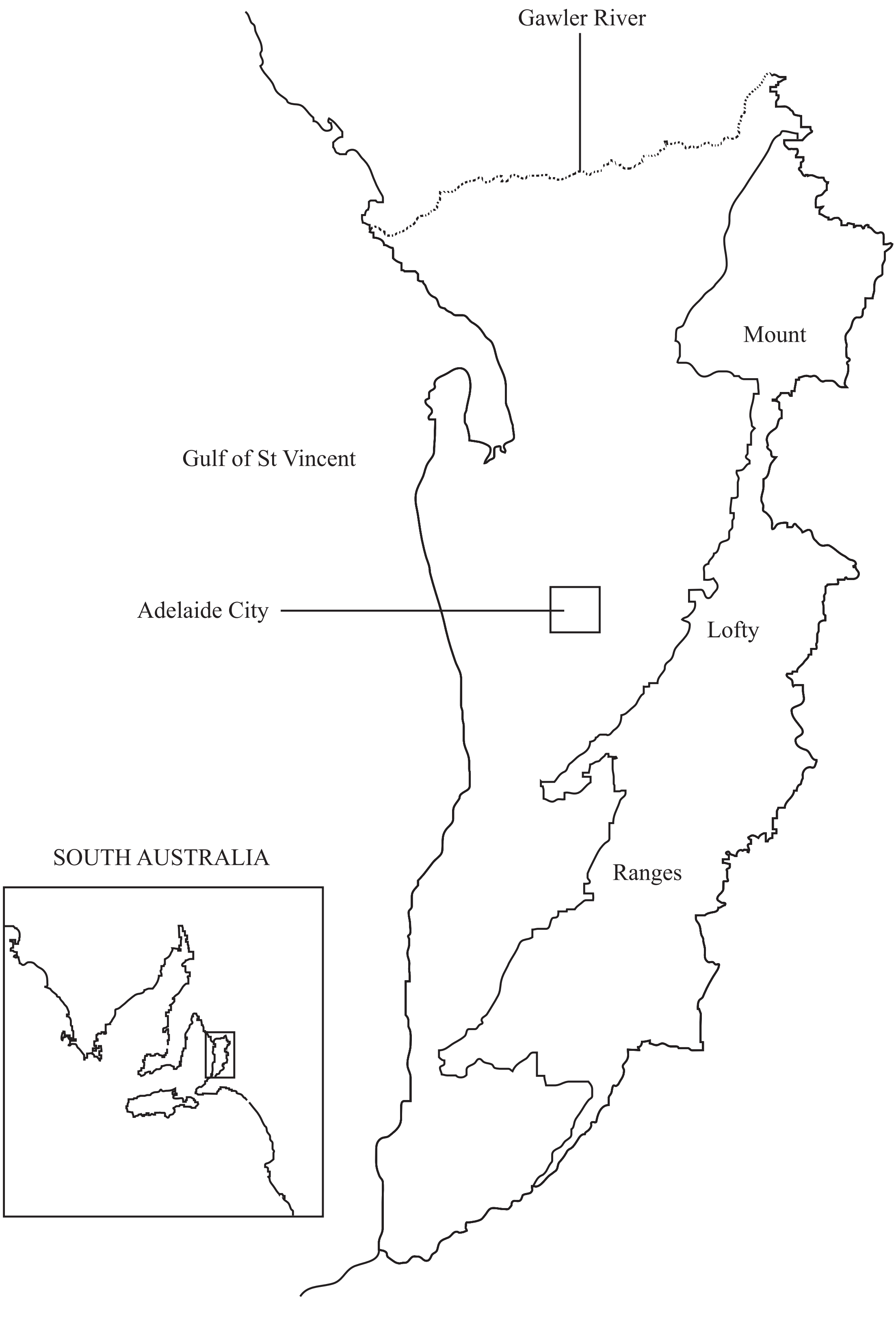

Fig. 1.1 The Adelaide plains in South Australia, bordered to the north by the Gawler River, to the east and south by the Mount Lofty Ranges, and to the west by the Gulf of Saint Vincent.

include resource diversion (e.g. water flows), reductions in habitat quality and availability (decreased carrying capacity and fragmentation), and competition and predation by introduced animals (Burbridge and McKenzie 1989). Flying or arboreal mammals experience some protection against predation from the domestic dog (*Canis familiaris*), European red fox (*Vulpes vulpes*), or feral cat (*Felis catus*), these mammals may also more readily navigate through fragmented habitats. Despite these advantages, arboreal and flying mammals have also suffered declines in Australia (Department for Environment and Heritage 2003). In the Adelaide region, 6 of the 18 native arboreal or flying mammal species recorded around the time of European settlement or since settlement have become locally extinct, including the western pygmy-possum (*Cercartetus concinnus*), the feathertail glider (*Acrobates pygmaeus*), the white-footed tree rat (*Conilurus albipes*), Mitchell's hopping-mouse (*Notomys mitchellii*), the common bent-winged bat (*Miniopterus schreibersii*), and the presumed extinct inland broad-nosed bat (*Scotorepens balstoni*) (Turner 2001; Reardon and Tait 2005).

The development of large urban zones transforms and often degrades natural environments, but urbanised regions retain some capacity to support and promote both vertebrate and invertebrate fauna (Parry-Jones and Augee 2001; Tait *et al.* 2005; Collier *et al.* 2006; Williams *et al.* 2006). Recently in Australia, urban wildlife populations have become the focus of research (for example Coulson and Coulson 1998; Parry-Jones and Augee 2001; Parsons *et al.* 2006; Rhodes and Wardell-Johnson 2006). A recent review of urban fauna by Garden *et al*. (2006) listed Australia's most frequently studied urban mammals as the koala (*Phascolarctos cinereus*), possums (*Trichosurus* spp.), gliders (*Petaurus* spp.), and bandicoots (*Isoodon* spp.). The review also noted that cryptic and survey-intensive mammal species such as dunnarts (*Sminthopsis* spp.), native rodents (Rodentia), or bats (Chiroptera) receive considerably less attention (Garden *et al.* 2006).

Insectivorous bats (Microchiroptera) are among the native mammalian taxa that persist in Australia's urban environments but only a small number of studies have examined the ecology of Australia's urban bat populations (Kirsten and Klomp 1998; Campain 2004; Biocity 2005; Hourigan *et al.* 2006; Rhodes and Wardell-Johnson 2006). Considerably more attention has been given to urban bat communities overseas, particularly in Europe and Central and North America. These studies have documented patterns of behaviour and persistence within metropolitan areas such as Indianapolis (Duchamp *et al.* 2004), Chicago (Gerht and Chelsvig 2003), Woodside, Portola Valley and Menola Park in California

(Evelyn *et al.* 2004), Detroit (Kurta and Teramino 1992), Mexico City (Avila-Flores and Fenton 2005), Athens (Legakis *et al.* 2000), Brno in the Czech Republic (Gaisler *et al.* 1998), London (Hooper 1981a; Guest *et al.* 2002), and even northern England during a music festival (Shirley *et al.* 2001). Some European studies have documented bat foraging behaviour at street lights where insects aggregate, enhancing feeding opportunities (Rydell 1991a; Rydell 1992; Barclay and Brigham 1994). Attributes of species that allow them to exploit insects at lights include fast-flight and long-range echolocation systems (Rydell 1992). The advantage conferred on some bat species in urban environments by their generalist nature, flight style, or echolocation design, has been linked to a decline in other bat species through interspecific competition (Arlettaz *et al.* 2000; Duchamp *et al.* 2004). A survey in the city of Athens found bat species were widely distributed across the metropolis, but sustained only low numbers of individuals (Legakis *et al.* 2000). Bat populations in London declined over 15 years (1985 to 1999) by at least 6% and potentially by as much as 38% (Guest *et al.* 2002). It is understood that urbanisation negatively affects bat abundance and diversity (Kurta and Teramino 1992) and that detailed information pertaining to their ecology is necessary to make informed and meaningful habitat recommendations.

No records of bat abundance and richness exist for the Adelaide Plains at the beginning of European settlement, so it is difficult to quantify the effect of urbanisation on bats in the region. The earliest mammal species list for the district was not produced until 1925 by Wood Jones (1925). Currently, the Microchiropteran species thought to persist on the Adelaide Plains include the chocolate wattled bat (*Chalinolobus morio*), Gould's wattled bat (*C. gouldii*), lesser long-eared bat (*Nyctophilus geoffroyi*), large forest bat (*Vespadelus darlingtoni*), southern forest bat (*V. regulus*), little forest bat (*V. vulturnus*), white-striped freetail bat (*Tadarida australis*), and the southern freetail bat (*Mormopterus planiceps* species 4) (Turner 2001; South Australian Museum 2006). *Mormopterus planiceps* is currently under taxonomic revision and is known as species 4 (long penis form) (Adams *et al.* 1988).

A recent publication describing the ecological history of Adelaide suggests that several bat species may have declined, contracted in range, or become locally extinct from the Adelaide Plains over the past 150 years (Reardon and Tait 2005). Potential casualties from urbanisation in the region included the inland broad-nosed bat (*Scotorepens balstoni*), the large bentwing bat (*Miniopterus schreibersii*), and the large-footed bat (*Myotis macropus*) (Table 1.1) (Wood Jones 1925; Reardon and Tait

2005). Three museum records exist for the yellow-bellied sheathtail bat (*Saccolaimus flaviventris*) in Adelaide; however, it is expected that Adelaide is not part of this species' normal range and the bat is listed as rare in South Australia (DEH 2003). A pilot study in 2004 recorded this species with a detector in the Adelaide parklands (Campain 2004); however, those data were not available for this study, or verified by T. Reardon at the Museum. The expected and unknown, absent, or extinct bat species persisting in the area are listed in Table 1.1.

Table 1.1 List of insectivorous bat species occurring on the Adelaide Plains with the IUCN Red List status category allocated by DEH (1999)
LR (nt) = lower risk near threatened; LR (lc) = lower risk least concern

Species	Common name	Status
Expected to occur in region		
Chalinolobus gouldii	Gould's wattled bat	LR (lc)
Chalinolobus morio	Chocolate wattled bat	LR (lc)
Nyctophilus geoffroyi	Lesser long-eared bat	LR (lc)
Vespadelus darlingtoni	Large forest bat	LR (lc)
Vespadelus regulus	Southern forest bat	LR (lc)
Vespadelus vulturnus	Little forest bat	LR (lc)
Mormopterus planiceps species 4	Little mastiff bat	LR (lc)
Tadarida australis	White-striped freetail bat	LR (lc)
Unknown, absent or extinct from region		
Scotorepens balstoni	Inland broad-nosed bat	LR (lc)
Miniopterus schreibersii	Bent-wing bat	LR (lc)
Saccolaimus flaviventris	Yellow-bellied sheathtail bat	LR (lc)
Myotis macropus	Southern myotis	LR (nt)

Conserving Adelaide City bats

Insectivorous bats occur around urban centres of the Adelaide Plains, yet almost no information is available on the ecology of these bats or how to manage their habitat in this urban landscape. Adelaide City is the Central Business District (CBD) of the Adelaide Plains; it is comprised of a grid of tall buildings surrounded by parkland areas covering approximately 700 ha (Fig. 1.2). The Adelaide parklands have been nominated for listing on Australia's National Heritage List (place ID: 105758) and for the Register of the National Estate (place ID: 6442) (DEH 2006). Colonel William Light first set aside these areas on 15 March 1837, making them the oldest dedicated public parks in the world (ACC 2006b; DEH 2006).

The Adelaide City Council (ACC), established under the *Local Government Act 1999* (PSA 1999), is the corporation responsible for managing the Adelaide City and parkland areas. The Council has objectives for encouraging ecological sustainability and for promoting the parklands to increase native biodiversity in the City (ACC 2006b). An Environmental Management Plan was developed by the Council to document goals and strategies for managing biodiversity along with key performance measures that include biodiversity inventories (ACC 2006b). Recently, ACC supported several urban wildlife projects in the City, including BioCity: Centre for Urban Habitats, which included a preliminary study into habitat utilisation by insectivorous bats in Adelaide (Campain 2004; BioCity 2006). My study aimed to build on this preliminary work to address a basic need for information about the ecology of Australia's city bats.

Little is known about which species occur in cities, whether they roost in urban environments or commute from adjacent habitats, what food resources are available, or why these bats occur in the city, and whether populations are viable given the decline of urban bat populations overseas. The bat species that occur on the Adelaide Plains are not considered to be particularly abundant because bat activity is at least 10 times higher in adjacent natural areas within the Adelaide Hills (Campain 2004; Reardon and Tait 2005), a pattern observed in other studies (Geggie and Fenton 1985; Gaisler *et al.* 1998; Kirsten and Klomp 1998; Duchamp *et al.* 2004; Avila-Flores and Fenton 2005). This research, conducted in collaboration with ACC, aimed to facilitate an understanding of the species assemblages and ecology of city bats, and to develop habitat recommendations for the management and promotion of city environments for bats.

The objectives of this study were to investigate the ecology of Adelaide City's insectivorous bats in relation to environmental cues, insect activity, and Adelaide City urban and park environments. Specifically, the following questions were addressed: (1) what is the difference among sites in bat activity? (2) What are the effects of season, weather, moon, insect activity, and artificial light on bat activity? (3) What are the effects of season, weather, moon, and artificial light on insect activity? (4) What is the diet of Adelaide City bats? (5) Where do Adelaide City bats roost? (6) What is the potential for radio-tracking bats in cities?

Thesis structure

This research constitutes an Honours degree. Research questions are organised into two main chapters. Apart from the general introduction and conclusion chapters, information relating to chapters, such as literature review or results, is presented within those chapters in the format of a scientific article. Chapters are intended to be mutually exclusive and some repetition may occur.

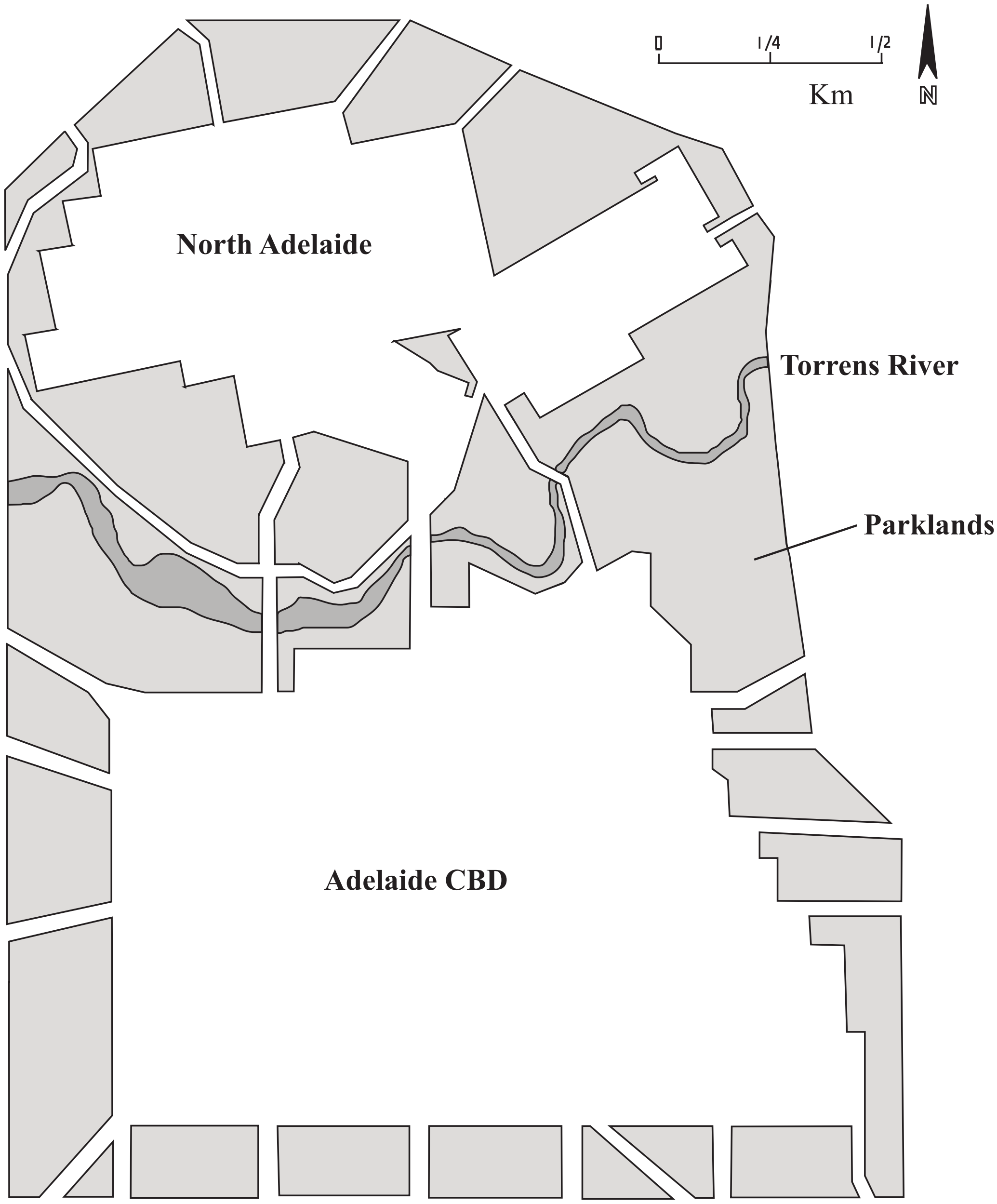

Fig. 1.2 Adelaide central business district and North Adelaide precincts separated by the Torrens River and surrounded by a belt of parkland (Adelaide City Council 2006a).

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CHAPTER 2: Bat and insect activity patterns in Adelaide City parklands

Abstract

Limited information is available on the ecology of city bat populations and recently overseas urban insectivorous bats have exhibited patterns of decline; in view of this trend Adelaide City Council (ACC) wants to encourage bats within its urban parklands. This study used echolocation call detectors to assess bat activity among different sites in the Adelaide City parklands and in response to season, weather, moonlight, and insect activity. Malaise traps, light traps, and sticky traps were used to assess insect availability in relation to artificial lights, environmental factors, and bat activity. The average length (mm) for each size class and insect order was used to calculate biomass (mg) for those analyses. From 228 detector-nights at 5 sites, I analysed 18 340 bat calls and identified at least 6 insectivorous bat species using the City's parklands: *Chalinolobus gouldii*, *C. morio*, *C. morio/Vespadelus vulturnus*, *V. darlingtoni/V. regulus*, *Nyctophilus geoffroyi*, *Mormopterus planiceps* species 4, and *Tadarida australis*. During the study, 10 107 insects were collected at the Adelaide zoo one night a week for 9 months; samples represented 13 orders and had a total biomass of 9 350.07 mg. Bat activity fluctuated among sites, and dark parkland areas were preferred by City bats. Bat and insect activity varied among season; the highest overall level of activity occurred during warm and hot months. Both bats and insects responded strongly to increasing temperatures with a distinct burst in activity occurring from around 12˚C. Rainfall limited bat activity but not species richness, and evidence of lunar phobic behaviour was recorded during summer activity of city bats. I recorded low species evenness from bat calls and found that two species, *C. gouldii* and *M. planiceps*, dominated call recordings. Species richness was negatively affected by artificial lights and *C. gouldii* and *M. planiceps* were the only species recorded at brightly lit areas, where insect abundance was greatest within 6 m of artificial light output. This research shows that dark park areas were more important for bat diversity and activity in cities than artificially lit parkland areas. Overall low levels of activity recorded from *Vespadelus* species, *T. australis*, and *C. morio* should make them priorities for conservation by the ACC.

Introduction

Bat echolocation calls, recorded with detectors, provide information that can be used to describe bat presence or activity in an area. Bat vocalisations supply a readily accessible and non-invasive means for researchers to access information pertaining to bat ecology (Fenton 1970; Fenton 1988; Brigham *et al.* 1997; Churchill 1998; Kirsten 1998; Avila-Flores and Fenton 2005). Detectors also frequently record bat species that fly outside the usual range of bat traps (mist nets or harp traps) (O'Farrell and Gannon 1999). Limitations to assessing bat populations with detectors are well known. In particular, some species are more easily recorded with bat detectors than others. Loud-calling, low-flying bats are readily detected, whereas high-flying species or species with low intensity calls, such as gleaning species, are less likely to be heard (Woodside and Taylor 1985). High-frequency echolocation calls may also be attenuated in the atmosphere, reducing the likelihood of those calls reaching a recording device (Griffin 1971; Lawrence and Simmons 1982). Another notable limitation to using bat detectors is that individual bats of the same species cannot be distinguished from each other, so population abundance cannot be extrapolated from those data collected with detectors. The acoustic signature of echolocating bats enables researchers to identify different species with detectors. However, differentiating between some species can be problematic, for example *Chalinolobus gouldii* and *Mormopterus planiceps* species 4 are frequently indistinguishable from each other (T. Reardon pers. comm. June 2006). Despite their limitations, bat detectors are commonly used in bat monitoring and research projects, and several studies have used detectors to describe bat activity within urban environments (Hooper 1981b; Kurta and Teramino 1992; Gaisler *et al.* 1998; Legakis *et al.* 2000; Gerht and Chelsvig 2003; Avila-Flores and Fenton 2005; Sanderson *et al.* 2005; Hourigan *et al.* 2006).

Bat activity fluctuates among different habitats (habitat partitioning) and in Adelaide City certain environments may be preferred by bats. Generally in urban areas, high-density housing and city centres or areas with high vehicle traffic and noise have low levels of bat activity compared to those activity levels recorded amongst low-density housing or sparsely built areas and urban park or riparian environments (Gaisler *et al.* 1998; Legakis *et al.* 2000; Avila-Flores and Fenton 2005). Levels of bat activity may become elevated at artificial light sources, where opportunistic species forage at insect aggregations (Haffner and Stutz 1985/86; Rydell 1992; Blake *et al.* 1994; Kirsten and Klomp 1998). A bat's ability to exploit different situations and environments will depend on its foraging strategy (i.e. gleaning, aerial insectivory) that is determined by physiological attributes such as wing morphology (wing loading and manoeuvrability) and echolocation strategy (frequency modulated / constant frequency) (Aldridge and Rautenbach 1987; Fenton 1990).

Bat activity may also fluctuate in response to different environmental factors. Insectivorous bats respond to daily or seasonal weather variation (Anthony *et al.* 1981; Hayes 1997; Gaisler *et al.* 1998; Sanderson and Kirkley 1998), moon phase (Fenton 1970; Crespo *et al.* 1972; Fenton *et al.* 1977; Usman *et al.* 1980; Reith 1982; Adams *et al.* 2005), air temperature (Anthony *et al.* 1981; Lackie 1984; Avery 1985; Audet 1990; Rydell 1991a; October *et al.* 1995; Gaisler *et al.* 1998), rainfall (Fenton 1970; Fenton *et al.* 1977; Bell 1980), wind (Avery 1985; Rydell 1991a), and insect abundance (Anthony *et al.* 1981; Avery 1985; Taylor 1988; Barclay 1991; De Jong and Ahlén 1991). Bats have several physiological and behavioural options to regulate body temperature during different seasonal or meteorological conditions. These options include: temporal variation in activity, selection of roosts with favourable microclimate, the ability to enter into torpor, fat storage, and sustaining a low metabolic rate, about 35% lower than that of similar-sized mammals (Wang and Wolowyk 1988; Neuweiler 2000; Sedgeley 2001; Milne *et al.* 2005; Geiser 2006). Usually, activity is suppressed during cool conditions and the majority of bat field studies are conducted during warm and hot seasons (for example Geggie and Fenton 1985; Audet 1990; Fullard *et al.* 1991; Barclay and Brigham 1994; Blake *et al.* 1994; Duchamp *et al.* 2004; Adams *et al.* 2005; Avila-Flores and Fenton 2005). Yet some species, including local species such as *Vespadelus darlingtoni*, are active year round (Sanderson and Kirkley 1998). The reasons for bats becoming active during cool conditions vary between species, but include feeding (Avery 1985) and drinking (Speakman and Racey 1989). This study examined bat activity in response to several abiotic factors, including season, temperature, rain, wind, and moonlight.

Lunar cycles influence the activity patterns of a variety of organisms. Both hunting in nocturnal birds (Brigham *et al.* 1999) and spawning in marine fish (Robertson *et al.* 1990) are influenced by the moon. Lunar phobic behaviour (i.e. suppressed activity during bright moon-lit nights) has been described in fruit-eating bats (Morrison 1978; Morrison 1980; Elangovan and Marimuthu 2001) and vampire bats (Crespo *et al.* 1972). Insectivorous bats use echolocation for orientation and prey detection, so presumably lunar light conditions are unimportant for foraging success; however, some insectivorous bats use vision in prey detection and navigation (Chase 1981; Chase 1983; Pettigrew *et al.* 1988; Eklöf *et al.* 2002; Eklöf and Jones 2003; Rydell and Eklöf 2003; Wang *et al.* 2004). The expression of lunar phobic behaviour in insectivorous bats may be attributed to increased predation risk from visually orientated predators, such as nocturnal raptors, and to a decrease in insect abundance during full moon nights (Bishop *et al.* 2000; Lang *et al.* 2006). Bright moonlight suppressed insectivorous bat activity in several temperate zone climates including Africa (Fenton *et al.* 1977), India (Usman *et al.* 1980), and New Mexico (Reith 1982), as well as in tropical areas including Panama (Lang *et al.* 2006) and the 'Top End' of the Northern Territory (Milne *et al.* 2005). No effect of bright moonlight on bat activity was found in cool climate zones such as Canada (Geggie and Fenton 1985; October *et al.* 1995), Sweden (Karlsson *et al.* 2002), or the Czech Republic (Gaisler *et al.* 1998). The relationship between moonlight and bat activity in temperate zones remains unclear (Lang *et al.* 2006). Additionally, it is unknown whether Australian bats exhibit lunar phobic behaviours, and whether in Adelaide, a temperate city, bat activity is suppressed by bright moonlight.

Insect activity has been linked to several climatic factors and affects bat activity directly and indirectly (Anthony *et al.* 1981; Avery 1985; Taylor and O'Neill 1988; Barclay 1991; De Jong and Ahlén 1991; Pavey *et al.* 2001; Lang *et al.* 2006). Insect abundance varies among seasons; generally low numbers of insects occur in winter (Wolda 1988; Hwang and Turner 2005). The interactions between insect activity and daily weather conditions are probably complex, for example Hwang and Turner (2005) found that strong wind or rain, and low daily temperatures may decrease insect presence. Yet rain did not suppress insect activity in Canada (Fenton 1970) and windspeed and temperature were secondary to the influence of moonlight on dipteran catches in NSW (Bishop *et al.* 2000). Bright moonlight may decrease insect captures with light traps, an effect attributed to the direct competition from moonlight to light-attraction traps (Bishop *et al.* 2000; Lang *et al.* 2006). Limited insect availability may suppress activity and induce torpor in insectivorous bats; for example, *Nyctophilus gouldi* entered torpor at 30˚C in response to fasting (Neuweiler 2000). I examined bat activity in function of insect activity to describe these interactions in Adelaide City. To explain some interactions among bats, insects, the environment, and the Adelaide City landscape, the following research questions were developed: (1) what is the difference among sites in bat activity? (2) What are the effects of season, weather, moonlight, insect activity, and artificial light on bat activity? (3) What are the effects of season, weather, moon-light, and artificial light on insect activity?

Methods

Study site

This study was carried out in Adelaide, the capital city of South Australia (34° 52′ S, 138° 30′ E). The climate is temperate and characterised by warm summers (average summer maximum 28°C), cool winters (average winter maximum 16°C), and average rainfall of 563 mm per annum, measured from 1977 to 2000 (Australian Bureau of Statistics 2005). Adelaide City has two distinct built areas separated by the Torrens River. South of the river is the central business district (CBD) consisting of high-density buildings and high levels of vehicular traffic, light, and noise (371.2 ha). North Adelaide, situated north of the Torrens River, is a low-density residential area covering approximately 200 ha. Adelaide's built areas are surrounded by a belt of parkland that covers a total area of about 720 ha (Fig. 2.1). The parklands contain formal gardens, botanic and zoological gardens, small grassland remnants, riparian environments (including stormwater retention and drainage), active and formal recreation area (e.g. cricket grounds), passive and informal recreation (e.g. picnic areas) and large grassed areas with mature exotic and indigenous trees (pers. obs.).

During this study, I recorded bat activity patterns within the Adelaide City parklands. Four locations were monitored with detectors weekly, they were Adelaide West Terrace Cemetery, the Royal Zoological Gardens of South Australia, Rymill Park, and the Wilderness School sports park (hereafter referred to as cemetery, zoo, Rymill Park, and Wilderness School). An additional site, located at weir no. 1 (referred to as weir) on the Torrens River, was monitored when equipment was available. Monitoring locations were distributed across the parklands area, representing different microhabitats and resource availability (i.e. proximity to water and light) and providing secure locations for equipment (Fig 2.1).

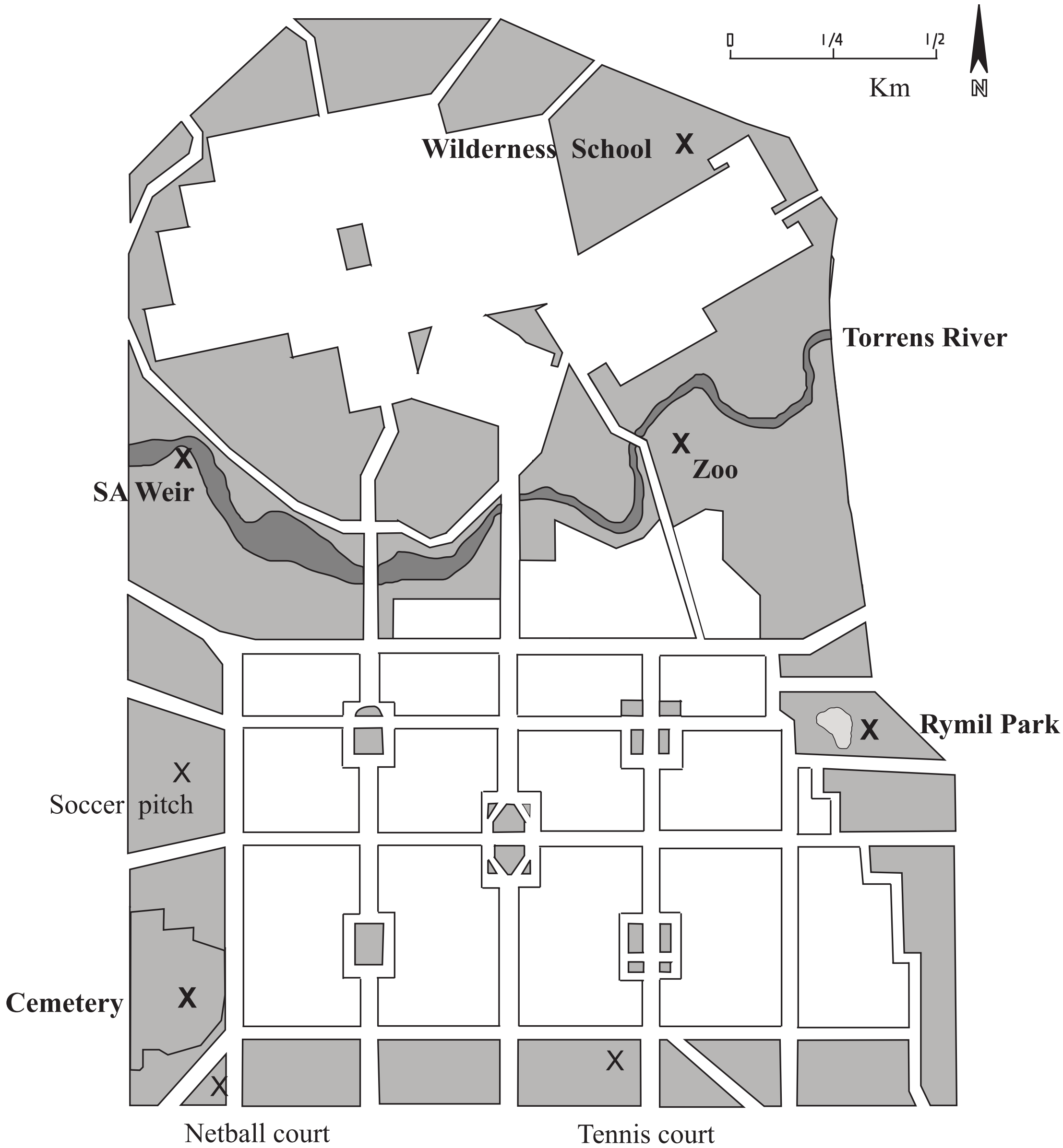


Fig. 2.1 Study sites within the Adelaide City parklands monitored with bat detectors. The cemetery, Wilderness school, zoo, and Rymill Park were monitored weekly from November 2005 to September 2006. Sampling at the weir occurred when equipment was available. Occasional transects were conducted at sporting areas in the south and west parklands, at a tennis court, netball court, and soccer pitch (adapted from Adelaide City Council 2006a).

Adelaide West Terrace Cemetery

Adelaide cemetery is characterised by old gravestones and is located west of the CBD. The cemetery has adjoining parks that provide buffer zones on the north and south borders. The site is recognised for its historic cultural value and is currently nominated for the Register of the National Estate (DEH 2006). The grounds cover 27.6 ha and are not artificially lit at night, making the cemetery one of the few relatively large, naturally dark parkland areas remaining in Adelaide City. Several ornamental and indigenous tree species occur around the site, with some remnant shrub and grassland vegetation. The bat detector for this site was placed on top of an olive hedge (*Olea europaea*), approximately 2 m high (Fig. 2.2 a and Fig. 2.2 b).

Royal Zoological Gardens of South Australia

Adelaide Zoological Gardens (zoo) are situated north-east of the CBD, bordered to the north and north-east by the Torrens River and to the south by a large parkland area named Botanic Park. The zoo displays a range of animal species. The grounds cover approximately 10 ha and are managed for human visitation and recreation. The area is lit periodically (dull yellow lights) at night for public functions, but is otherwise dark at night. The gardens consist of large exotic mature trees and shrubs that are maintained with high watering regimes. The bat detector was placed in a restricted access area underneath an elevated public walkway (about 5 m high). The detector was placed 1 m above the ground and the microphone was directed towards an enclosure with a shallow water pond (average depth about 80 cm) (Fig. 2.2 c and Fig. 2.2 d).

Rymill Park

Rymill Park is an informal public recreation park located east of the CBD. The Park has scattered landscape gardens but is dominated by irrigated turf areas and mature exotic and indigenous trees. It covers an area of approximately 15.5 ha. At the Park's centre is an artificially maintained lake, with an average depth of about 60 cm. Rymill Park is lit by isolated dull yellow lights at night. A small building (Rymill Café) is adjacent to the lake; the bat detector was placed on the roof of the Café at about 3 m height (Fig. 2.2 e and Fig. 2.2 f).

The Wilderness School

The Wilderness School grounds in North Adelaide are located within a large open parkland area that covers about 72 ha, encompassing a large turf area and tennis courts, and are used for sports and recreation. The sporting facilities are periodically lit in summer, but otherwise the area is one of the largest naturally dark parks in the Adelaide parklands. Large exotic and indigenous trees occur on the perimeter and within the park's interior, predominantly along walkways. The bat detector was placed on the roof of the Wilderness School's sports shed in the park, about 3 m high (Fig. 2.2 g and Fig. 2.2 h).

The Torrens River weir

The weir is located on the Torrens River between North Adelaide and Adelaide (Fig. 2.1). The weir maintains the water level for aesthetic purposes in the city, retaining a large water body covering approximately 15.7 ha. A restaurant and car park are adjacent to the weir; the area and the weir are flood-lit with white light at night. The river banks have reed beds of *Typha* species and *Phragmites australis*, as well as a mixture of native and exotic trees, and infestations of woody, grassy, and herbaceous weed species. The weir structure has a walkway for public crossing and a separate locked area, used by City Council maintenance and contract personnel. A detector was placed in the locked area on the weir, about 2 m above water level during this study (Fig. 2.2 i and Fig. 2.2 j).

Sports sites

Surveys with bat detectors were conducted at three sports parks within the west and south parklands (Fig. 2.1).   The soccer pitch has a turf area, while the netball and tennis courts have asphalt surfaces; all three sites have isolated trees along their perimeters. The sports sites were regularly lit with white spotlights during sporting events.


(a)


(b)


(c)


(d)


(e)


(f)


(g)


(h)

(i)

(j)

Fig. 2.2 Study sites and position of bat detectors in Adelaide City parklands. Sites included the cemetery (a), the detector was placed on a hedge (b); the zoo (c), detector placed underneath a public walkway overlooking a shallow water pond (d); Rymill Park (e) detector placed on the roof of Rymill Café (f); Wilderness School (g) detector positioned on the roof of a sports shed (h); and the Torrens River weir (i) detector placed in restricted access area on the weir structure (j).

Sampling bat activity with detectors

Bat activity was monitored with Anabat II® electronic bat detectors connected to Anabat CF Storage Zcaim (Titley Electronics, Ballina, NSW) from November 2005 to October 2006. Five detectors were calibrated by adjusting their sensitivity levels against an ultrasound frequency generator (bat chirper made by Tony Messian). Every week, one detector was placed at each of the study sites, left to record for 3 consecutive nights, and then collected for battery recharge and data download. Detector microphones were facing upwards except for the zoo microphone, which was directed above the water pond in order to avoid interference from the walkway structure. All detectors were placed in locked areas or on top of buildings to reduce the risk of theft and vandalism. Plastic containers housed the detectors to protect them against moisture damage during the sampling period.

Sampling bats at artificial lights

In addition to regular weekly monitoring, I conducted surveys with bat detectors in the Adelaide parklands at sporting areas with artificial lights (flood lights) from March to September 2006. A tennis court, netball court, and soccer pitch were surveyed with walked transects during naturally dark and artificially lit nights. At least two people were present during the naturally-dark surveys for safety reasons.

Three 20-min walked transects were completed on each sampling night. Commencing 30 min after sunset, three transects (one per site) were completed in random order. During the survey, I walked slowly along the perimeter of the pitch or court with a detector, holding the microphone towards the lights (whether off or on). When a bat was detected, I moved the microphone to follow that individual and ensure a clear recording. When possible, transects between conditions (lit and dark nights) occurred on the same or consecutive evenings; otherwise, the next night with the required condition was sampled. Nights with strong wind or heavy rain were not sampled. Surveys were conducted on 24 nights, recording 12 transects per condition (lights on or lights off).

Identification of bat calls

Call data recorded with bat detectors were downloaded to a computer using CFCread version 4.1 d then analysed using AnalookW version 3.2 o (Corben 2006) and matched against reference calls in the South Australian Museum collections. I sorted manually through sonograms of recorded bat calls in order to define activity, noting the number of calls, the time each call was made, and the species of bat identified through the structural characteristics of the call. An automated bat-call analysis program was available (AnaScheme designed by Matt Gibson University of Ballarat, Victoria), but it was not favoured over manual analysis for this study. Differentiating bat species from their vocalisations can be problematic and during analysis, when I encountered a call with the structural elements of both *C. gouldii* and *M. planiceps* species 4, but not clearly distinguishable as either, the call was recorded as *C. gouldii* / *M. planiceps*. Similarly, indistinct calls of *C. morio* and *V. vulturnus* were recorded as *C. morio* / *V. vulturnus*. Calls within the range of *V. darlingtoni* and *V. regulus* were listed as *V. darlingtoni / V. regulus* because these calls were often fragmented and lacked adequate information for definite identification. All other calls indistinguishable from reference samples were recorded as unknown species (Appendix 1). Only data recorded for whole nights were subject to analysis (i.e. dusk to dawn); partial recording occurred occasionally because of mechanical failure and these nights were not included in the analyses.

Data organisation and statistical analyses of bat activity

- To describe the difference in bat activity among five monitoring sites, I compared the activity at all sites on matched recording nights. Matched nights analyses were necessary to negate extraneous effects of daily or seasonal variation on bat activity. A non-parametric test, Friedman *k* two-way analysis of variance for matched data was used to test for differences in bat activity (number of bat calls) among sites. A non-parametric t-test (sign test) was used to pinpoint the difference, *P*-values were adjusted accordingly for the number of matched pairs (Glover and Mitchell 2004).
- Daily and monthly intervals were used to describe the activity distribution of different species at different sites. Average monthly bat activity was plotted for 4 sites: cemetery, Wilderness School, Rymill Park, and zoo. Average nightly activity for *C. gouldii*, *M. planiceps*, *C. morio*, and *T. australis* at 1-hr intervals after civil twilight in summer was plotted for the Wilderness School and Rymill Park. *Chalinolobus gouldii*, *M. planiceps*, and *C. morio* nightly activity at 1-hr intervals after civil twilight was plotted for the cemetery. Civil twilight times were accessed from Geoscience Australia (2006).
- The difference in bat activity among season was examined by comparing activity recorded during different seasons; data from 80 sample nights at Rymill Park were used in the analysis. Sample nights were grouped into: summer (Dec-Feb), autumn (Mar-May), winter (Jun-Aug), and spring (Sep-Nov). The Kruskal-Wallis test, a nonparametric analogue to a one-way analysis of variance for independent data, was used to test for a difference among season in activity with the mean separation technique Mann-Whitney *U* used to pinpoint differences (*P*-values adjusted as above) (Glover and Mitchell 2004).
- To assess the effect of weather on bat activity, call data from Rymill Park were compared to weather information from Kent Town weather station (Bureau of Meteorology 2006). Rymill is in proximity to Kent Town weather station, 2 km east of the city centre (station 023090), where daily weather observations were sourced (Bureau of Meteorology 2006). Wind information was recorded as the strongest gust (km/hr) in 24 hours; this method for recording wind was not deemed meaningful for this study because the strongest gust may occur during the day or as an isolated gust in an otherwise calm 24-hour period. However, wind

data recorded at Kent Town during the study period were positively correlated with temperature (Pearson's Correlation r = 0.316, $P = 0.004$, n = 80). Temperature data, recorded as the minimum temperature (˚C) in 24 hours, were considered adequate for this study; although, it is noted that temperature is not independent of wind. Spearman's Rho correlation coefficient for non-parametric data was used to test for a relationship between temperature and bat activity (Field 2003).

- The effect of rainfall on bat activity was tested on activity data collected at Rymill Park. Bat activity (number of calls) recorded during nights with rain events (greater than 1 mm precipitation in 24 hours, recorded at Kent Town), were compared to bat activity recorded on no-rainfall nights. The no-rainfall nights were defined as the next closest night with no rainfall recorded in the 24 hours at Kent Town, these nights were chosen randomly from either before or after the rain night. A paired-samples t-test was used to compare activity between conditions (Glover and Mitchell 2004).
- The relationship between moonlight and bat activity was tested on bat call data collected at Rymill Park during summer. Moonlight fluctuates according to its stage in the lunar cycle (average 28 days in length) and as such was considered independent of weather variables, such as temperature that fluctuates in response to atmospheric pressure. The illuminated fraction of the moon's disk for each sample night was accessed from the U.S. Naval Observatory, using Universal Time (UT) + 9.5 hrs to approximate central standard time in South Australia (Astronomical Applications Department 2006). Illumination fractions were taken at 10 mins to midnight (23:50) or at the next available time closest to midnight (for example illumination fractions output see Appendix 2). Fractions were multiplied by 0.1 to convert to a relative lux value, assuming full moon overhead is 0.1 lux (M. Lewicki, pers. comm. January 2006). Nights where cloud cover may have affected moonlight were not included in the analysis. Cloud data were accessed from the Adelaide Airport Bureau of Meteorology (station no. 23034) at midnight for each sample night. I used cloud classifications described by Milne *et al*. (2005); in particular, only nights where cloud amount = 0 or 1, or when cloud amount > 1 but only high cloud present were used in the analysis (Milne *et al.* 2005). The relationship between summer bat activity and moonlight for each

sample night was tested with Spearman's Rho correlation (Glover and Mitchell 2004).

- Finally, bat activity recorded at sports fields during transect surveys was organised into lit and unlit nights. For each site (soccer, tennis, and netball) transect nights were matched, so transects during lit conditions were matched to a consecutive night with the dark condition (lit versus unlit). The difference in the number of bat calls recorded between conditions was tested with a paired-samples t-test (Glover and Mitchell 2004).

Sampling insect activity

Nocturnal insects were collected in the Adelaide Zoo one night per week from December 2005 to September 2006 with passive and active traps, and extra trap nights were conducted during summer. One Malaise trap (passive) (Malaise 1937), which funnels flying insects into a collecting bottle, was set in a dark area near a water pond. One light trap (active) had a battery-powered fluorescent white light and a black ultraviolet light that actively attracted insects to a collection bottle. The light trap was also set in a dark area near a water pond. Collection bottles contained 70% alcohol solution. Traps were set after sunset and dismantled shortly after sunrise. Insects were taken from traps and stored in 70% alcohol, for later analysis.

Sticky insect traps were also used to sample nocturnal insect activity at artificial lights in Adelaide. Traps consisted of yellow A4 paper coated with Tangle-Trap® insect trap coating (Australian Entomological Supplies, Bangalow, NSW) stapled to cardboard backing for support. Two transects were used to measure insect concentrations at bright lights, 100-m line transects were extended away from an isolated bright light (flood light) into darkness. String was used to mark transects, about 2 m off the ground. Sticky traps were attached to the string transect, placed at 10-m intervals starting at the light source (0 m). Two other transects were completed with a similar method, except that the first 10-m period was sub-divided into 40-cm intervals to pinpoint the distance away from light critical to insect activity levels. Transects were set up after dusk and left for 1-3 hours, depending on weather conditions. All traps on a single transect were removed at the same time and clear plastic film (cling wrap) immediately placed over the sticky surface to allow storage and handling. The total number of insects caught on each sticky trap was recorded and noted against distance from light (m).

Data organisation and statistical analyses of insect data

Samples of insects collected with Malaise and light traps were organised into taxonomic order, size-classed, counted, and the biomass calculated using a combination of methods derived from Rogers *et al.* (1976), Sage (1982), and Sample *et al.* (1993). Size classes for insect body length were developed from pilot data, which showed a distinction between 4 length groups among the collected specimens: < 3, 3-8, 8-13, and > 13 mm. The mean body length was determined for each size group within each order, based on measurements of 30 individuals (see Sage 1982). For insect groups containing fewer than 30 individuals, all individuals were measured. Damaged specimens were not measured but were included in absolute counts. Length measurements were recorded using a stereo-microscope (Olympus SZX12, Japan) and a glass slide micrometer (M7.30 Minigrid, Southern Biological, Nunawading, VIC). Insect length was measured from the most anterior part of the head to the tip of the abdomen and noted to the nearest 0.05 mm (Fig. 2.3).

Biomass was calculated from the model describing the length-mass relationship of insects [Formula 1] (Rogers *et al.* 1976), substituting values of a and b (see formula) for different insect orders as determined by Sample *et al.* (1993). Sample *et al.* (1993) used data transformation techniques (natural logarithms) to describe linear relationships between different insect orders and their mass, producing constant values, a and b, for each insect order. For this study, those values of a and b corresponding to the appropriate insect order were entered with average length (L), calculated for collected specimens, into an equation that inverses the natural logarithm and produces biomass for any value of L [Formula 2] (Sample *et al.* 1993). The mass (mg) per individual was multiplied by the number of individuals to obtain insect biomass for statistical calculations.

[Formula 1]

Model describing length-mass relationships of insects, where m = mass (mg) and L = length (mm)

$$m = a(L)^b$$

[Formula 2]
Equation for biomass estimate using transformed values, where m = mass (mg), e = exponential function to inverse the natural logarithmic transformations, L = length (mm), a and b = values produced by Sample *et al*. (1993) for different insect orders.

$$m = e^{b}(L)a$$

Methods used to analyse relative abundance of insects (biomass) in function of environmental variables were similar to bat activity analyses (see *Data organisation and statistical analyses of bat call data*). The Kruskal-Wallis test was used to check for a difference in insect biomass among season: summer (Dec-Feb), autumn (Mar-May), winter (Jun-Aug), and spring (Sep-Nov). Separation tests were used to determine where differences occurred (*P*-values adjusted). Temperature (˚C) data were obtained from Kent Town weather station (Bureau of Meteorology 2006) for each insect sampling night and the relationship between insect biomass and temperature was tested with Spearman's Rho. The number of rainfall (mm) nights was inadequate for comparative tests with insect biomass.

The moon illumination fraction, converted to lux, for each insect sample date was determined from the U.S. Naval Observatory (Astronomical Applications Department 2006). Insect biomass in summer was related to the moonlight in lux for that night. Relationships were tested with Spearman's Rho.

Finally, insect biomass was related to the number of bat calls recorded at the zoo for each insect sampling night. Spearman's Rho correlation was used to test whether the number of bat calls increased with relative abundance of insects at the zoo.

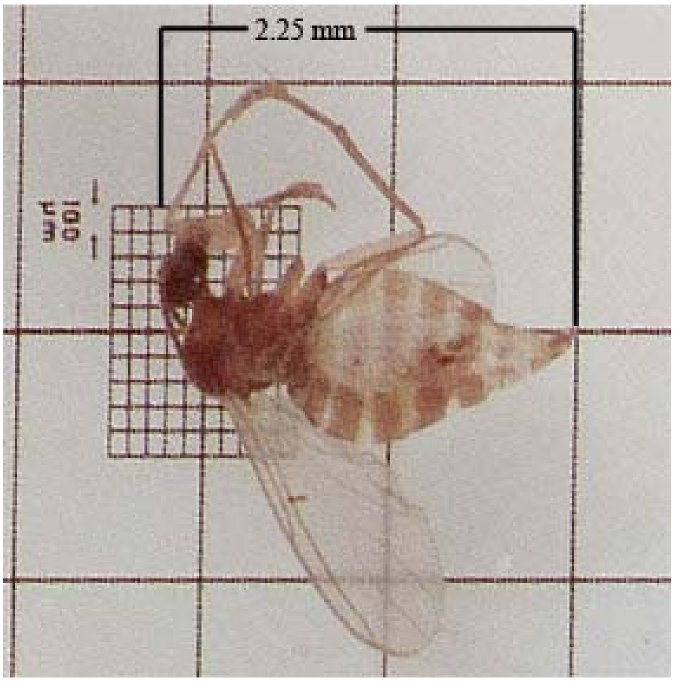


Fig. 2.3 The length of insects measured with a stereo-microscope and glass slide micrometer, was taken from the most anterior part of the head to the tip of the abdomen and noted to the nearest 0.05 mm.

Statistical analysis

The statistical package SPSS for Windows version 14.0 (SPSS 2005) was used to run all statistical tests. Significance levels were set at 0.05 except for analyses using separation techniques, where significance values were lowered according to the number of pairwise comparisons (Glover and Mitchell 2004). One-tail tests were set as default; two-tail tests were used if the direction of potential association between measured variables was unknown (for example difference in bat activity among sites). An attempt to transform the data had no satisfactory outcome. Bat call data recorded high variability compared to other variables such as temperature, and no uniform transformation method was suitable. Nonparametric or parametric tests were used where appropriate; data were tested for normality with the Kolmogorov-Smirnov test.

Results

General results

I analysed 18 340 bat calls recorded with detectors over 228 detector-nights from November 2005 to October 2006 at five monitoring sites in the Adelaide City parklands. At different sites, several data nights were missing because of mechanical failure or limitations in the availability of equipment. Only 9 nights were sampled at the weir (Table 2.1). Recording at the weir occurred mostly in December and January, the warmest months, so these data were separated for statistical tests. From detector recordings I identified the following taxa: Vespertilionidae: *Chalinolobus gouldii*, *C. morio*, *C. morio/Vespadelus vulturnus*, *V. darlingtoni/V. regulus*, *Nyctophilus geoffroyi*; and Molossidae: *Mormopterus planiceps* species 4, and *Tadarida australis* (Appendix 3). Most calls were recorded for *C. gouldii* (65.87%) and *M. planiceps* species 4 (19.37%); these species represented 93.65% of all calls analysed (including 8.41% of calls from *C. gouldii / M. planiceps* species 4, Table 2.2). *Chalinolobus morio* and *T. australis* represented 4.80% and 1.21% of all calls respectively, while several species groups, *C. morio / V. vulturnus*, *V. darlingtoni / V. regulus*, *Nyctophilus geoffroyi*, and unknown, had a combined total of less than 1% of all calls analysed (Table 2.2).

Table 2.1 Number of detector nights analysed from November 2005 to October 2006 at five sites in the Adelaide parklands

(Dec-Feb = summer, Mar-May = autumn, Jun-Aug = winter, Sep-Nov = spring)

no. of nights per season	Cemetery	Wilderness School	Rymill Park	Zoo	Weir
Dec-Feb	31	13	34	13	6
Mar-May	11	11	29	11	2
Jun-Aug	18	9	15	14	1
Sep-Nov	-	-	10	-	-
Total nights	60	33	88	38	9

Table 2.2 Bat species groups, number of calls, and percentage of calls recorded for each species group with bat detectors in the Adelaide City parklands from November 2005 to September 2006

Species	Calls	%
Family: Vespertilionidae		
C. gouldii	12 081	65.87
C. gouldii / M. planiceps	1 550	8.41
C. morio	880	4.80
C. morio / V. vulturnus	39	< 1
N. geoffroyi	2	< 1
V. darlingtoni / V. regulus	4	< 1
Family: Molossidae		
M. planiceps species 4	3 553	19.37
T. australis	222	1.21
Unknown	9	< 1
Total	18 340	100

Difference among sites in bat activity

I recorded bat calls over 29 matched nights from December 2005 to August 2006 at 4 monitoring sites: cemetery, Rymill Park, Wilderness School, and the zoo. From 29 matched nights, 9 nights included data collected at the weir (Table 2.3). Data were not normally distributed. The Wilderness School site recorded the highest number of bat calls, with 50% of total calls recorded (Fig. 2.4). The Rymill Park, cemetery, and weir sites recorded a similar number of bat calls, whereas the zoo recorded the lowest number of calls, with 3-4% of calls (Fig. 2.4). The difference among monitoring sites in the number of bat calls recorded per night was significant ($F_r = 40.433$, $P < 0.001$, df = 3, n = 29). In particular, the zoo recorded significantly fewer bat calls than the other sites (Table 2.4). Call data from 9 nights showed no significant difference between the weir and other sites in number of bat calls recorded per night (Table 2.4).

The zoo and Rymill Park recorded the most species groups over the entire sampling period with 6 groups; the cemetery and Wilderness School recorded 5 species groups, and the weir recorded the lowest number of species with a total of 3 species groups (Table 2.5). During matched night analysis, *Chalinolobus gouldii* and *M. planiceps* species 4 were the most commonly recorded species at all sites during

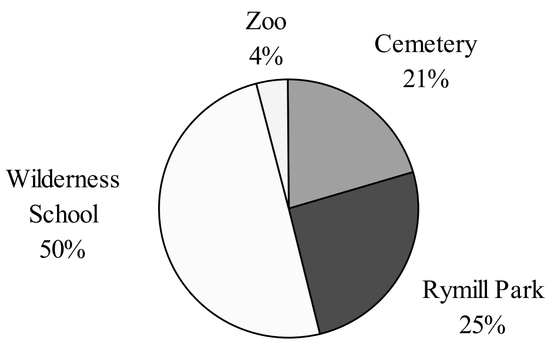
29 nights (Fig. 2.5) and 9 nights (Fig. 2.6). *Chalinolobus morio* was frequently recorded at the cemetery and very few calls from *N. geoffroyi* and *V. darlingtoni*/*V. regulus* were recorded. Both were recorded at the zoo and *V. darlingtoni*/*V. regulus* was also recorded at Rymill Park (Table 2.4).

Activity patterns varied monthly across sites from 212 detector-nights at 4 sites (cemetery = 58, Wilderness School = 33, Rymill Park = 81, zoo = 38) (Fig. 2.7). The cemetery recorded its highest bat activity during May (Fig. 2.7 a), April was the most bat-active month at the Wilderness school (Fig. 2.7 b), whereas the Rymill Park and zoo sites recorded most activity in December and January (Fig. 2.7 c and d). Nightly activity patterns for different bat species showed *C. gouldii* and *M. planiceps* activity was consistently higher throughout the night than other species at the cemetery (Fig. 2.8), Rymill Park (Fig. 2.9), and Wilderness School (Fig. 2.10) sites. *Chalinolobus morio* activity peaked at 7 hours after sunset at the cemetery (Fig. 2.8) and at 9 hours after sunset at the Wilderness School (Fig. 2.10), whereas *T. australis* activity peaked at different times of the night sites. Few calls for any species were recorded in the first 2 hours after civil twilight.

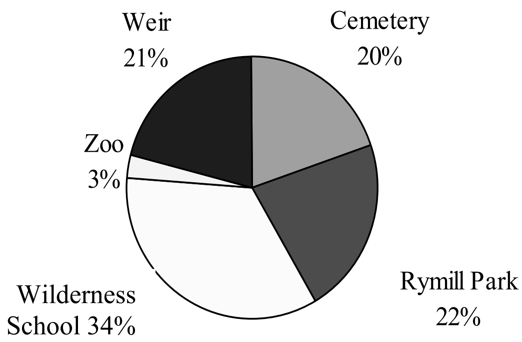
Table 2.3 Number of matched sample nights analysed for each season at five sites in the Adelaide parklands

(Dec-Feb = summer, Mar-May = autumn, Jun-Aug = winter, Sep-Nov = spring)

	Cemetery	Wilderness School	Rymill Park	Zoo	Weir
Dec-Feb no. of nights	13	13	13	13	6
Mar-May no. of nights	11	11	11	11	2
Jun-Aug no. of nights	5	5	5	5	1
Sep-Nov no. of nights	-	-	-	-	-
Total nights	29	29	29	29	9



(a)



(b)

Fig. 2.4 Percentage of bat calls recorded at different sites in the Adelaide parklands over 29 matched nights at Wilderness School, Rymill Park, the cemetery, and the zoo (a), and over 9 matched nights including data collected at the weir site (b).

Table 2.4 Number of calls and median calls per night recorded with detectors over 29 and 9 matched nights at different sites in the Adelaide parklands; *P*-values resulting from pairwise comparisons with a sign test on median calls per night at each site

	Total no. calls	Median calls n = 29	Median calls n = 9	Cemetery	Wilderness School	Rymill Park	Zoo	Weir	
Cemetery	2 369	57	42	1.000	0.063	0.265	< 0.001*	0.508	Cemetery
Wilderness School	5 774	153	104		1.000	0.063	< 0.001*	1.000	Wilderness School
Rymill Park	2 935	92	41			1.000	< 0.001*	1.000	Rymill Park
Zoo	484	10	4				1.000	0.508	Zoo
Weir	1 295	-	12					1.000	Weir

*significantly different sites tested with paired comparison sign test, *P*-values significant at α < 0.0083 for 6 pairwise comparisons (4 sites) and α < 0.0125 for 4 pairwise comparisons, comparing activity at all sites to the activity at the weir (Glover and Mitchell 2004).

Table 2.5 Bat species groups recorded at five sites in the Adelaide parklands

Species	Cemetery	Wilderness School	Rymill Park	Zoo	Weir
Family: Vespertilionidae					
C. gouldii	✓	✓	✓	✓	✓
C. morio	✓	✓	✓	✓	x
C. morio / V. vulturnus	✓	x	✓	x	x
N. geoffroyi	x	x	x	✓	x
V. darlingtoni / *V. regulus*	x	✓	x	✓	x
Family: Molossidae					
M. planiceps species 4	✓	✓	✓	✓	✓
T. australis	✓	✓	✓	✓	✓
Total	5	5	6	6	3

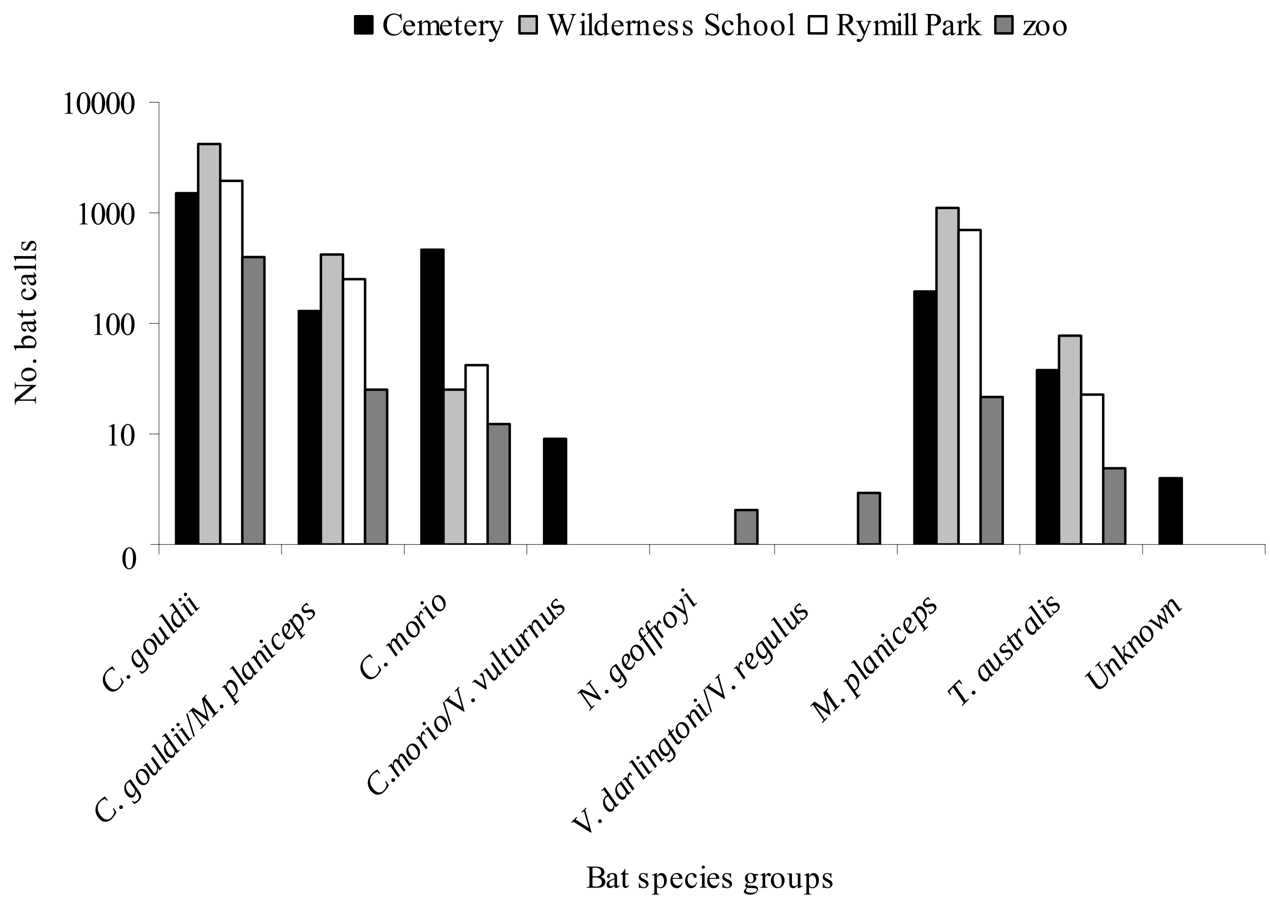


Fig. 2.5 Number of bat calls noted on a logarithmic scale for each species group among four sample sites: the cemetery, Wilderness School, Rymill Park, and zoo, and recorded with detectors over 29 matched nights.

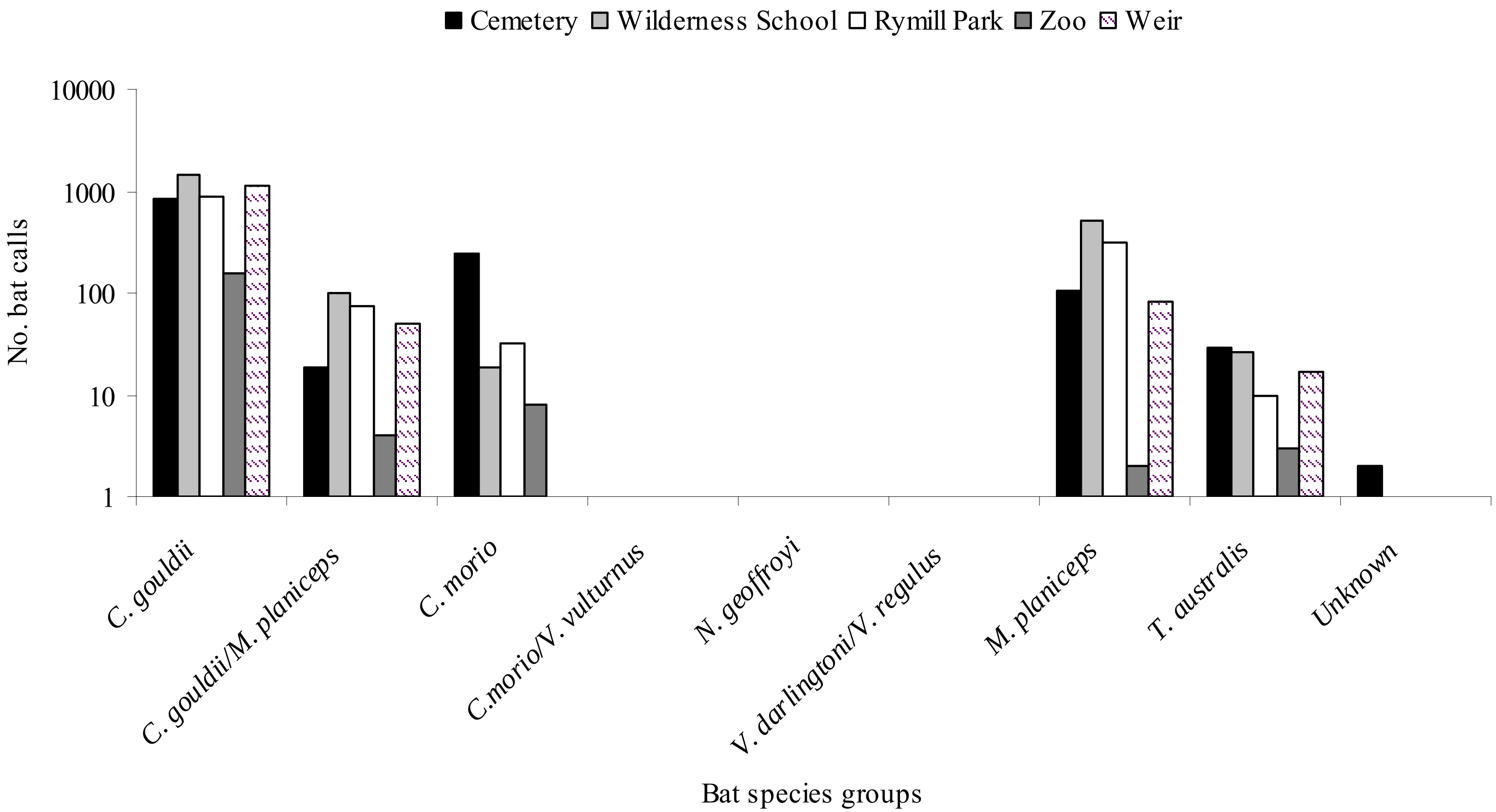


Fig. 2.6 Number of bat calls noted on a logarithmic scale for species groups among five sample sites, the cemetery, Wilderness School, Rymill Park, zoo, and weir, and recorded with detectors over 9 matched nights.

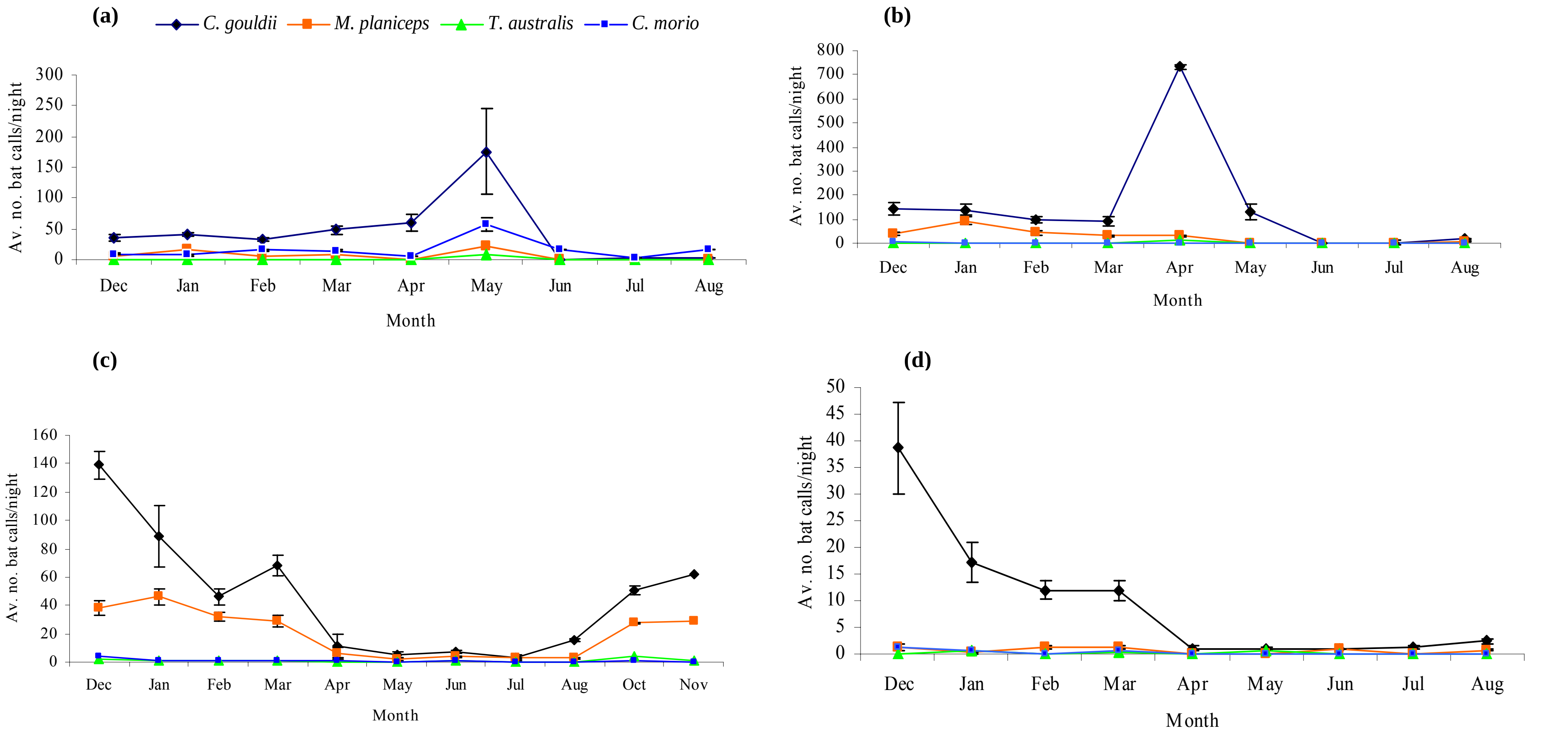


Fig. 2.7 Average number of bat calls per night from *Chalinolobus gouldii*, *Mormopterus planiceps*, *Tadarida australis*, and *Chalinolobus morio* in monthly intervals at the cemetery (a), Wilderness School (b), Rymill Park (c), and zoo (d). The standard error of average calls per night is shown by error bars for the 2 most commonly recorded species at each site.

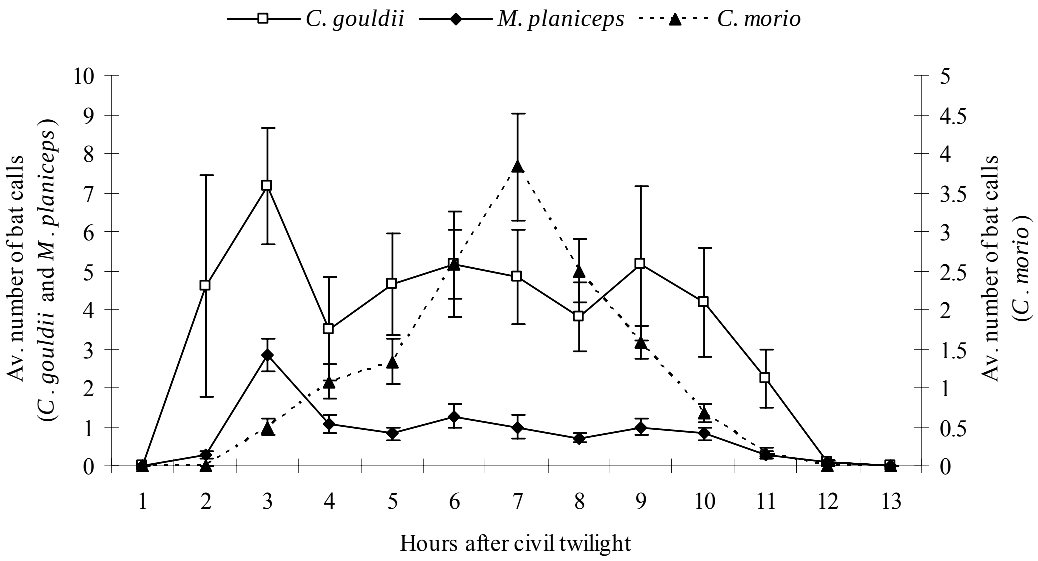


Fig. 2.8 Average number of bat calls detected for each hour after civil twilight for *Chalinolobus gouldii*, *Mormopterus planiceps*, and *Chalinolobus morio* over 12 nights at the cemetery in summer. Standard error of average calls per night is indicated by error bars.

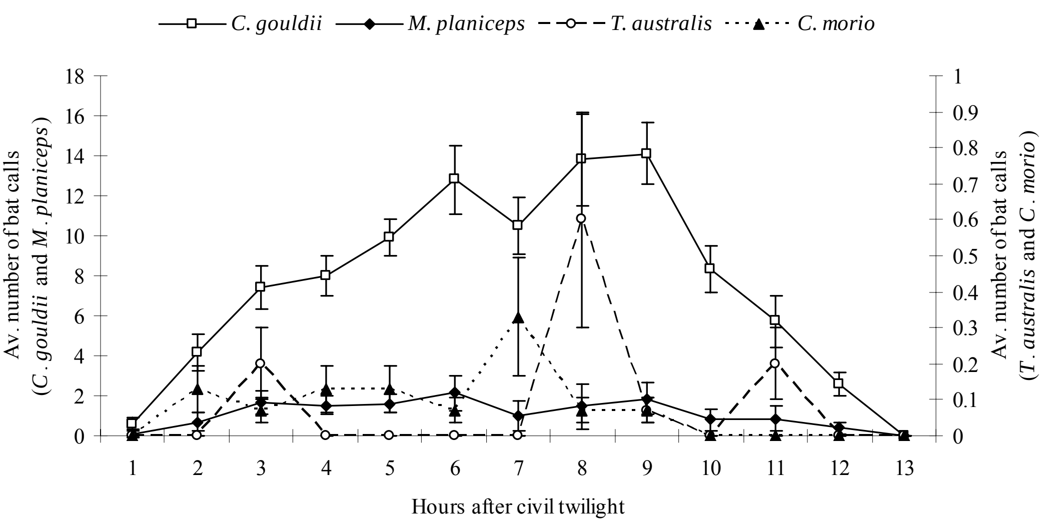


Fig. 2.9 Average number of bat calls detected for each hour after civil twilight for *Chalinolobus gouldii*, *Mormopterus planiceps*, *Chalinolobus morio*, and *Tadarida australis* over 15 nights at Rymill Park in summer. Standard error of average calls per night is indicated by error bars.

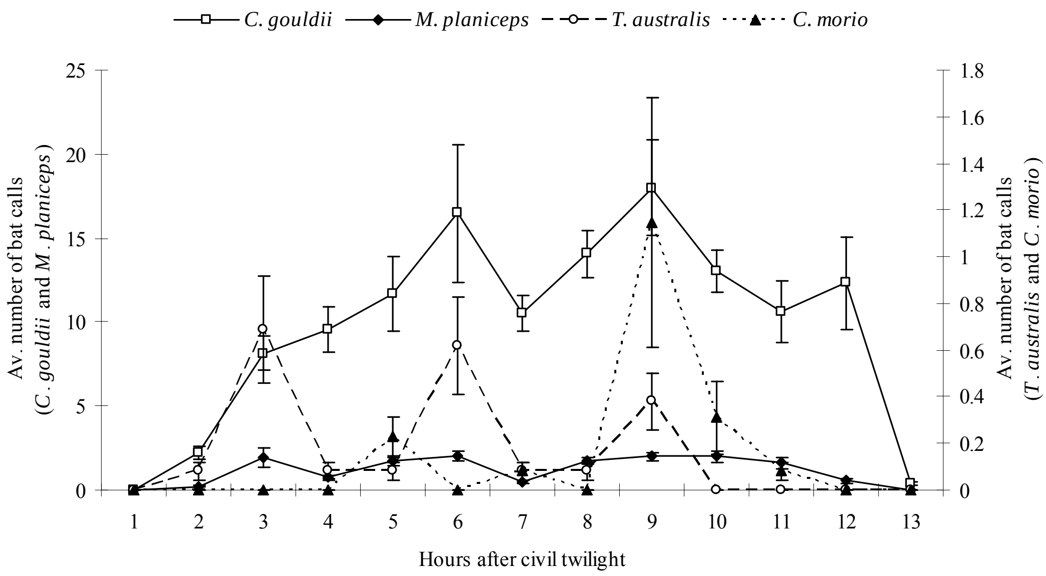


Fig. 2.10 Average number of bat calls detected for each hour after civil twilight for *Chalinolobus gouldii*, *Mormopterus planiceps*, *Chalinolobus morio*, and *Tadarida australis* over 13 nights at the Wilderness School in summer. Standard error of average calls per night is indicated by error bars.

The effect of season on bat activity

At Rymill Park 7 109 bat calls were recorded over 88 nights from November 2005 to October 2006. The highest numbers of species were recorded during autumn, including *N. geoffroyi* and *Vespadelus* species. No difference was observed between the number of species groups detected and other seasons (summer, winter, or spring) (Table 2.6). From those data, the median number of bat calls per night was highest in summer (median = 125.50 call passes per night), spring recorded moderate activity and autumn and winter recorded relatively low median calls per night (Table 2.7). The difference in the number of bat calls among seasons was significant (KW = 39.476, $P < 0.001$, df = 3, n = 87). In particular, the number of calls recorded in summer was significantly higher than the number of calls recorded in autumn or winter (Table 2.7).

Seasonal variation in bat activity was different among sites. The Rymill Park data showed typical seasonal variation in activity that peaked in summer (Fig. 2.7c); however, the cemetery and Wilderness School sites recorded different seasonal activity patterns, with high levels of activity occurring in autumn (Fig. 2.7a and Fig. 2.7b). The difference in bat activity among season (summer, autumn and winter) at the Wilderness School and cemetery was significant (Wilderness School: KW =

10.170, df = 2, *P* = 0.006; cemetery: KW = 28.500, df = 2, *P* < 0.001). Summer and autumn activity was not different at either site and autumn recorded significantly more activity than did winter (Wilderness School: autumn and winter MW = 21.500, *P* = 0.031, n = 20; cemetery: autumn and winter MW = 9.500, *P* <0.001, n = 28).

Table 2.6 Species groups recorded among season; data collected from all sites in the Adelaide City parklands

Species	Summer	Autumn	Winter	Spring
Family: Vespertilionidae				
C. gouldii	✓	✓	✓	✓
C. morio	✓	✓	✓	✓
C. morio / V. vulturnus	✓	✓	✓	x
N. geoffroyi	x	✓	x	x
V. darlingtoni / *V. regulus*	x	✓	x	✓
Family: Molossidae				
M. planiceps species 4	✓	✓	✓	✓
T. australis	✓	✓	✓	✓
Total	5	7	5	5

Table 2.7 Number of sample nights, number of bat calls and median number of calls per night recorded during summer, autumn, winter, and spring, and *P*-values from pairwise comparisons with a sign test on median calls per night between seasons

	Sample nights	Total no. calls	Median calls/night	Summer	Autumn	Winter	Spring	
Summer	34	4 951	125.50	1.000	< 0.001*	< 0.001*	0.047	Summer
Autumn	28	1 203	13.00		1.000	0.210	0.060	Autumn
Winter	15	193	9.00			1.000	0.003*	Winter
Spring	10	761	38.00				1.000	Spring
	80	6 672						

*significantly different seasons with pairwise comparisons sign test, *P*-values significant at α < 0.0125 for 4 comparisons (4 seasons).

The effect of weather on bat activity

The number of bat calls recorded per night at Rymill Park increased exponentially with temperature; a distinct kick in activity occurred at approximately 12˚C (Fig. 2.11). The same pattern was recorded at the zoo over 31 nights and a burst in activity occurred at around the same temperature (Fig. 2.12). A positive association between logarithmic transformed temperature and bat calls was significant (Rymill Park: S_r = 0.742, $P < 0.001$, n = 87; zoo: S_r = 0.638, $P < 0.001$, n = 31) (Fig. 2.11 and Fig. 2.12). A difference in the number of bat species detected between cool and warm temperatures was noted, *N. geoffroyi* and *Vespadelus* species were not recorded at temperatures less than 12˚C (Table 2.8).

Consistently fewer calls were recorded for all species during rain nights compared to no-rain nights (Fig. 2.13). Rainfall events, greater than 1 mm in 24 hrs, occurred on 14 days during the sample period. Rain and no rain data were parametric (KS test rain: $P = 0.298$, no rain: $P = 0.738$). The number of calls recorded on no rain nights (mean calls per night = 107.07 ± 29.49) was significantly higher than recorded on rain nights (mean calls per night = 27.00 ± 8.48) (t = -2.887, df = 13, $P = 0.013$). No difference in species assemblage between rainfall and no rainfall nights was apparent.

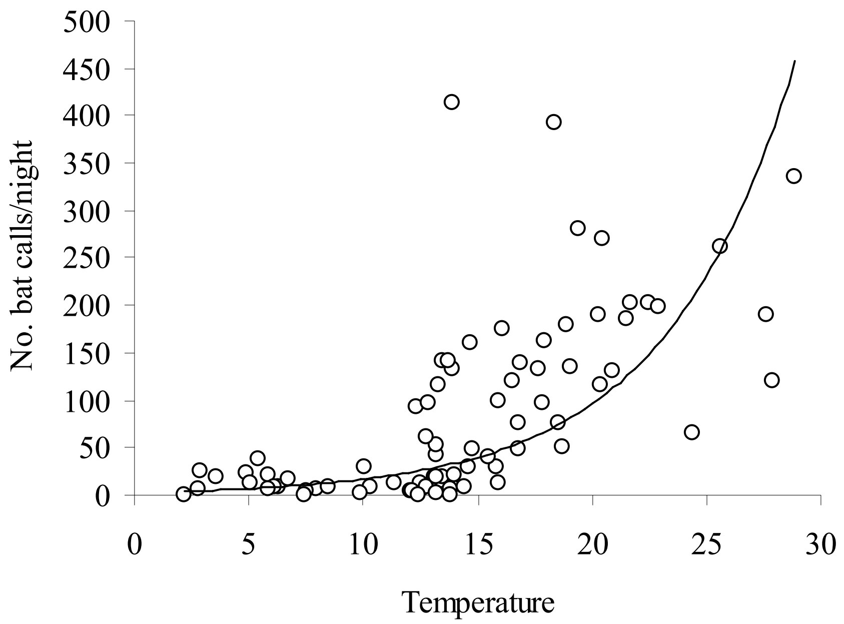


Fig. 2.11 Number of bat calls with minimum nightly temperature (˚C) per night, recorded at Rymill Park.

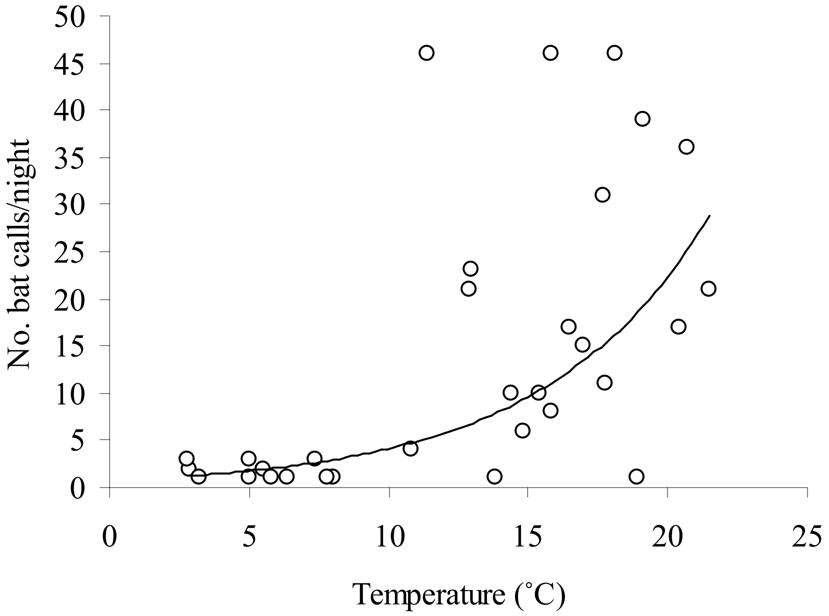


Fig. 2.12 Number of bat calls with minimum nightly temperature (˚C) per night, recorded at Adelaide zoo.

Table 2.8 Bat species recorded with detectors during cool (< 12˚C minimum temperature) and mild (> 12˚C minimum temperature) conditions

Species	< 12˚C	> 12˚C
Family: Vespertilionidae		
C. gouldii	✓	✓
C. morio	✓	✓
C. morio / V. vulturnus	x	✓
N. geoffroyi	x	✓
V. darlingtoni / *V. regulus*	x	✓
Family: Molossidae		
M. planiceps species 4	✓	✓
T. australis	✓	✓
Total	4	7

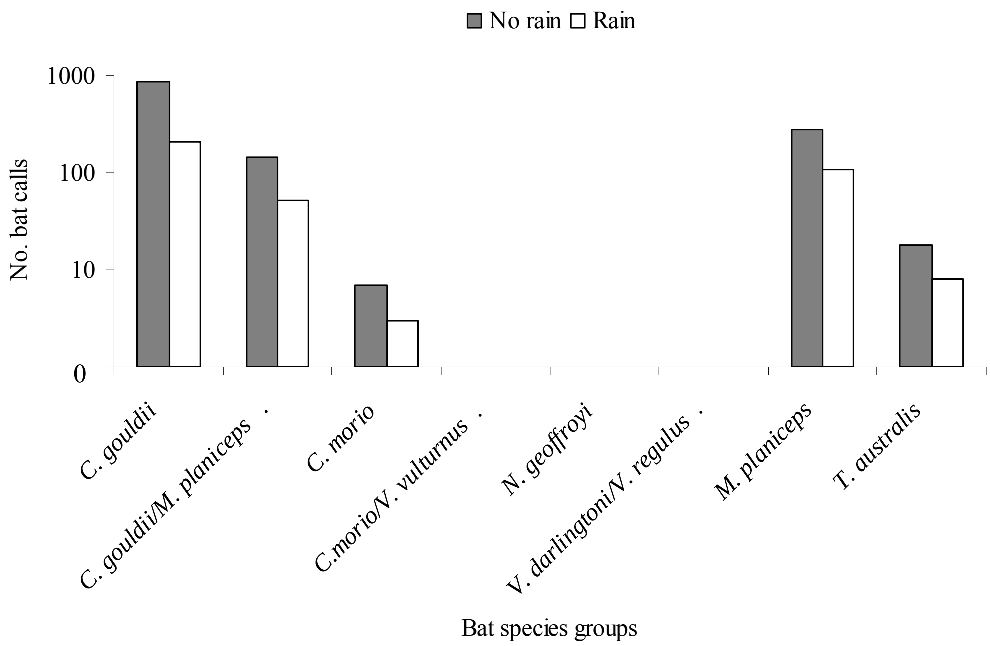


Fig. 2.13 Number of bat calls recorded on a logarithmic scale for rain and no rain nights for different species groups (n = 14 nights per condition).

The effect of moon phase on bat activity in summer at Rymill Park

A significant negative relationship was found between lunar light and the number of bat calls recorded during clear nights (low cloud cover) in summer at Rymill Park (S_r = -0.531, P = 0.003, n = 26) (Fig. 2.14). The relationship between bat calls recorded during summer at the cemetery and moonlight was tested with a Spearman's Rho correlation; 23 nights were available from summer sampling and no significant association was determined there (S_r = -0.185, P = 0.198, n = 23).

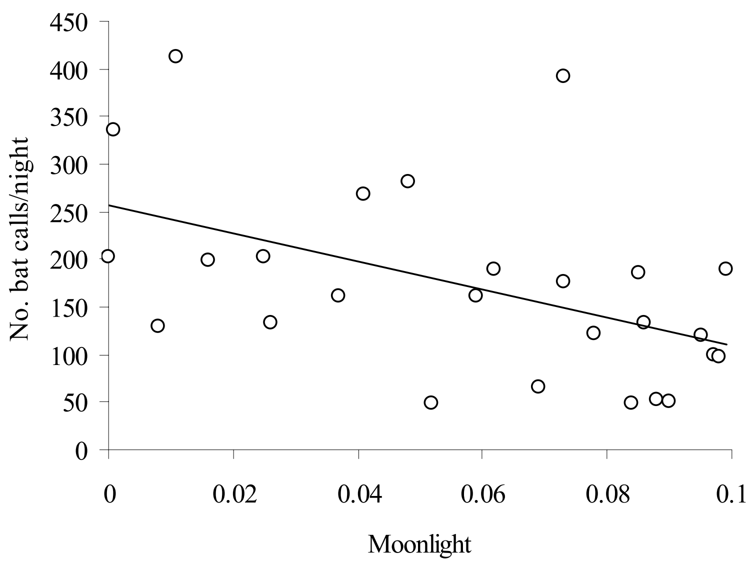


Fig. 2.14 Number of bat calls and the moon illumination fraction recorded at Rymill Park during summer.

Bat activity at artificial light

I completed 24 transects with bat detectors, 12 per condition (lights off and on) at sports fields in the west and south parklands. Two bat species, *C. gouldii* and *M. planiceps* species 4, were recorded during transects with lights on. During transects with lights off I recorded *C. gouldii* and *M. planiceps* species 4, plus three additional species: *T. australis*, *C. morio*, and *Vespadelus* species (Table 2.9). Data were parametric (Kolmogorov-Smirnov: lights on $P = 0.180$; lights off $P = 0.829$). Matched comparisons showed no significant difference between conditions in the number of bat calls recorded ($t = 0.412$, $P = 0.688$, df = 11).

Table 2.9 Number of matched transects, study site, number of calls and the bat species detected during lit and unlit nights at sports fields in the Adelaide parklands

Bat species: (Cg) *Chalinolobus gouldii*, (Mp) *Mormopterus planiceps* species 4, (Cm) *Chalinolobus morio*, (Ta) *Tadarida australis*, (Vr/Vd) *Vespadelus regulus* / *V. darlingtoni*

Survey sites: N = Netball court, T = Tennis court, S = Soccer pitch

Matched		LIGHTS OFF			LIGHTS ON		
Transects	Site	Date	no. calls	Bat species	Date	no. calls	Bat species
1	N	25/3/06	9	Mp, Cg, Ta	21/03/06	29	Mp, Cg
2	N	19/8/06	4	Mp	21/08/06	1	Cg
3	N	27/8/06	8	Mp, Cg	28/08/06	0	-
4	T	25/3/06	26	Mp, Cg	21/03/06	15	Mp, Cg
5	T	21/5/06	1	Mp	22/05/06	0	-
6	T	27/8/06	1	Mp	28/08/06	5	Mp, Cg
7	T	1/10/06	12	Mp, Cg, Cm, Vr/Vd	3/10/06	0	-
8	S	25/3/06	7	Mp, Cg	21/03/06	32	Mp, Cg
9	S	23/4/06	2	Mp	10/4/06	17	Mp, Cg
10	S	21/5/06	0	-	22/05/06	1	Cg
11	S	20/8/06	13	Mp, Cg	21/8/06	0	-
12	S	27/8/06	0	-	28/8/06	1	Mp/Cg

Insects collected at the zoo

Nocturnal invertebrates (Phylum: Arthropoda) were collected with a Malaise trap over 33 weeks and with a light trap for 27 weeks (Table 2.10). The light trap attracted and collected many more invertebrates than did the Malaise trap (median biomass Malaise = 23.67 mg versus light trap median = 313.85 mg); although, the two collection methods showed a similar capture pattern (Fig. 2.15). In total I captured 10 107 individuals, predominantly insects (Class: Insecta), but also a few spiders (Class: Arachnida). The combined biomass of all captured invertebrates was 9 350.07 mg. Specimens represented at least 13 taxonomic orders; body length ranged from 0.1-40.0 mm, and individual biomass varied from 0.12-262.98 mg (Table 2.11).

Table 2.10 Number of insect collection nights with Malaise and light traps from November 2005 to September 2006 in the Adelaide zoo

(Dec-Feb = summer, Mar-May = autumn, Jun-Aug = winter, Sep-Nov = spring)

no. of nights per season	Malaise	Light trap
Dec-Feb	16	7
Mar-May	13	11
Jun-Aug	8	9
Sep-Nov	-	-
Total nights	37	27

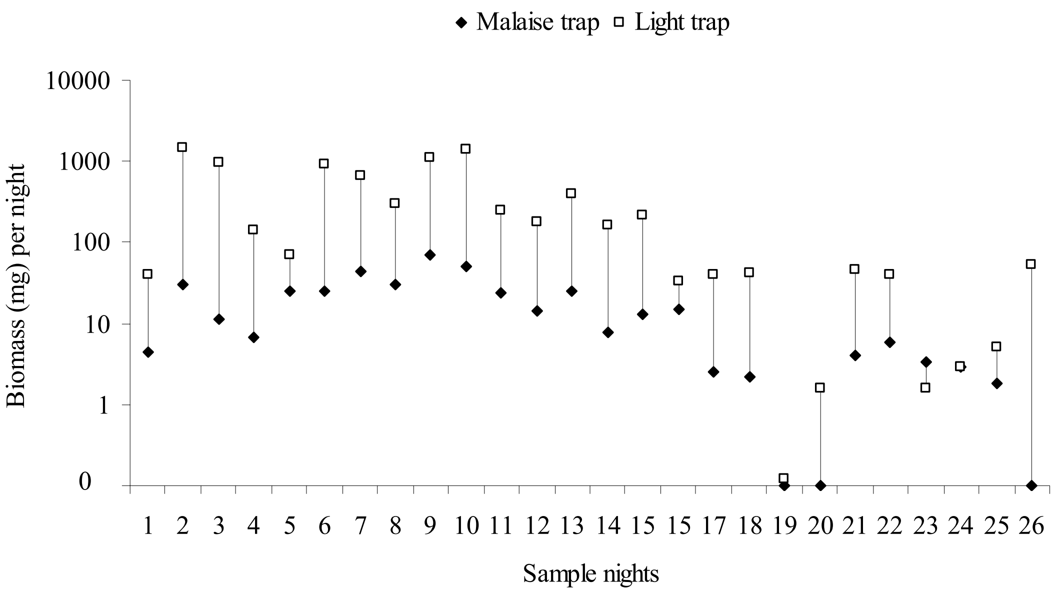


Fig. 2.15 Capture patterns of nocturnal insects (biomass in mg per night) on a logarithmic scale with a Malaise trap and light trap at the Adelaide zoo.

Table 2.11 Invertebrates collected at the zoo with Malaise and light traps. Arthropod order, length range, number of individuals measured to obtain average length, and the biomass (mg) per individual were recorded. Biomass was calculated using a and b values determined by Sample *et al*. (1993) for different Arthropod orders (see methods in text)

Order	Size class (mm)	Range (mm)	Number measured	Average Length (mm)	a	b	Biomass/individual mg = $e^b(L)^a$
Mix	< 3	0.7 – 2.9	100	1.8190 ± 0.0480	2.494	-3.628	0.118141470
Neuroptera	3 - 8	3.2 – 7.8	30	4.7433 ± 0.2604	2.570	-4.483	0.617426069
	8 – 13	8.0 – 9.4	10	2.5700 ± 0.1507	2.570	-4.483	0.127816218
Ephemeroptera	3 – 8	3.1 – 4.3	30	3.4800 ± 0.04970	2.494	-3.628	0.595769484
Lepidoptera	3 – 8	3.1 – 7.8	30	5.9267 ± 0.2088	2.959	-5.036	1.257901086
	8 – 13	8.1 – 11.3	30	9.4133 ± 0.1737	2.959	-5.036	4.945329925
Trichoptera	3 – 8	3.2 – 7.8	30	5.2367 ± 0.2202	3.044	-4.610	1.537142255
	8 – 13	8.1 – 12.2	30	9.8467 ± 0.2434	3.044	-4.610	10.50701492
Hemiptera	3 – 8	3.1 – 4.6	9	3.8333 ± 0.1893	3.075	-4.784	0.520980642
Coleoptera	3 – 8	3.2 – 7.8	30	5.4100 ± 0.2544	2.492	-3.247	2.612001379
	8 – 13	8.1 – 12.2	30	9.9167 ± 0.1988	2.492	-3.247	11.82477315
Hymenoptera	3 – 8	4.3 – 7.4	30	5.2200 ± 0.1172	2.696	-4.284	1.186648557
	8 – 13	8.1 – 9.2	7	8.6000 ± 0.1746	2.696	-4.284	4.559217008
Diptera	3 – 8	3.3 – 7.9	30	4.4367 ± 0.1752	2.213	-3.184	1.119825339
	> 13	13.4	1	13.4	2.213	-3.184	12.92674817
Dermaptera	3 – 8	5.1 – 7.4	7	6.4143 +-0.3011	2.494	-3.628	2.737851539
Blattodea	> 13	22	1	22	2.494	-3.628	59.20819010
Odonata	> 13	35	2	35	2.494	-3.628	188.4887014
Orthoptera	> 13	40	1	40	2.494	-3.628	262.9766799
Other e.g. Aranaea					2.494	-3.628	

The effect of season on invertebrate biomass

The highest median biomass of insects collected per night was recorded in summer with the Malaise trap and in autumn with the light trap (Fig. 2.16). Biomass of insects collected per night with both trap types was significantly different among seasons: summer, autumn, or winter (Malaise: KW = 17.370, $P < 0.001$, df = 2; light: KW = 13.249, $P = 0.001$, df = 2) (Table 2.12 and Table 2.13).

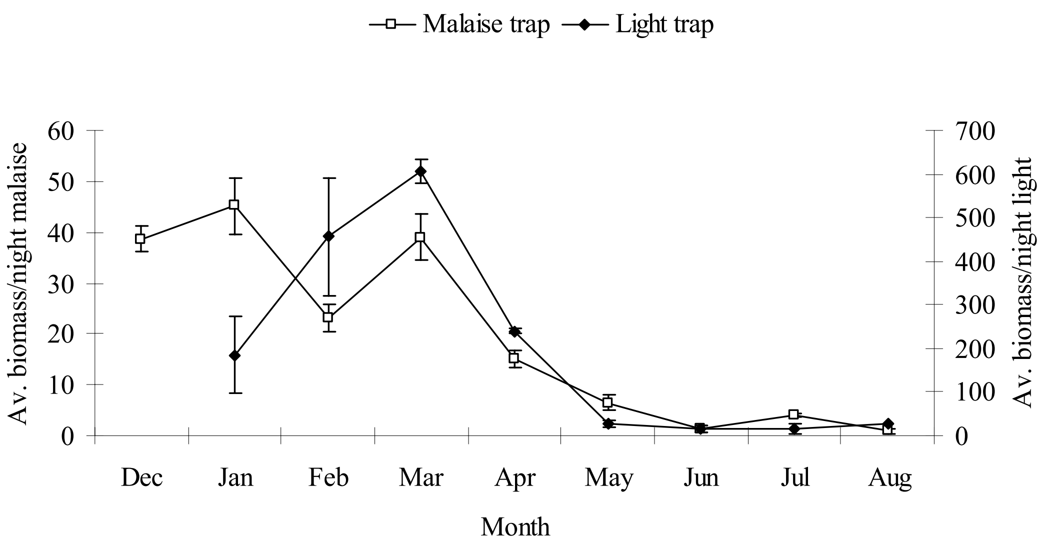


Fig. 2.16 Monthly variation in nocturnal insects (average biomass in mg per night) collected with a Malaise trap and a light trap at the Adelaide zoo. Standard error of average biomass is shown by error bars.

Table 2.12 Number of sample nights, total biomass per season, and median biomass per night collected with a Malaise trap at the Adelaide zoo, and *P*-values from pairwise comparisons with a sign test on median biomass per night between seasons

	Malaise no. nights	Total biomass (mg)	Median biomass/night	Summer	Autumn	Winter	
Summer	16	577.27	27.72	1.000	0.092	< 0.001*	Summer
Autumn	13	281.01	15.06		1.000	< 0.001*	Autumn
Winter	8	17.75	2.34			1.000	Winter
Total	37	976.03	-				

*significantly different seasons tested with the pairwise comparison sign test, *P*-values significant at α < 0.017 for 3 comparisons (3 seasons).

Table 2.13 Number of sample nights, total biomass per season, and median biomass per night collected with a light trap at the Adelaide zoo, and *P*-values from pairwise comparisons with a sign test on median biomass per night between seasons

	Light no. nights	Total biomass (mg)	Median biomass/night	Summer	Autumn	Winter	
Summer	8	14 220.93	788.36	1.000	0.092	< 0.001*	Summer
Autumn	11	4 098.69	218.46		1.000	< 0.001*	Autumn
Winter	9	153.42	4.30			1.000	Winter
Total	27	976.03	-				

*significantly different seasons tested with the pairwise comparison sign test, *P*-values significant at α < 0.017 for 3 comparisons (3 seasons).

The effect of temperature on insect biomass

Insect biomass collected with both Malaise and light traps increased exponentially with temperature and, as did bat activity, increased with a burst at around 12˚C (Fig. 2.17 and Fig. 2.18). Data were logarithmic-transformed and linear correlation analyses between insect biomass and temperature were statistically significant (Malaise: $S_r = 0.505$, $P < 0.001$, n =35; light: $S_r = 0.634$, $P < 0.001$, n = 27).

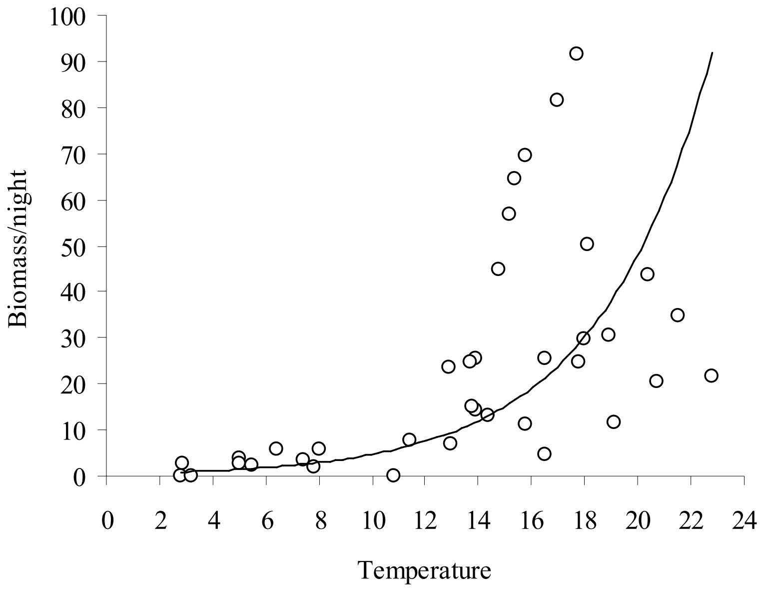


Fig. 2.17 Relationship between temperature (˚C) and insect biomass (mg) per night, for insects captured with a Malaise trap at the Adelaide zoo.

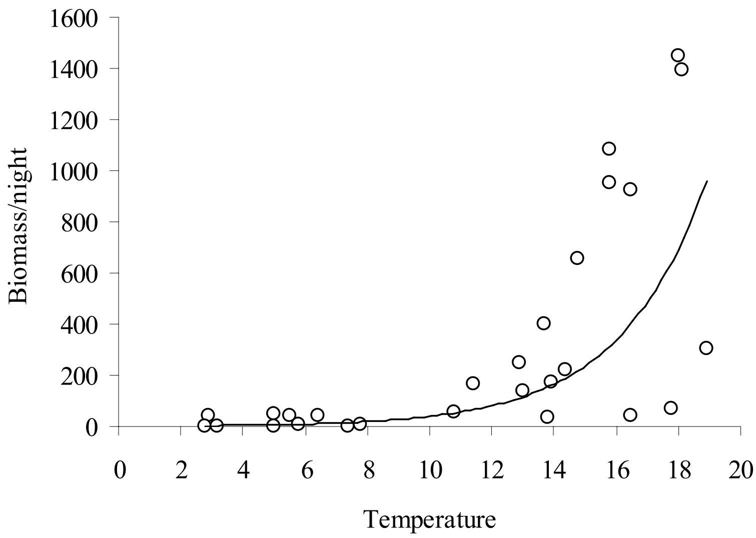


Fig. 2.18 Relationship between temperature (˚C) and insect biomass (mg) per night, for insects captured with a light trap (UV and white light) at the Adelaide zoo.

The effect of moonlight on insect biomass

I found that moonlight did not suppress insect activity at the zoo, collected with a Malaise trap. No significant relationship was observed between moonlight and insect biomass collected in summer with a Malaise trap ($S_r = 0.056$, $P = 0.419$, $n = 16$). The sample size for light-trapped insects in summer was inadequate for correlation analyses ($n = 7$).

The effect of insect biomass on bat activity

I examined bat activity as a function of insect biomass at the zoo. I found a significant positive relationship between the number of bat calls and the biomass of insects collected with both insect-trap types (Malaise: $S_r = 0.584$, $P < 0.001$, $n = 30$; light: $S_r = 0.654$, $p < 0.001$, $n = 23$) (Fig. 2.19 and Fig. 2.20).

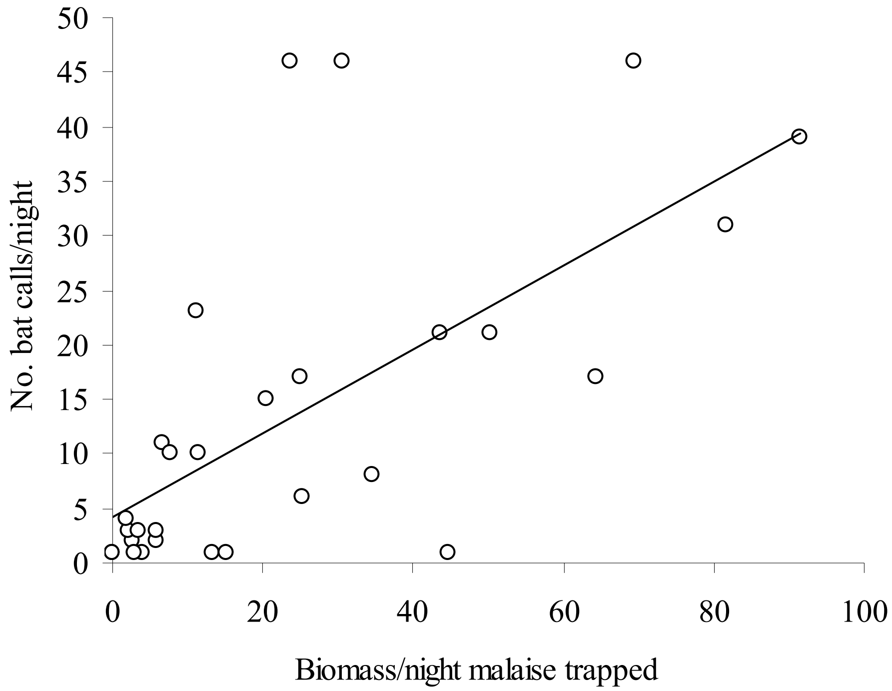


Fig. 2.19 Relationship between the number of bat calls and insect biomass (mg) per night, for insects collected with a Malaise trap at the Adelaide zoo.

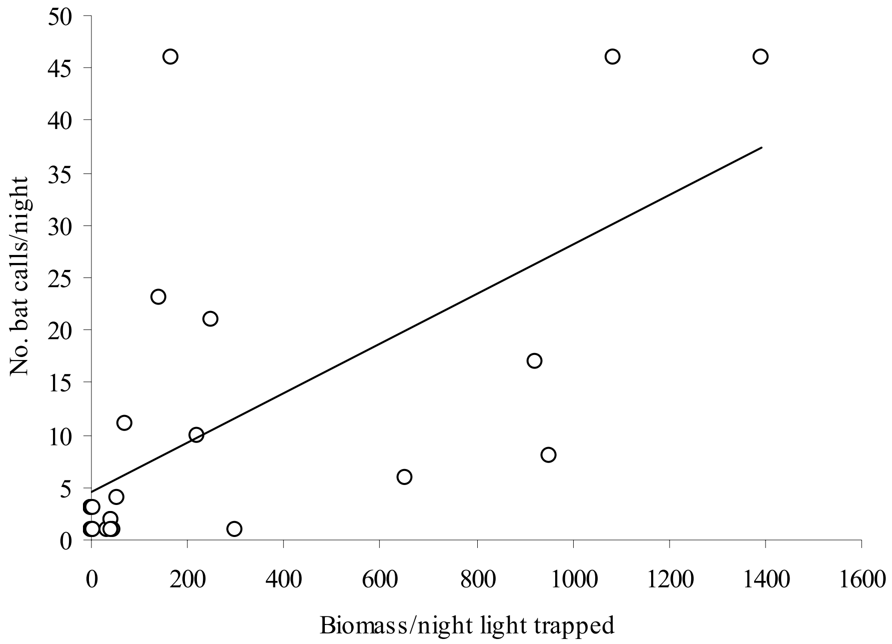


Fig. 2.20 Relationship between the number of bat calls and insect biomass (mg) per night, for insects collected with a light trap at the Adelaide zoo.

Effect of artificial light on insect activity

Four transects with sticky traps away from lights showed insect activity (numbers of insects per trap) was concentrated at artificial lights in the city. The first two transects showed that activity was greatest at 10 m from a light source (Fig. 2.21), while the third and fourth transects refined the distance at which insect activity was greatest to within the first 6 m of a light output (Fig. 2.22).

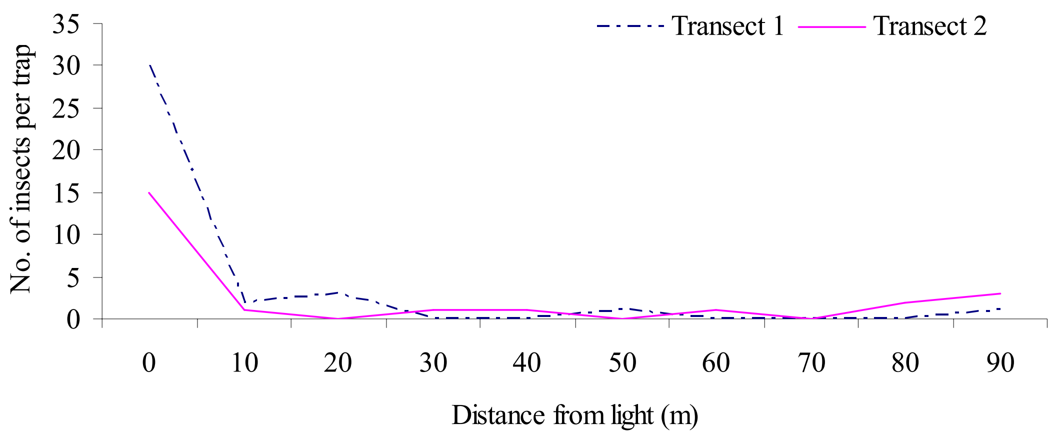


Fig. 2.21 Transects with sticky traps away from a light source; insect abundance (number of individuals per trap) recorded at 10-m intervals away from light output.

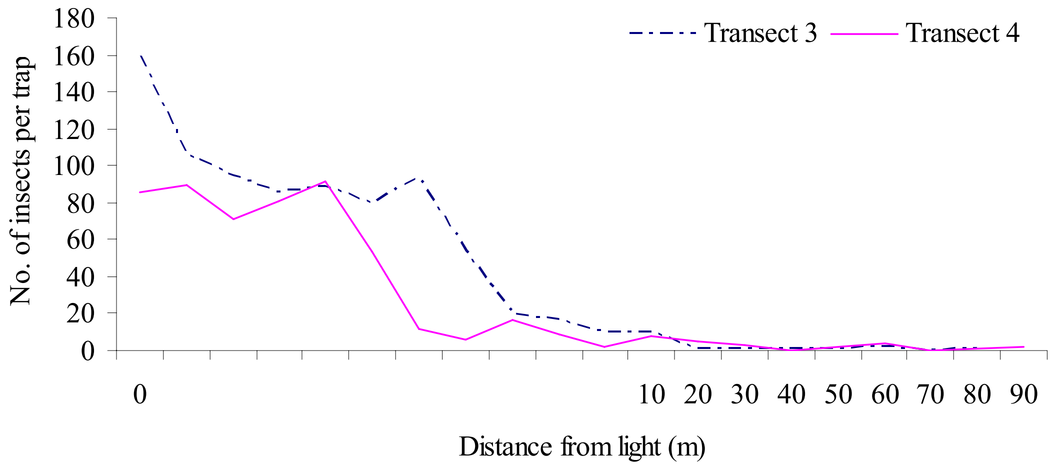


Fig. 2.22 Transects with sticky traps away from a light source; insect abundance (number of individuals per trap) recorded at 40-cm intervals during first 10 m of transect, then every 10 m away from light output.

Discussion

Insectivorous bats recorded in Adelaide city parklands

At least six insectivorous bat species were recorded with detectors in Adelaide City, a relatively moderate richness given the alterations to the landscape resulting from urbanisation and compared to richness recorded in the available literature for cities elsewhere (Table 2.14). Adelaide's bat fauna have low species evenness; activity was dominated by two species: *Chalinolobus gouldii* and *Mormopterus planiceps* species 4. Uncommon bat species included forest bats (*Vespadelus* species), which comprised less than 1% of total calls. No isolated calls of *V. vulturnus* were recorded, so this species was not included in the richness estimate. Several calls in the category *C. morio* / *V. vulturnus* were noted; however, I suspect that these calls were produced by *C. morio* because they frequently occurred at the cemetery, where the highest level of *C. morio* activity was detected.

I could not distinguish between *V. regulus* and *V. darlingtoni* calls recorded during this study; both species have previously been collected in the City (South Australian Museum records). More comprehensive acoustic recordings or individual captures would be necessary to determine which of these two species currently persists in the Adelaide parklands, or whether both do. It is encouraging in terms of biodiversity to record *Vespadelus* species in Adelaide City, particularly when these species show preference for natural areas over urban environments in the nearby Adelaide Hills (Sanderson and Kirkley 1998). Nevertheless, the overall low level of activity recorded from *Vespadelus* species in Adelaide's parklands should prioritise them for conservation by the Adelaide City Council.

Table 2.14 Number of insectivorous bat species recorded during surveys in Australian and overseas cities from available literature

Study City	Number of bat species	Reference
Adelaide City	At least 6	This study
Albury, NSW	5	(Kirsten 1998)
Mexico City and adjacent natural forest	6 plus unidentified	Avila-Flores and Fenton (2005)
Brno (Czech republic) (pop 350 000)	6 plus 2 species groups	Gaisler *et al*. (1998)
Greater London	5	Guest *et al*. (2002)
Athens metropolitan area	5	Legakis *et al*. (2000)
Suburban Detroit	4 (mist netted)	Kurta and Teramino (1992)

Fewer than 2% of total recorded bat calls were from *Tadarida australis*. I expected more activity from this species because it occurs in this region, is known to use urban areas, and is readily recorded with detectors (Fullard *et al.* 1991; Churchill 1998; Herr 1998; Sanderson and Kirkley 1998; Museum of South Australia 2006; Rhodes and Wardell-Johnson 2006). It is also possible that some echolocation calls produced by *T. australis* were not recorded with the detectors. These bats fly high above the ground so calls may have attenuated before reaching the recording devices (Griffin 1971; Lawrence and Simmons 1982). Molossids benefit from the resources provided in urban habitats elsewhere, often roosting in human-made structures overseas (Avila-Flores and Fenton 2005). The preferred roosts for *T. australis* in suburban Brisbane (Queensland) were tree holes in *Eucalyptus* species (Rhodes and Wardell-Johnson 2006); networks of roost-trees appeared to be critical to their roosting success (Rhodes *et al.* 2006). It is unknown whether suitable networks of tree roosts are available in Adelaide's parklands or whether roost availability is a limiting factor for *T. australis* in Adelaide. Therefore an assessment of available and suitable tree roosts would be an important step toward conserving this species in Adelaide's urban areas.

Similarly, fewer than 1% of calls were registered from *Nyctophilus geoffroyi*, a species less readily recorded with detectors because its calls are relatively softer in intensity, it also uses a range of sensory cues including passive listening and vision in prey detection (Grant 1991; Maddock and Tidemann 1995; Churchill 1998). It is difficult to quantify the activity of *N. geoffroyi* in Adelaide City with bat detectors. This species appears to be successful in other urban centres; however, it is prone to predation by feral cats (*Felis catus*) (Churchill 1998) and caution should be applied when estimating its abundance in Australian cities.

Frequently recorded bat species in Adelaide City parklands

The most frequently detected bat species in the Adelaide City parklands were *C. gouldii* and *M. planiceps* species 4. This finding was not unexpected because these species are widespread in Australia and are known to live in and around human habitations (Fullard *et al.* 1991; Dixon 1995; Richards 1995a; Churchill 1998). Both fly fast and use echolocation calls with mid-range frequency and duration, suited to open and edge habitats (Fullard *et al.* 1991; Richards 1995a). *Chalinolobus gouldii* and *M. planiceps* species 4 have the wing morphology and echolocation system that enable them to exploit insects at lights in cities. These traits are important for bat species foraging for insects congregating at artificial lights elsewhere (Rydell 1992; Blake *et al.* 1994). *Chalinolobus gouldii* and *M. planiceps* species 4 were the only species for which I recorded activity at illuminated conditions at sports fields in this study.

Because relatively slow-flying and/or manoeuvrable species, such as *C. morio* and some *Vespadelus* species, were not detected foraging around artificial lights, I expect that *C. gouldii* and *M. planiceps* species 4 have a competitive advantage over these species in Adelaide's urban environment. Some bat populations overseas increased dramatically in recent years and their success was attributed to an ability to exploit insects at urban lights (Arlettaz *et al.* 2000). *Chalinolobus gouldii* and *M. planiceps* were the most frequently detected species in dark parkland areas and were active for greater lengths of time during the night than were *T. australis* or *C. morio*. The ability to forage for great lengths of time, utilise a wide range of habitats, and exploit dark areas as well as insects attracted to lights, explains the presence and relative success of *C. gouldii* and *M. planiceps* species 4 compared to other bat species in Adelaide City.

Differences among sites in bat activity

Simultaneous recordings at monitoring sites (matched night analysis) showed habitat preferences for Adelaide's insectivorous bats were for dark parkland areas. The Wilderness School site is a large dark parkland area in low-density surroundings that was the most bat-active site during matched nights. Findings were similar to those in other studies of bat habitat preference in urban microhabitats (for example Gaisler *et al.* 1998; Legakis *et al.* 2000; Avila-Flores and Fenton 2005). Unlike other studies where artificial lights were considered important for attracting insectivorous bats in urban environments (Rydell 1991b; Blake *et al.* 1994; Avila-Flores and Fenton 2005), our research found dark areas were more important for bat diversity and activity in a city. The Rymill Park site has dull yellow lighting (footpath-grade) that did not exclude slow-flying or highly manoeuvrable species, whereas the nearby weir site with similar resource availability but bright white lights (flood-lit) recorded low species diversity. Furthermore, observations of bats foraging at white lights revealed that a few individuals make repeated passes on insects swarming at those lights;

therefore, data collected with detectors at brightly lit sites probably over-estimate the abundance of bats in those areas.

The Adelaide City cemetery recorded moderate bat activity levels. Five species were recorded at this site, including the highest activity level of *C. morio* for all sites, which demonstrates the importance of dark cemeteries to biodiversity in urban landscapes. *Chalinolobus morio* is an opportunistic aerial forager that uses reasonably fast, direct flight and considerable agility to capture prey in closed, edge, and open zones (O'Neil and Taylor 1986; Fullard *et al.* 1991; Churchill 1998). During this study, *C. morio* avoided illuminated foraging areas, such as the weir and flood-lit sports fields, but was recorded at the same sports fields when the lights were off. *Chalinolobus morio* did not appear to be particularly advantaged by urban habitats in Adelaide, and was mostly confined to the cemetery site. It is possible that *C. morio* is faithful to the foraging opportunities at that site; repeatedly returning to foraging sites is a recorded behaviour of this species (Churchill 1998).

Cemeteries have importance that extends beyond cultural and spiritual purposes and this study showed that cemeteries can provide refuge areas for fauna within highly urbanised environments. The Adelaide cemetery is valued for its historic and cultural importance. The site is 150 years old, is the burial place for a large number of South Australia's founders and legislators, and is recognised as a historic reserve (DEH 2006). As such, the site is afforded some degree of protection against encroaching development. Other parkland areas in Adelaide have been developed and most recently the National Wine Centre of Australia was built in the City's east parklands. This study supports the recognition of cemeteries made elsewhere, as valuable and relatively stable islands for biodiversity within densely urbanised environments (Barrett and Barrett 2001; Leicester City Council 2003; Hull Biodiversity Partnership 2005).

Echolocation data recorded at the Royal Zoological Gardens of South Australia were curious because the site recorded the least activity (number of calls) but high species diversity. It is possible that bat richness recorded at the zoo was background noise from individuals flying over the zoo from adjacent river or parkland environments. These areas were not sampled because of safety concerns; however, *C. gouldii* is known to use the zoo grounds because individuals were captured there for a separate part of this study (Chapter 3). Low numbers of calls may be partially explained by the location of the detector, which was positioned underneath a walkway structure that obscured the recording range. Yet six species groups were still recorded at the zoo, including *N. geoffroyi*, which was not recorded at any other site. The zoo gardens have a complex vegetation structure that includes open (above canopy), edge, and closed (amongst shrub layer) habitat, thus providing for a range of bat feeding strategies. Shallow (mild temperature) freely-available water, complex vegetation structure, and high nutrient environment (plant and animal waste) may benefit insect production as well as provide heterogeneity within the parklands. Other studies have recognised that heterogeneity in urban habitats is valuable to insect production (reviewed by Frankie 1978), hence even small parkland areas are important for bat perseverance (Avila-Flores and Fenton 2005).

The effect of season on bat and insect activity

As expected, bat activity and insect activity were high in summer; only low levels of activity were recorded during winter. Insectivorous bats in southern Australia, including those species recorded in Adelaide City, give birth to their young in late spring or summer (Maddock and Tidemann 1995; Richards 1995a; Richards 1995b; Tidemann 1995a; Tidemann 1995b; Tidemann 1995c), which coincides with mild to hot temperatures as well as increased local insect abundance. Although the total number of bat calls decreased significantly during cool conditions, species richness (number of species detected) did not differ among season; 6 species, including *T. australis*, were detected during winter.

I separated daily and monthly activity patterns of different species in order to observe species-specific fluctuations. Many studies have noted that bats become active at or near dusk (for example Catto *et al.* 1995; Rydell *et al.* 1996); however, I recorded very few bat calls in the first two hours after civil twilight in Adelaide, which implies that local bats may roost outside of the City but make nightly migrations to the parklands. This notion is supported by a study in the nearby Adelaide Hills that frequently recorded *C. gouldii* and *V. darlingtoni* within the first hour after twilight (Sanderson 1999). From monthly observations, *C. gouldii* and *M. planiceps* were most active in summer months and this activity decreased dramatically during winter months. Because these two species dominated call data, the difference among season in total calls was significant. However, when separated from the noise created by *C. gouldii* and *M. planiceps*, *T. australis* and *C. morio* activity was not significantly different among seasons. Indeed, those data showed *T.*

australis activity peaked in April and May, while *C. morio* activity peaked in May. These findings support recommendations that sampling methods should account for species-specific temporal variations (Milne *et al.* 2005). *Tadarida australis* is a widespread migratory species that expands and contracts its range seasonally, and its ideal minimum nightly temperature ranges from 5-15˚C, with absences noted when minimum temperatures exceed 20˚C (Bullen and McKenzie 2005). Adelaide's average monthly temperatures during the 2005-2006 sample period were within the preferred range of this species, from 5.6˚C in June to 19.9˚C in January (Bureau of Meteorology 2006). Low bat activity levels from June to August may be attributed to northward migration by this species, as observed in Victoria (Churchill 1998). *Chalinolobus morio* may become active during cool conditions to utilise the niche on the cusp of optimum foraging times (Churchill 1998), which explains its activity during May but not why activity peaked in this month when average minimum nightly temperature was 8.8˚C (Bureau of Meteorology 2006). However, activity also peaked for other bat species in May at the cemetery, so the patterns of activity are most probably site specific.

Insect capture patterns (expressed as biomass) with a malaise trap and a light trap were similar. Both traps result in the death of collected specimens, so for similar studies on fluctuations in insect activity and to minimise unnecessary collecting, it is preferable to use only a Malaise trap. Insect biodiversity was not examined for this study.

The effect of weather on bat and insect activity

Temperature was a key descriptor of bat and insect activity in Adelaide City; both bats and insects responded to temperature with a sharp increase in activity occurring at approximately 12˚C. The relationship between temperature and bat activity was statistically significant as was the relationship between insect activity and temperature. These results contradict previous findings in Adelaide City (Campain 2004) and support assertions made elsewhere that bat activity and insect activity are primarily a function of temperature (Rydell 1991b; Gaisler *et al.* 1998; Bishop *et al.* 2000). Bat calls were recorded over a range of temperatures and although activity was negligible below 12˚C, bat calls were recorded during nights with minimum nightly temperature as low as 3.6˚C (19 *C. gouldii*/*M. planiceps* calls recorded on 12 August 2006). Bat activity during very cool nights was concentrated into the first few hours after sunset, before temperature decreased to the nightly minimum, which occurred usually in the last hours before dawn. As expected from their relationship to temperature, bat and insect activity were significantly positively correlated. It remains unclear whether Adelaide's insectivorous bats respond independently to increased prey availability, whether they only respond to temperature of which prey availability is a symptom, or a complex of both.

Rainfall had a negative effect on bat activity that was expected. Rainfall provides resistance to normal flight activity, affects thermoregulation, and creates echoing noise (clutter) that may be problematic to echolocating bats (Fenton *et al.* 1977). It also decreases prey availability (Hwang and Turner 2005).

To date, few studies have examined urban bat activity in relation to abiotic factors, yet it is important to observe these relationships so we can understand how urban phenomena, such as urban heat islands (UHI), influence these species in the long term. A UHI occurs when a metropolitan area becomes significantly warmer than its surroundings; many United States cities and suburbs record air temperatures up to 5.6˚C warmer than their surrounding natural areas (U.S. Environmental Protection Authority 2006). Urban heat islands are caused by the alteration of the normal surface material's thermal properties, thus reducing the cooling processes of evapotranspiration in urban areas. Additionally, a UHI results from elevated pollution levels and tall buildings with multiple surfaces that reflect and absorb sunlight; consequently, as urban centres grow, so does their average air temperature (Oke 1982). The City parklands provide Adelaide with some protection against the UHI effect and the associated night-time warming. The Kent Town weather station recorded temperatures on average 2.34 ºC higher than those recorded at the Parafield Airport station (17 km North) and 0.46 ºC higher than those recorded at the Adelaide Airport station (7 km West, 1 km from coast), but it remains to be established whether an UHI occurs within the immediate area (averages taken December 2005 to September 2006 from Bureau of Meteorology 2006). If the average temperature significantly increased in Adelaide City as a result of increased high-density development, the long-term consequences for biodiversity in the parklands may be acute; for example, the specialised cool-condition niche occupied by *C. morio* would be diminished and the migratory patterns of *T. australis* offset.

The effect of moonlight on bat and insect activity

I recorded a significant negative relationship between moonlight and bat activity during summer in Adelaide. Lunar cycles are known to influence insectivorous bat activity in other temperate climates; other studies used a variety of methods to observe activity as a function of moonlight including: observations during a lunar eclipse (Usman *et al.* 1980), detectors recording activity in variable moonlight (Reith 1982; Hecker and Brigham 1999; Milne *et al.* 2005), and observations of light-tagged individuals (Fenton *et al.* 1977). During this study, measurements of moonlight were quantified by calculating nightly lunar light from the moon illumination fraction; this method produced an output ranging from 0.0-0.1 lux. As such, I was able to observe bat activity during varying lunar light conditions, not only according to a distinct phase or moonlight category. To date, I have not located any research that describes lunar phobic behaviour in Australian temperate zone insectivorous bats or in any urban bats, yet Australian bat researchers often design their sample schedules to avoid bright moonlit nights and the potential lunar phobic reaction of bats (for example Churchill 1994; Law and Chidel 2002). I recorded bat activity data in response to lunar conditions at Rymill Park, a dark parkland area with isolated yellow (dull) lights. Although Rymill Park is situated within the City, the difference between bright and dark moonlit nights was obvious. During sampling at that site, head torches were often not required during bright moonlit nights for the completion of menial tasks but were necessary during dull-moon nights (pers. obs.). Our findings suggest that dark parkland areas are important for the maintenance of normal bat behaviours, such as moonlight avoidance, in city environments. Further research in surrounding suburban areas and in naturally dark areas of the Adelaide Hills is required to understand the extent of this complex behaviour in local bats.

Conclusion

Moderate insectivorous bat species richness was recorded in Adelaide City compared to that recorded in other cities, through available literature. However, I found that species evenness was low in Adelaide City and that some bats, such as *C. gouldii* and *M. planiceps* species 4, experience a competitive advantage over other bat species in Adelaide's urban environment. To promote bat diversity in cities, conservation priority should then be directed toward less abundant bat species, including those species not directly advantaged by foraging opportunities at artificial lights. Local councils can then protect and promote those habitats preferred by less abundant species to increase biodiversity; in Adelaide, those habitats include dark parkland areas and parks with complex vegetation structures suited to edge- or closed-zone foraging bats. This study demonstrated that city bats and their insect-prey populations respond to a variety of abiotic factors including season, temperature, and moonlight, and that these factors should be accounted for by future studies on urban bat population dynamics. Adelaide City bats displayed lunar phobic behaviour in summer; thus it appears important for some bats persisting in city environments to have access to dark 'islands' of parkland where they can maintain normal behaviours. Preserving dark parks as well as reducing light pollution or spill should be considered by biodiversity managers who want to promote bat activity in highly urbanised areas. Finally, accounting for urban phenomena such as urban heat islands may be necessary to describe long-term trends in urban-wildlife communities that would be useful for predicting the distribution and suitability of city environments to these fauna.

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CHAPTER 3: Investigations of bat diet, roosting sites, and potential for radio-tracking bats in the City of Adelaide

Abstract

Because of their nocturnal or cryptic behaviour, Australian bats are generally not well managed or understood in their urban habitats, as is the case in Adelaide City. The City Council expressed an interest in promoting the bat fauna in their urban parklands. I investigated the diet and availability of roosting resources for Adelaide City bats, and tested the potential for radio-tracking from tall buildings in the Adelaide central business district. From *Chalinolobus gouldii* and *Mormopterus planiceps* species 4 scats I positively identified invertebrate fragments of Coleoptera, Hymenoptera, and Hemiptera, as well as Lepidopteran scales in each scat, and noted the similarity between their diets in Adelaide City to their diet elsewhere. During this study, I inspected bat boxes and potential tree roosts with a 24-m mechanic elevation platform. However, no roosting bats were recorded. In every potential tree roost I recorded evidence of occupation by either birds or feral honey bees (*Apis mellifera*), indicating that roost competition is high in some urban parks. I found minimal potential for radio-tracking with low-strength transmitters from building rooftops. However, potential exists for radio-tracking medium to large arboreal and flying animals from rooftops in Adelaide City.

Introduction

Managing fauna in urban environments

The Adelaide City Council (ACC) in South Australia has expressed a willingness to support and promote native biodiversity within its urban parklands (Adelaide City Council 2006b). Bats (Chiroptera) are among the few indigenous mammals persisting in Australia's urban habitats (Kirsten and Klomp 1998; Tait *et al.* 2005; Garden *et al.* 2006; Rhodes and Wardell-Johnson 2006). Yet because of their nocturnal or cryptic behaviour or because of nuisance issues, such as those associated with expanding flying-fox populations (Williams *et al.* 2006), Australian bats are generally not well managed or understood in their urban habitats (Garden *et al.* 2006).

Several insectivorous bat species (Microchiroptera) are known to occur in Adelaide City (Chapter 2). Diet and access to roosting resources were identified as important requirements for these bats and understanding those requirements was necessary to provide insight into suitable management options in Adelaide. I also conducted trials to test the radio-tracking potential of urban wildlife from the building rooftops within the Adelaide central business district (CBD). The results from the trial are presented in this chapter, as well as the insect taxa consumed by Adelaide's bats, and the City's roosting resources.

Diet of Adelaide city bats

Insectivorous bats are the primary predators of nocturnal insects, and their dietary preferences include insect species of agricultural and human concern such as moths and mosquitoes (Duncummon 2001; Lee and McCracken 2005). The number and type of insects consumed by bats vary among seasons (Arlettaz 1996), during pregnancy and lactation (Swift *et al.* 1985), and may be synchronised with emergence, migration, and availability of insects (Lee and McCracken 2005). Some bats have defined foraging areas to which they return to repeatedly, a behaviour recorded in local species *Nyctophilus geoffroyi* (Lumsden and Bennett 2000) and *Chalinolobus morio* (Churchill 1998). Opportunistic insectivorous bat species also forage for aerial insects congregating at artificial lights in urban centres (Rydell 1992; Blake *et al.* 1994). By describing the insect taxa consumed by local bats, I hope to provide the ACC with a means for promoting insectivorous bats to the public and for conservation by highlighting the ecological service provided by bats as natural insect controllers and by understanding their dietary requirements.

Faecal analysis is a method for assessing those diet items consumed by insectivorous bats. Previous studies have used stomach contents analysis to describe bat diet (for example Pine 1969; Whitaker *et al.* 1981). This method allowed researchers to observe undigested materials in the stomach, but it requires bats to be killed. In contrast, faecal studies allow researchers to conduct non-invasive diet analysis because scats can be collected from captured bats or obtained from roosting and foraging sites. Faecal analysis is frequently used to assess the diet of insectivorous bats (for example Swift *et al.* 1985; Arlettaz 1996; Lee and McCracken 2005). Kunz and Whitaker (1983) found that faecal analysis was an accurate method for assessing consumed insect material when compared to stomach contents analysis. Insectivorous bats thoroughly chew insects, but because food items pass through the gut rapidly, they provide relatively intact insect fragments within scat samples

(Whitaker 1988). Insect prey from faeces can then be identified to order, to provide a qualitative assessment of bat diet. However, chitin-based exoskeletons of some arthropod orders are more readily identified than others (Rabinowitz and Tuttle 1982) and the relative skill and/or experience of the observer may influence the outcome. Faecal analysis was used to describe the diet of Adelaide City bats.

Roosting resources for bats in Adelaide

Microchiropteran bats depend on roosting sites for survival and reproduction and a previous study highlighted roosting resources as an important indicator of habitat quality in the Adelaide City parklands (M. Long, cited in Campain 2004). Roosts provide bats with favourable modification of microclimate (Kurta 1985; Schulz 1997; Sedgeley 2001) and structural protection from predators (Tidemann and Flavel 1987; Agosta 2002). Bats may use temporary roosts to adapt to changing seasons, or to meet reproductive requirements and may be faithful to a roosting area, having several roosting sites that provide a range of conditions conducive to their survival (Lunney *et al.* 1988; Taylor and Savva 1988; Anderson and Racey 1993; Law and Anderson 2000b; Agosta 2002). Tree cavities are important shelters for bats in temperate Australia (Tidemann and Flavel 1987; Kunz and Lumsden 2003; Campbell *et al.* 2005); many urban bats also roost in artificial structures such as buildings (Kunz and Lumsden 2003; Evelyn *et al.* 2004; Rhodes and Wardell-Johnson 2006) and more recently in bat boxes (for example Bender and Irvine 2000; Flaquer *et al.* 2006; Whitaker Jr *et al.* 2006).

In urban centres such as Adelaide, much of the native vegetation including hollow-bearing trees have been removed and cavity-roosting species displaced (Kraehenbuehl 2005). In the last two years, ACC has installed artificial roosting boxes to provide alternate roosts for local bats. These bat boxes were monitored as part of this study and suggestions were made for maximising their suitability to local bats. Surveys of tree holes were also conducted using an ACC mechanic elevation platform.

Radio-tracking in a city

Describing movement patterns in relation to resources provides valuable insight into animal ecology and behaviour. These movement patterns may be accessed by radio-tracking individuals. Bat-monitoring studies based on echolocation calls or bat captures may not permit documentation of a complete range of activities in different habitats (Fenton 1990), and because bats are nocturnal and volant, they present particular problems to researchers trying to follow them (Wilkinson and Bradbury 1988). Radio-telemetery permits researchers to find bats and observe movement patterns, and radio-transmitters are frequently used in bat research (for example Law and Anderson 2000b; Pavey *et al.* 2001; Duchamp *et al.* 2004; Evelyn *et al.* 2004). Monitoring bats with radio-transmitters allows researchers to find roosts as well as follow individuals during several nights or days, and over varying distances (Wilkinson and Bradbury 1988; Lumsden *et al.* 2002; Campbell *et al.* 2005).

The extent to which radio-tracking methods can be applied to microchiropteran bats in highly urbanised areas, such as in cities, is limited. Radio-telemetry was used by Duchamp *et al*. (2004) to follow microchiropteran bats in a rural area undergoing suburban development, by Evelyn *et al*. (2004) in residential California, and recently by Rhodes and Wardell-Johnson (2006) in suburban Brisbane. The tracking studies occurred at sites that consisted of predominantly open, semi-urban, or rural habitats. In cities, most bat studies have been based on echolocation call monitoring (for example Gaisler *et al.* 1998; Legakis *et al.* 2000; Gerht and Chelsvig 2003; Campain 2004) rather than radio-tracking. Radio-tracking of large animals is not unusual in urban areas; red foxes (*Vulpes vulpes*) have frequently been radio-tracked (Kolb 1984; White and Harris 1994; White *et al.* 1996; Deplazes *et al.* 2004) as have black bears (*Ursus americanus*) (Lyons 2004) and flying foxes (*Pteropus alecto*) (Markus and Hall 2004). These radio-tracking studies used ground-based, vehicle-based, and aerial techniques (receiving from a plane) for locating their signals in urban environments; the large animals carry proportionally heavier transmitters with greater signal strength and range than those required for smaller animals, such as microchiropteran bats. Mechanical (structural) and frequency (radio) disturbance is also high in cities; these factors may confound signal reception and transmission with light-weight transmitters suited to Microchiroptera. To the best of my knowledge, methods for avoiding mechanical and frequency interruptions and applying radiotelemetry techniques with light-weight radio-transmitters in a city environment have not been established. I aimed to access the roofs of tall buildings to test the validity of using low-strength radio-transmitters in Adelaide City.

Methods

Diet of urban Microchiroptera

Faecal samples were collected from insectivorous bats in Adelaide. I trapped bats with mist nets and harp traps at the Adelaide zoo (Chapter 2) from November 2005 to March 2006 on warm and hot nights (> 15˚C minimum nightly temperature). Nine bat boxes in the Adelaide parklands were also checked for bats and scats. Captured bats were identified to species; their sex, age, reproductive status, forearm length, mass, and time of capture were also recorded. I temporarily marked captured bats by trimming a small patch of hair on their backs (no larger than 1 cm^2). Individual bats were kept in cotton bags until scats were produced; bats were released on the same night and at least 1 hr before dawn. Guano traps (large clear plastic sheets laid beneath foraging sites) were used on warm nights (minimum nightly temperature ≥ 15º C) to collect scats at a flood-lit car park on the Torrens River during February and March 2006. All scats were air-dried for two days and stored in labelled bijou vials (volume = 7 ml).

In the laboratory, each faecal sample was placed in an individual Petri dish, rehydrated with distilled water, and left to soften overnight (24 hours) as per McAney *et al*. (1991). Softened scats were placed on a cover slide with a few drops of glycerine and scats were gently teased apart (Fig. 3.2 a) under a dissecting microscope (Olympus BH-2, Japan). The entire scat was analysed for fragments of body parts (Fig. 3.2 b) including heads, legs, wings, and antennae that were examined against descriptions in the literature (McQuillan and Forrest 1985; Whitaker 1988; Common 1990; Notestine 1990; McAney *et al.* 1991; Lawrence and Britton 1994; Zborowski and Storey 1996) and vouchers from this work (Chapter 2) for identification.

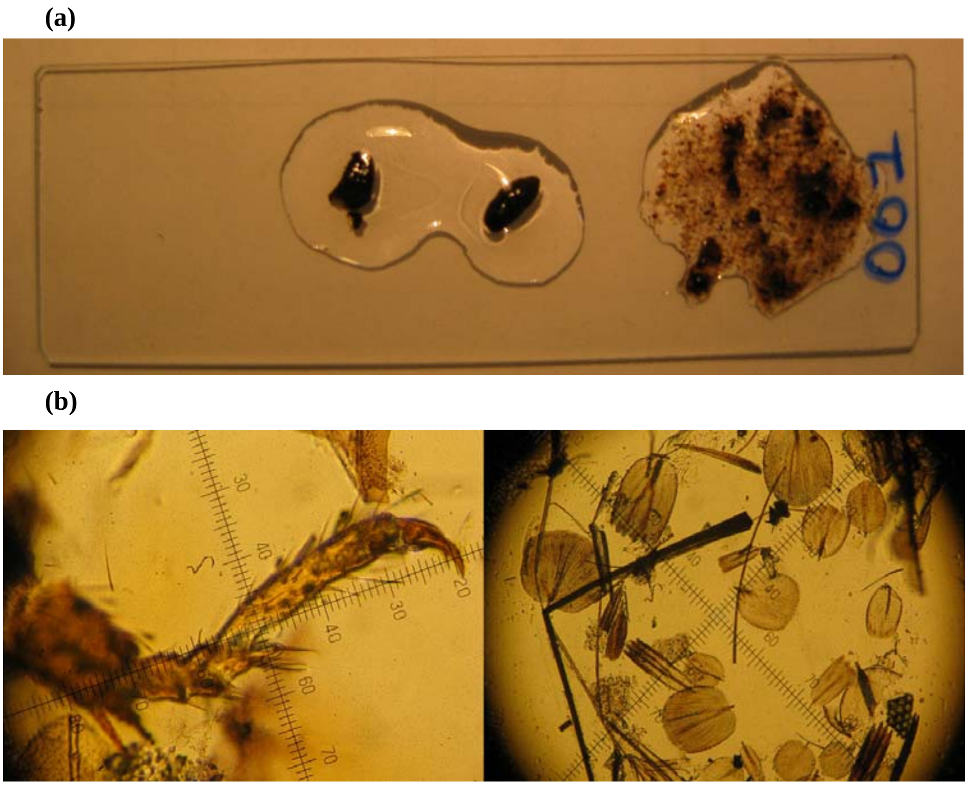

Fig. 3.1 Softened scats whole and teased apart in glycerine on a cover slide (a) and insect fragments in bat scats (b) may include legs (left) and lepidopteran scales (right).

Roosting resources of Adelaide City bats

Bat roosting resources in Adelaide City were assessed by monitoring bat boxes and by inspecting sites for which reports of roosting bats existed. All potential roosts were checked for bats as well as for other signs of bat presence, such as smell or scats. Four bat boxes in the west parklands (accessed with a ladder) were checked 5 times during November 2005 to March 2006; two of these boxes had previous records of single roosting bats (September 2005, Z. Drechsler pers. comm. 2005). Five bat boxes in tall trees along the Torrens River were accessed on 30 August 2006; the survey was the first inspection of these bat boxes since installation over 8 months previously. The boxes were between 15 and 20 m above the ground and were checked via a 24-m mechanic elevation platform provided by the ACC. The elevation platform was also used in August to survey tall trees in the south parklands where bats were reported to be roosting (P. Miekle from ACC arboriculture team, April 2006). A building in North Adelaide was also inspected after a resident contacted the South Australian Museum and reported bats roosting in an exterior wall.

Radio-tracking potential

The radio-tracking potential of microchiropteran bats in cities was tested from the rooftops of tall buildings in Adelaide City. Other studies have used aerial-tracking from planes (for example Marzluff *et al.* 1994; Lyons 2004) and this study aimed to test aerial-tracking from buildings. I liaised with Campus Facilities Managers at two University of South Australia metropolitan campuses (City East and City West) to organise rooftop access. Several buildings were inspected at each University campus for their suitability to the trial. I gained access to the tallest buildings on campus, which were required to have safe passage up to and on the roof and a clear view of the cityscape, without interrupting or trespassing on other equipment or machinery (such as mobile phone towers). Insurance was arranged through the University of South Australia and letters were forwarded to the staff involved outlining the project aims. On-campus security officers were notified of the project through Campus Managers; during each trial, the on-duty security officer provided the physical access to rooftops. An attempt was made to organise similar arrangements with privately owned buildings, but was unsuccessful.

For purposes of comparison I tested signal reception of a single radio-transmitter set at two different strengths, one half tail (138 mm) and one full tail (293 mm) (transmitter made by Allan Salisbury at Transceiver Services). The radio-transmitter was carried by a volunteer on a bicycle while signal reception was received from building roof tops using a Biotel RX3 receiver (Bio Telemetery Tracking Australia, Adelaide, SA). The signal was tested for direction and distance amongst structurally cluttered (CBD) and parkland areas; the signal strength and range for both transmitters were depicted on maps of Adelaide City.

Results

Diet and roosts of Adelaide City bats

Eight scats were collected during this study from November 2005 to September 2006 using a variety of collection methods. Seven bats were caught at the Adelaide zoo; all captured bats were *Chalinolobus gouldii* (Table 3.1). Six individual bats were caught before a recapture was identified from the marking. All captures occurred within five weeks (12 Dec 2005 to 20 Jan 2006) despite a large capture effort spanning from November 2005 to March 2006 (Table 3.2). Bat captures provided the most scats, while guano traps were the most efficient method for scat collection (Table 3.2). No bats or scats were recorded from sampling bat boxes, previously known bat roosts, or from potential tree roosts in Adelaide City and parklands; results are summarised in Table 3.2. I positively identified fragments of Coleoptera, Hymenoptera, and Hemiptera, as well as Lepidopteran scales in each scat.

Table 3.1 Details of bats captured at the zoo during December 2005-February 2006

No.	Date	Trap	Time*	Species	Sex	Age	Forearm (mm)	Mass (g)	Scat
1	12 Dec 05	Mist net	12:15 am	*C. gouldii*	F	A	44.4	12.5	Y
2	21 Dec 05	Harp trap	11:15 pm	*C. gouldii*	M	A	45.4	14.8	Y
3	23 Dec 05	Harp trap	12:50 am	*C. gouldii*	F	A	44.7	17.8	Y
4	31 Dec 05	Mist net	1:00 am	*C. gouldii*	M	A	43.7	15.5	Y
5	5 Jan 06	Harp trap	2:00 am	*C. gouldii*	F	A	44.5	13.5	N
6	5 Jan 06	Harp trap	12:05 am	*C. gouldii*	M	A	44.9	11.5	Y
6	5 Jan 06	Harp trap	2:15 am	Recapture					N
7	20 Jan 06	Mist net	1:15 am	*C. gouldii*	M	A	43.3	14.3	Y

*Time is local central standard time, South Australia.

Radio-tracking trial in Adelaide City

The radio-tracking reception from the Playford building (City East campus) in Adelaide City for a medium-strength (long tail) and a low-strength (short tail) radio-transmitter are depicted in Fig. 3.3 a-c. From the building's rooftop, the medium-strength transmitter's signal was received up to 3 km away in mostly open parkland areas (Fig. 3.3 b). A signal was not received when the transmitter was taken amongst high density buildings in the central business district. The low-strength radio-transmitter's signal was received up to 1 km away in flat parkland areas, from the building's rooftop but not in the high density CBD area (Fig. 3.3 c).

Table 3.2 Trapping and survey methods with relative effort, the number of scats, and other factors observed during roost surveys, November 2005 to March 2006

Collection method	Collection effort	Timing of effort	no. scats	Other animals
Mist net	▪ 299 mist net hrs at the Zoo, using 1 x 9, 3 x 12, and 1 x 20 m nets	November 2005 to March 2006	3 from 3 bats	-
Harp trap	▪ 123.5 harp trap hrs, using 3 harp traps at the Royal Zoological Gardens of SA	November 2005 to March 2006	3 from 5 bats	-
Guano trap	▪ 20 m^2 x 14 hrs at Torrens River car park	February and March 2006	2	-
Bat boxes	▪ 5 bat boxes checked with Council machinery	August 2006	0	Spiders in all boxes, small lizards also in most boxes
	▪ 4 bat boxes checked; bats were previously recorded in these boxes (Z. Drechsler pers. comm. 2005)	November 2005 to March 2006	0	
Other	▪ Inspection of residence in north Adelaide; bats reported roosting between external and internal walls	March 2006	0	
	▪ Inspection of 15 potential trees roosts in south parklands, bats reportedly roost in area, noted by ACC arboriculture team	August 2006	0	Tree roosts: honey bees (*Apis mellifera*) and honeycomb in two roosts; bird feathers and eggs in all other roosts. Birds in the area included: rainbow lorikeets (*Trichoglossus haematodus*), galahs (*Cacatua roseicapilla*), musk lorikeets (*Glossopsitta concinna*), Adelaide rosellas (*Platycercus elegans adelaidae*), and noisy miners (*Manorina melanocephala*
Total			8	

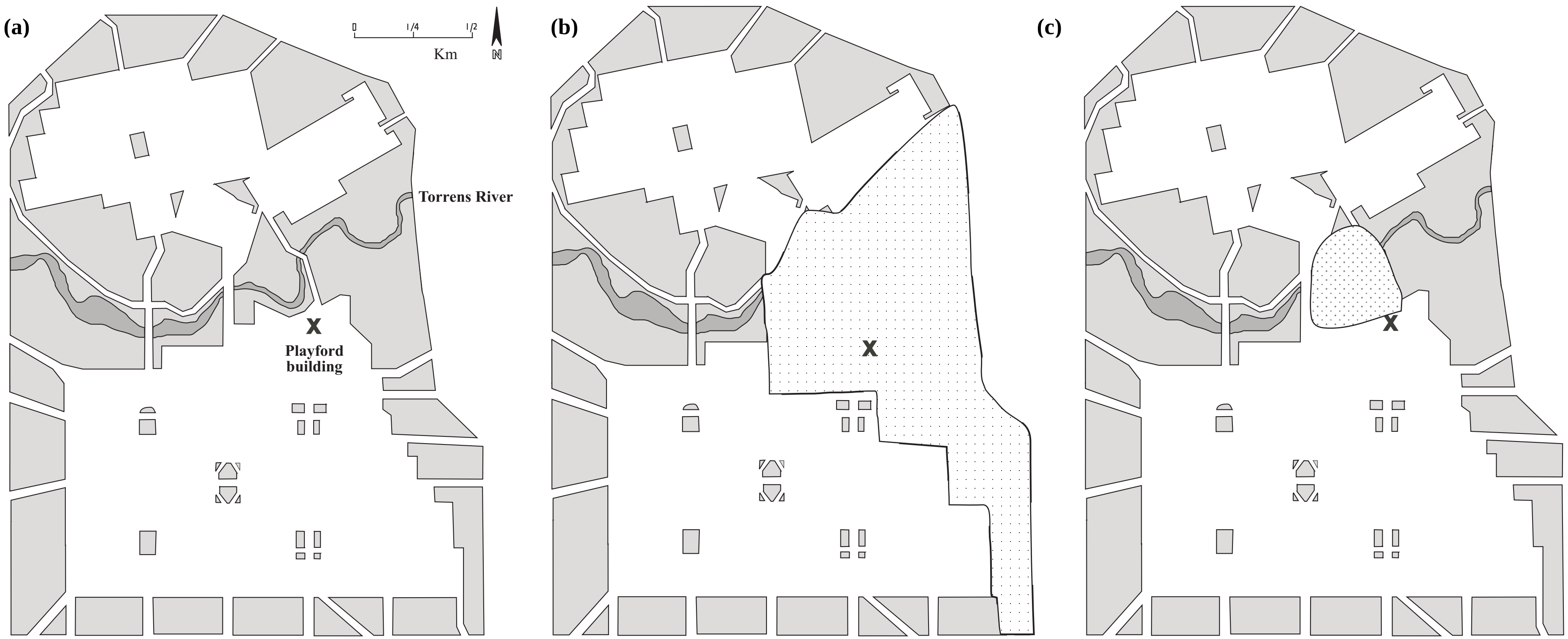

Fig 3.2 Playford building located at the University of South Australia, City East campus within the City of Adelaide (a), and the reception range of a medium-strength transmitter with a 293 mm tail (b) and a the low-strength transmitter with a 138 mm tail (c) received from the building's roof top (maps adapted from ACC 2006a).

Discussion

The diet of Adelaide City's insectivorous bats

Scats were collected either from captured *Chalinolobus gouldii* or from foraging bats at artificial lights with a guano trap. Bats that were recorded foraging at lights during this study were either *C. gouldii* or *Mormopterus planiceps* species 4 (Chapter 2); as such, the scat analysis is only representative of these two species. The scats of Adelaide City bats contained Coleoptera, Hymenoptera, Hemiptera, and Lepidoptera. Our results were closely supported by other diet studies of both species; however, I did not record Diptera (flies and mosquitoes) in any scats, although it is a known component of their diet (Vestjens and Hall 1977; O'Neil and Taylor 1989; Churchill 1998). Some insects, such as mosquitoes, are more prone to dissolve or become unrecognisable in scats than other insects (Rabinowitz and Tuttle 1982). It is possible that local bats also consume mosquitoes as part of their city diet because mosquitoes were frequently recorded in the city (Chapter 2), but I was unable to confirm this possibility from the few scats collected.

Despite a large capture effort with harp traps and mist nets, I was only able to catch 7 bats and 1 recapture during the study. The recaptured bat was caught in the same trap 2 hrs after it was first captured. Trapping results only reflect the bat activity at the Adelaide zoo, where it was necessary to work for safety at night in the City.

Roosting habits of Adelaide City bats

During this study I was not able to locate any bat roosts within the Adelaide City parklands. I experienced several difficulties while attempting to locate roosts that again highlight the complications associated with working in a city environment. Firstly, surveys at dusk or dawn to search for bats emerging or returning to roosts in the city or parklands were difficult because of personal safety concerns. Secondly, I had limited access to likely roost areas; for example, a 24-m mechanic elevation platform with licensed driver was required to reach several bat boxes as well as tree holes in which bats were previously observed; the elevated platform was made available for this study on two occasions and the cost was covered by the Adelaide City Council (ACC). Thirdly, the time lag between receiving reports of roosting bats and organising the appropriate permissions, access, equipment and people, meant that bats had apparently vacated these roosts by the time the surveys occurred.

It appears that bats may at least occasionally roost in different urban and park environments of Adelaide City, including buildings (North Adelaide), bat boxes (west parklands), and large trees (south parklands). Bats in tree roosts in the west parklands were originally located by the ACC's arboriculture team when they cut down the branch in which the bats were roosting. Tree senescence is an important hollow-forming process that may be problematic for urban park managers, who tend to remove dying or dead overhead branches for human-safety reasons. I observed evidence of animals in every inspected hollow in the south parklands. Indications of animals at those hollows included observations of feral honey bees (*Apis mellifera*), their honeycomb, and bird feathers and eggs; birds observed in park included rainbow lorikeets (*Trichoglossus haematodus*), galahs (*Cacatua roseicapilla*), musk lorikeets (*Glossopsitta concinna*), Adelaide rosellas (*Platycercus elegans adelaidae*), and noisy miners (*Manorina melanocephala*). It is appears that competition for hollows is high in the south parklands, particularly because *A. mellifera* is an invasive species known to compete with bats for hollows elsewhere (for example Tidemann and Flavel 1987; Rhodes and Wardell-Johnson 2006).

During this study, I found that local bat boxes were infrequently used by city bats. Finding bats in boxes may depend on survey timing, and seasonal variability, or entrance size (Bender and Irvine 2000) as well as time since installation, with some bats taking between 1 and 10 years before using artificial boxes (Whitaker *et al.* 2006). The bat boxes in Adelaide City have uniform shape and size, hence in the long term they may not cater for a diversity of different-sized bat species, an observation supported in Victoria where installing a range of box sizes resulted in more species using those resources (Bender and Irvine 2000). Additionally, only two groups of 4 and 5 boxes, as well as isolated boxes at schools or houses, have been installed in Adelaide City; elsewhere, large numbers of boxes were most successful and isolated boxes were not favoured (Racey 1992). It is recommended that annual surveys of bat boxes continue, that future installations occur in well vegetated dark parkland areas with limited roosting opportunities, such as the south parklands, and that a range of box types be considered.

Radio-tracking in cities

The radio-tracking potential for low-strength (short tail) radio-transmitters is weak in Adelaide City; I only received signals within the immediate (< 1 km) area of the receiver and only within uncluttered zones (open parks). Insectivorous bats have the capacity to fly several kilometres during an evening (Churchill 1998; Law and Anderson 2000a; Lumsden *et al.* 2002), thus roof-top radio reception is not practical in this instance. A trial receiving radio-signals from a medium-sized (long tail) transmitter was moderately successful from a roof-top in Adelaide City. Larger animals, such as foxes (*Vulpes vulpes*) have been successfully radio-tracked using ground-based techniques in urban areas (White and Harris 1994; White *et al.* 1996). Future radio-monitoring from rooftops may be applied to medium to large arboreal and flying animals such as flying-foxes (Pteropodidae), large birds (e.g. Accipitridae), or possums (Petauridae and Phalangeridae).

Conclusion

This study, investigating the diet and roosts of city bats as well as the potential for radio-tracking from rooftops, highlights some of the difficulties associated with working in urban parkland areas at night. The bat trapping effort was mostly confined to the Royal Zoological Gardens of South Australia, a sub-optimal trapping area that resulted in poor capture data. From just 8 scats, I found that *Chalinolobus gouldii* and *Mormopterus planiceps* feed on insect orders similar to those reported in different environments, including Lepidoptera, Coleoptera, Hymenoptera, and Hemiptera. I was unsuccessful in locating any roosting sites of Adelaide City bats, although reports exist of bats roosting in buildings, tree roosts, and bat boxes. Inspection of tree hollows with Council machinery revealed that many roosts were occupied by either birds or introduced honey bees (*Apis mellifera)*, indicating that roost competition is high in some urban parks. As such, the future installation of bat boxes should occur within those areas where roosts appear to be limited, such as Adelaide's south parklands. Finally, I found that minimal potential exists for radio-tracking with low-strength transmitters, but that a potential remains for radio-tracking medium to large arboreal and flying animals from rooftops in city environments.

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CHAPTER 4: General conclusion and recommendations for habitat management

Conclusion

Many city councils now see the presence of indigenous fauna in urban precincts as an indicator of a healthy city. Management strategies both to encourage existing urban fauna to flourish, and to attract displaced fauna to the urban environment, require at the very least, basic information on the natural history of the species of interest. This study addressed the lack of fundamental information available on factors that influence the presence of insectivorous bats in an urban environment, and was conducted in the City of Adelaide, South Australia.

Cities may be defined by their human-dominated, high-density environments that discourage fauna diversity. But as is the case with Adelaide City, the urban parkland areas have also become valuable islands of habitat for urban wildlife. I found that at least 6 insectivorous bat species use Adelaide's city parks, and like their natural or rural areas counterparts, their presence and activity were affected by abiotic conditions such as temperature, season, rainfall, and moonlight and I recommend that these elements be considered in future studies assessing bat behaviour or activity patterns in cities. Biotic influences included insect biomass, which was highest at artificial lights where opportunistic generalist species, *Chalinolobus gouldii* and *Mormopterus planiceps* species 4 regularly foraged. Biodiversity studies of insects at and away from lights would provide a more comprehensive understanding of diet. High competition existed for tree roosts in urban parks and although the Adelaide City Council has installed bat boxes to promote habitat, bats were not recorded in those boxes during the study. Temporal variation in daily activity indicates that these bats may migrate to the parklands from outside of the City each night; therefore, further research into the extent of the habitat network and connectivity for these bat populations in the wider Adelaide metropolitan area is necessary to understand the extent of their urban habitats.

Recommendations for habitat management

Habitat recommendations to promote insectivorous bat fauna in Adelaide City were based on information collected as part of this honours study from September 2005 to October 2006. Recommendations will be presented to the Adelaide City Council

(ACC) to be considered for action under objectives detailed in the City's Strategic Environmental Plan, specifically to promote biodiversity and to provide habitat for indigenous species in the Adelaide City parklands (Adelaide City Council 2006a).

- Maintain Adelaide's urban parklands as important islands of habitat for urban bats, which support at least 6 native insectivorous bat species including *Chalinolobus gouldii*, *C. morio*, *V. darlingtoni/V. regulus*, *Nyctophilus geoffroyi*, *Mormopterus planiceps* species 4, and *Tadarida australis*.
- Prioritise the conservation of dark parkland areas to support bat diversity and those bat species not directly advantaged by foraging opportunities at artificial lights. I support the ACC's Lighting Policy objective (Adelaide City Council 2005) to reduce spill, glare, and pollution from existing lights to facilitate the maintenance of normal bat behaviour, such as avoidance of bright moonlight, in city environments.
- Plant vegetation that provides parkland heterogeneity for a variety of bat feeding strategies, for example *N. geoffroyi* or *C. morio* forage amongst closed and edge vegetation whereas *T. australis* forages above tree canopies. Include different vegetation strata such as shrub-layers and leaf litter.
- To enhance biodiversity, promote bat species-specific and site-specific resources; for example, investigate types of bat boxes preferred by small forest bats (*Vespadelus* species) and provide those resources in bat-rich areas such as the Royal Zoological Gardens of South Australia, the Wilderness School parkland area in North Adelaide, West Terrace cemetery, and in Rymill Park. Useful information concerning bat boxes is available from the Bat Conservation International website at http://www.batcon.org/home/default.asp
- Continue monitoring bat boxes and keep records of what boxes contain bats as well as the date, name of observer, and the box number. A sample data sheet has been attached (Appendix 4).
- Develop a map of bat box locations in Adelaide City, assign each box with a number or code (for example Golf Course bat box number 3 as GC3), and complete a habitat assessment in the vicinity of the boxes. Liaise with other organisations managing parks in the City, such as the Royal Zoological Society of South Australia and the West Terrace Cemetery, and include those boxes on the map.

- Monitor bat boxes that are or have been occupied along with an unoccupied nearby box for differences in microclimate (data loggers are a useful way to measure temperature and humidity over time).
- Collect scats after boxes have been vacated and check boxes for parasites. Air dry scats for at least two days after collection and store parasites in 70% alcohol (note: take precaution against respiratory disease when collecting scats by wearing a disposable dust mask).
- Conduct a training session for council grounds staff outlining monitoring and communication procedures as well as safety considerations; a Certificate of Completion could be used to recognise staff that complete the course.
- Harness the initiative made by Adelaide biodiversity managers and make Adelaide the leader among Australian cities in efforts to encourage insectivorous bats to the City by a major urban bat box program (as has occurred in Europe).
- Where possible, reduce the incidences where dead or split branches are cut from trees, particularly when this practise occurs only for aesthetic reasons. When removing potential habitat, ensure a thorough inspection for wildlife occurs beforehand (note: vaccinations required for people handling bats).
- Investigate why *Scotorepens balstoni*, previously recorded from Adelaide City, no longer occurs in the City.
- Continue interpretative and community involvement with programs such as Bat Track that improve public awareness and education about urban wildlife.

Appendix 1: Example data sheet used during bat call analysis

Site		Date	Time		Cg	Mp	Cg/Mp	Ta	Cm	Vv	Cm/Vv	Vr/Vd	Sb	Unknown
8. [Wildern	s schoo	Feb-06	- [20060214] - G2142045.15#		1									
9. [Wildern	s schoo	Feb-06	- [20060214] - G2142049.06#											
0. [Wildern	s schoo	Feb-06	- [20060214] - G2142052.19#		1	1								
1. [Wildern	s schoo	Feb-06	- [20060214] - G2142053.02#			1								
2. [Wildern	s schoo	Feb-06	- [20060214] - G2142053.26#		1									
3. [Wildern	s schoo	Feb-06	- [20060214] - G2142053.33#			1								
4. [Wildern	s schoo	Feb-06	- [20060214] - G2142053.40#				1							
5. [Wildern	s schoo	Feb-06	- [20060214] - G2142053.49#			1					1			
6. [Wildern	s schoo	Feb-06	- [20060214] - G2142054.01#				1							
7. [Wildern	s schoo	Feb-06	- [20060214] - G2142054.11#			1								
8. [Wildern	s schoo	Feb-06	- [20060214] - G2142054.22#			1								
9. [Wildern	s schoo	Feb-06	- [20060214] - G2142054.37#			1								
0. [Wildern	s schoo	Feb-06	- [20060214] - G2142055.30#											
1. [Wildern	s schoo	Feb-06	- [20060214] - G2142055.37#		1									
2. [Wildern	s schoo	Feb-06	- [20060214] - G2142056.03#				1							
3. [Wildern	s schoo	Feb-06	- [20060214] - G2142056.25#											1
4. [Wildern	s schoo	Feb-06	- [20060214] - G2142056.32#		1									
5. [Wildern	s schoo	Feb-06	- [20060214] - G2142056.46#				1							
6. [Wildern	s schoo	Feb-06	- [20060214] - G2142056.57#			1								
7. [Wildern	s schoo	Feb-06	- [20060214] - G2142057.09#			1								
8. [Wildern	s schoo	Feb-06	- [20060214] - G2142057.26#			1								
9. [Wildern	s schoo	Feb-06	- [20060214] - G2142058.30#		1									
0. [Wildern	s schoo	Feb-06	- [20060214] - G2142100.10#		1									
1. [Wildern	s schoo	Feb-06	- [20060214] - G2142100.51#											1
2. [Wildern	s schoo	Feb-06	- [20060214] - G2142101.40#		1									
3. [Wildern	s schoo	Feb-06	- [20060214] - G2142102.10#		1	1								
4. [Wildern	s schoo	Feb-06	- [20060214] - G2142102.48#		1									

Appendix 2: The moon illumination fractions taken at UT + 9.5 hrs

Astronomical Applications Dept.
U.S. Naval Observatory
Washington, DC 20392-5420

ADELAIDE

E138˚ 30′, S34˚ 52′

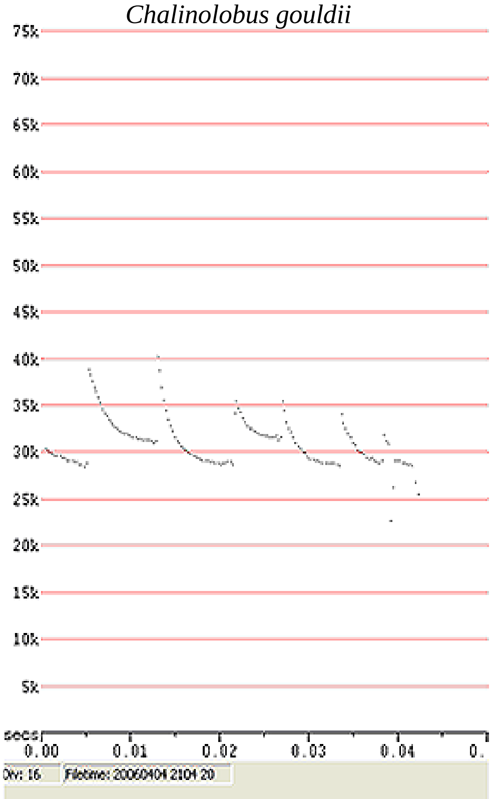
Altitude and Azimuth of the Moon
Jan 10, 2006
Zone: 10h East of Greenwich

h m	Altitude (o)	Azimuth (E of N) (o)	Fraction Illuminated
00:00	16.6	314.5	0.78
00:10	15.2	312.7	0.78
00:20	13.7	311.0	0.78
00:30	12.1	309.3	0.78
00:40	10.6	307.7	0.79
00:50	9.0	306.1	0.79
01:00	7.4	304.6	0.79
01:10	5.7	303.1	0.79
01:20	4.1	301.6	0.79
01:30	2.4	300.2	0.79
01:40	0.9	298.8	0.79
01:50	-1.3	297.4	0.79
02:00	-3.1	296.1	0.79
02:10	-4.9	294.8	0.79
02:20	-6.7	293.5	0.79
02:30	-8.6	292.2	0.79
02:40	-10.4	291.0	0.79
15:40	-11.5	67.4	0.84
15:50	-9.7	66.1	0.84
16:00	-7.9	64.8	0.84
16:10	-6.2	63.5	0.84
16:20	-4.4	62.2	0.84
16:30	-2.7	60.8	0.84
16:40	-1.0	59.5	0.84
16:50	1.1	58.1	0.84
17:00	2.6	56.6	0.84
17:10	4.2	55.1	0.84
17:20	5.7	53.6	0.84
17:30	7.2	52.1	0.84
17:40	8.8	50.5	0.84
17:50	10.2	48.9	0.84
18:00	11.7	47.2	0.84
18:10	13.1	45.5	0.84
18:20	14.5	43.7	0.84
18:30	15.8	41.9	0.84
18:40	17.1	40.1	0.84
18:50	18.3	38.1	0.85
19:00	19.5	36.2	0.85
19:10	20.6	34.2	0.85
19:20	21.7	32.1	0.85
19:30	22.7	30.0	0.85

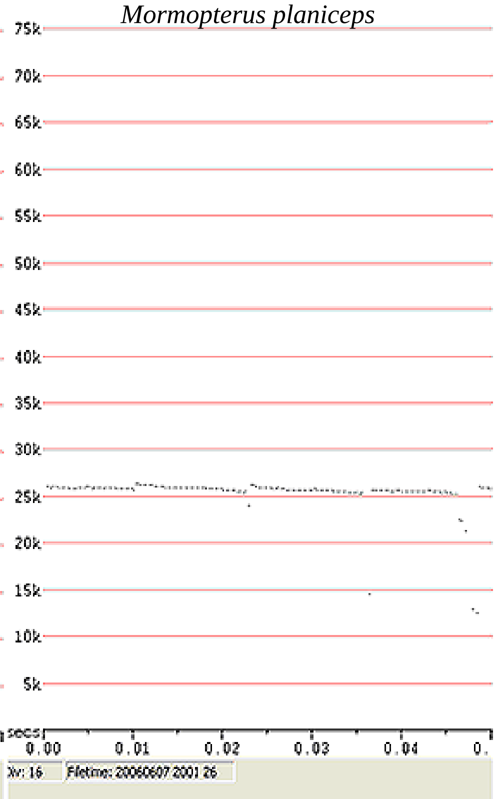
19:40	23.6	27.9	0.85
19:50	24.5	25.6	0.85
20:00	25.3	23.4	0.85
20:10	26.1	21.1	0.85
20:20	26.7	18.7	0.85
20:30	27.3	16.4	0.85
20:40	27.8	14.0	0.85
20:50	28.2	11.5	0.85
21:00	28.5	9.0	0.85
21:10	28.8	6.6	0.85
21:20	29.0	4.0	0.85
21:30	29.0	1.5	0.85
21:40	29.0	359.0	0.85
21:50	28.9	356.5	0.85
22:00	28.7	354.0	0.85
22:10	28.5	351.5	0.86
22:20	28.1	349.1	0.86
22:30	27.7	346.6	0.86
22:40	27.2	344.2	0.86
22:50	26.6	341.9	0.86
23:00	25.9	339.6	0.86
23:10	25.1	337.3	0.86
23:20	24.3	335.0	0.86
23:30	23.4	332.9	0.86
23:40	22.5	330.7	0.86
23:50	21.4	328.6	0.86

Appendix 3: Sonograms of characteristic call structures for bat species recorded in Adelaide City, produced with AnalookW 3.2 o

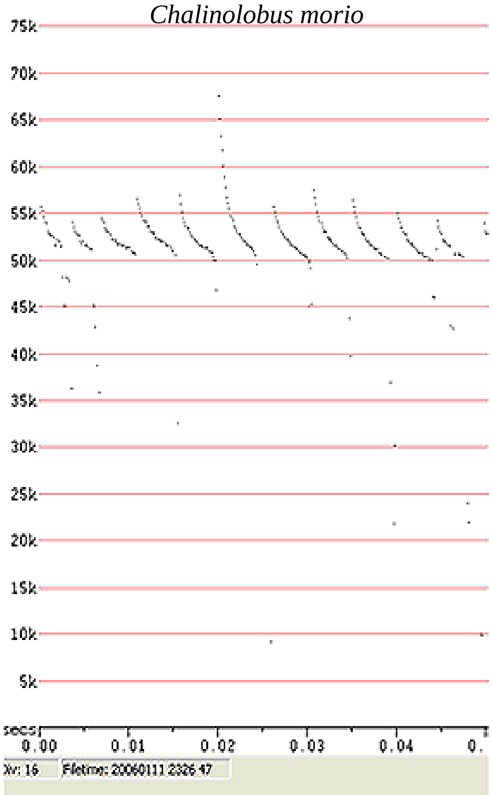
Chalinolobus gouldii



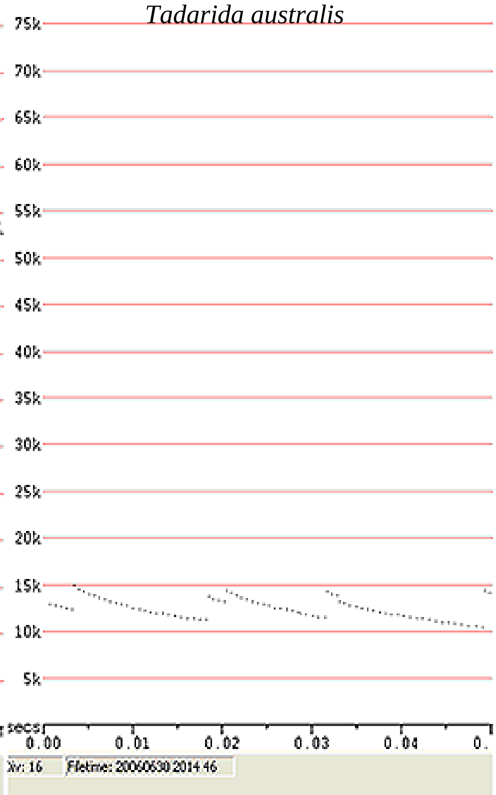
Mormopterus planiceps



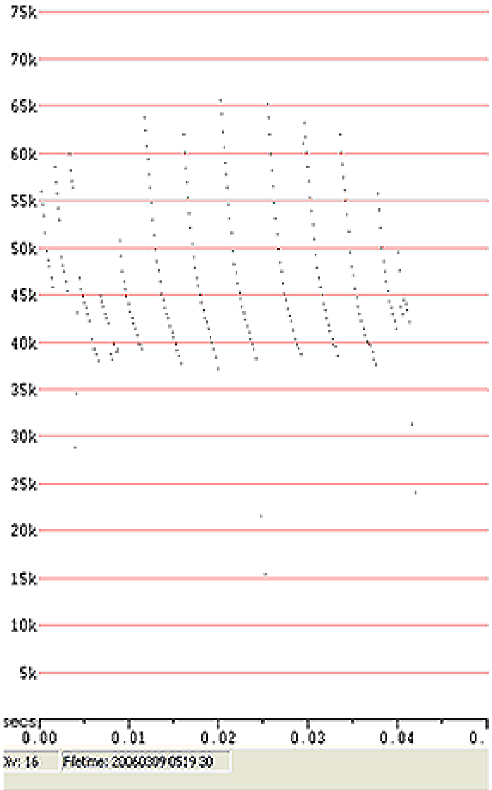
Chalinolobus morio



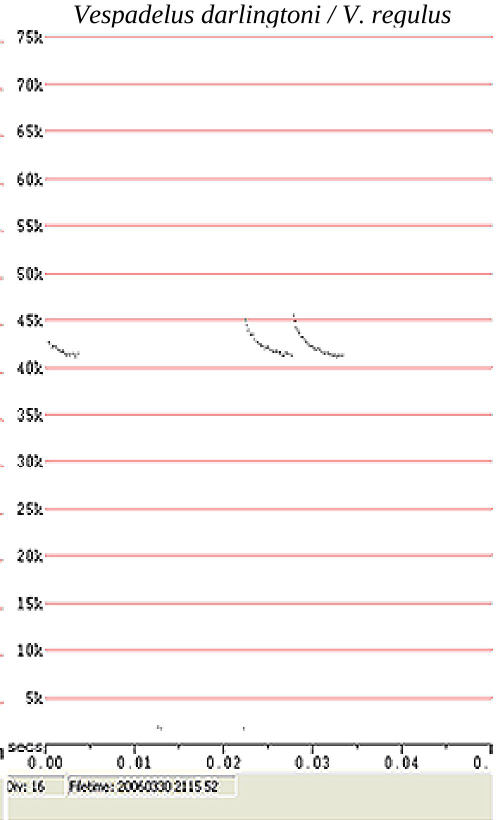
Tadarida australis



Nyctophilus geoffroyi



Vespadelus darlingtoni / V. regulus



Appendix 4: Suggested datasheet to keep record of bat boxes in Adelaide City

Bat box no.	Date	Time	Observer's name	Bats present Yes/No	No. of bats	Species name (if known)	Date contacted Environmental Office
e.g. GC3	26/10/06	10:00 am	John Gould	Yes	2	*C. gouldii*	30/10/06