OVERWINTERING BEHAVIOURAL STRATEGIES AND ROOSTING ACTIVITY BUDGET OF THE COMMON BENT WING BAT (*Miniopterus schreibersii*) AT THE NARACOORTE CAVES CONSERVATION PARK

By

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A thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Science with Honours

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DECLARATION

"I certify that this thesis does not incorporate without acknowledgment 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 material previously published or written by another person except where due reference is made in the text"

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Date:

SUMMARY

This study was undertaken in the Naracoorte Caves Conservation Park in South Eastern South Australia. The aim of this project was to observe and quantify the wintering behaviour and time activity budget of the common bent wing bat *Miniopterus schreibersii.* Bat Cave at Naracoorte is currently the only cave system in the world that has a permanent infra red camera system installed. The system comprises four cameras which allow an unprecedented opportunity to observe the resident bat population without the usual inherent problems of observer disturbance.

The activity budget was quantified using scan and focal sampling techniques. Analysis of the activity budget of *M.schreibersii* revealed that around 60 % of the time was spent roosting, 16 % grooming, 19 % active while around 1% of time was spent crawling. The activity budget of *M.schreibersii* was influenced by the chamber they were in, the location in cluster, the size of the cluster, the area of the cave sampled from and the period of the day.

ACKNOWLEDGMENTS

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I would also like to thank Steve Bourne for being the most enthusiastic person about caves I have ever met and for not losing me on our survey trips. Thanks also go to Brian Clark for allowing me to undertake this study and for his patience as we worked through the teething problems inherent with doing something for the first time. My thanks also to the whole staff at Naracoorte who were most helpful.

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CHAPTER 1

Introduction

1.1 Ecology of bats

Of all the mammals in the world one in five is a bat (Yalden & Morris 1975). Bats comprise around one quarter of Australia's native mammalian species (Reardon & Flavel 1987). Despite their abundance they remain one of the least understood and least studied of all animals. Their predominantly nocturnal lifestyle and generally secretive nature has meant that bats have become the subject of more misinformation than almost any other group of animals (Yalden & Morris 1975). Myths and old wives tales abound, ranging from the infamous 'blind as a bat' to thoughts of blood sucking vampires. These stories are, of course, largely unfounded - all bats can see and despite the attention they receive, there are only three species which feed on blood and these only occur in South America (Hall & Richards 1979).

However maligned, bats exhibit some of the most remarkable adaptations seen in the animal world. They are the only mammals capable of sustained flight. The first studies into how bats could 'see in the dark' were conducted in the 1700's by Lazarro Spallanzani. However it was not until relatively recently in the 1930's when Donald Griffin used an ultrasonic microphone to give credence to this idea. Together with adaptations for hibernation, bats have long held the interest of the scientific world.

Bats belong to the order Chiroptera (derived from the Greek words meaning 'hand wing') which is separated into two distinct sub orders, the megachiroptera and the microchiroptera. Megachiropterans, as the name implies, are generally the larger bats often referred to as flying foxes or fruit bats. All megachiropterans are fruit, blossom or nectar feeders, have large eyes, excellent night vision, and most have no echolocating

abilities (Hall & Richards 1979). The microchiropterans are much smaller and are generally insectivorous, echolocating to capture their prey (Reardon & Flavel 1987). There are twenty species of bat known in South Australia, representing four families and eleven genera (Reardon & Flavel 1987) and with the exception of the Little Red Flying Fox which is a rare visitor to this state they are all microchiropteran.

1.2 Study species

The focus of this study is the common bent wing bat *(Miniopterus schreibersii)* which is microchiropteran and is the dominant cave dwelling species of South Eastern South Australia (Dwyer 1966). It is a small bat typically weighing around 13 -17 grams. Pregnant females may weigh up to 20 grams. The fur is a uniform chocolate brown fading to slightly lighter brown ventrally (see figure 1.1). The distinctive feature of this species is the bent wing so called as the terminal phalanx on the third finger is over 25 mm long and folds under when the wing is at rest (Dwyer 1983).

The only known maternity colony in South Australia is found in Bat Cave at Naracoorte. Bat Cave is around 500m long with a large maternity area covering 30 m^2 deep inside. The cave has a single entrance ten metres above the floor of the cave (see figure 1.2) and is reported to contain up to 200 000 bats at peak summer occupation (Dwyer 1966). Like many bats, *M.schreibersii* will aggregate together to form large clusters. Dwyer (1983) reported an adult cluster packing density of 1763/m^2 and up to 3000/m^2 for juveniles (see figure 1.3). Young are born from October to November and the colony remains in Bat Cave until dispersing out to overwintering caves towards the end of May (Dwyer 1983).

1.3 Roosting ecology

Bats spend around half of their lives in their roosting environment (Kunz 1983). Despite the large proportion of time that bats spend roosting there have been few studies that have looked into how bats apportion this time. Caves with suitable climatic conditions are an essential requirement for *M.schreibersii* to facilitate breeding and only eight maternity caves are known in Australia (Dwyer 1966). Suitable caves are an important limiting resource.

The susceptibility of roosting bats to disturbance by humans is one of the main reasons why observations of bats in roosts are difficult. Non tactile stimuli have been demonstrated to adversely affect roosting and hibernating bats with observations of bats arousing and flying following human visits to caves (Speakman, Webb & Racey 1991, Thomas 1995). Disturbing hibernating bats can also have more serious implications. Increased mortality and population declines have been attributed to depletion of fat reserves caused by premature arousal of hibernating bats (Gaisler, Hanak & Horacek 1981, Fenton 1982, Thomas 1995).

1.4 Techniques for monitoring roosting bats

Early work observing bats at roost included using red cellophane over headlamps (Twente 1955), or simple illumination with red light (O'Shea & Vaughan 1977) and progressed to include the use of infra red filters over headlamps (Anthony, Stack & Kunz 1981). Recent advances in television and camera technology have meant significant improvements have been made which offer better opportunities to observe bats in their natural environment undisturbed. These include the use of low light

television camera equipment (Barclay 1982) and infra red cameras (McCracken & Gustin 1991, Winchell & Kunz 1996).

Bat Cave at Naracoorte is currently the only cave system in the world to have a permanent infra red remote controlled camera system installed, although similar ventures are planned in both Asia and America. This camera system provides an unparalleled opportunity to study the activities and behaviour of the resident bent wing population. Infra red light is an excellent choice for illuminating bats as it does not cause any adverse effects or disturb the bats (McCracken & Gustin 1991, Winchell & Kunz 1996, pers obs). The camera system is described in chapter 2.

1.5 Activity budgets

The amount of time that animals spend in different behavioural states affects their energy budget and ultimately their fitness and survival (Winchell & Kunz 1996). Being small mammals with relatively high energetic demands bats are constantly having to regulate their energy output (Kunz 1988). Therefore examining time activity budgets for different behaviours is important both for looking at the energetic costs of different behaviours and for monitoring how bats respond to changes in their environment (Kunz 1988, Winchell & Kunz 1996).

The time budget method was originally developed to examine the activities and energetics of lizards (Tracy 1982, Tracy & Christian 1986). It has been used extensively to examine the activity budgets of birds (Lo & Fordham 1986, Boxall & Lein 1989, Rave & Cordes 1993), and for larger mammals (Altmann 1977, Estes, Underwood & Karman 1986, Watts 1988, Gillingham & Klein 1991) and has even been used in studies of Stickleback fish (Wooton 1971). However such studies on bats are rare.

Burnett & August (1981) and Winchell & Kunz (1996) reported the first detailed activity budgets for the little brown bat (*Myotis lucifugus*) and the eastern pipistrelle bat (*Pipistrellus subflavus*) respectively. Their results indicated that these bats spent up to 80 % of their time in day roosts resting and that grooming was most likely to occur after the bats had returned from feeding (Burnett & August 1981, Winchell & Kunz 1996).

The majority of studies on bat activity have tended to focus on specific types of behaviours or interactions. These include nursing behaviour (McCracken & Gustin 1991), social grooming (Wilkinson 1986), other types of social behaviour (Barclay 1982, Wilkinson 1985, Bhat & Kunz 1995) and the seasonal patterns of bat activity (Avery 1985, Fenton & Rautenbach 1986, Taylor & O'Neill 1988 and Taylor & Savva 1990).

1.6 Study rationale and objectives

This study explores how bats spent their time in roosts, by observing and quantifying the roosting activity budgets of *M.schreibersii*. The purpose of this study was to test the hypothesis that the roosting activity budgets of *M.schreibersii* were influenced by a number of factors. These were season, roost temperature, location of cluster in cave (chambers 1 - 4), cluster configuration (tight, loose, dispersed & lined up), cluster size (lge >12 or sml < 12 bats), location in cluster (central, peripheral or solitary bats), sampling period (day, pre-emergence, foraging or post foraging return), elevation of bats in cave (high, middle or low) and sex (male, female or juvenile female). To test the hypothesis the time allocated to different behaviour states was quantified and related to the above factors.

CHAPTER 2

Materials and Methods

The aim of this study was to test the hypothesis that the activity budgets of *M.schreibersii* were influenced by temperature, location of cluster in cave, cluster configuration, cluster size, position in cluster, sampling period, height of bats in a chamber and sex of the bat. To test this hypothesis the amount of time allocated to six behavioural states was monitored. Behavioural states were taken from Burnett & August (1981) and are described in table 2.1. To account for behavioural differences between species the behaviours monitored had slight differences from those used by Burnett & August (1981) and Winchell & Kunz (1996) for example tail fanning, as observed in *M.lucifugus*, is not observed in *M.schreibersii*. Using similar behavioural classification facilitates comparisons between species.

Table 2.1: Behavioural categories used in this study

BEHAVIOURAL CATEGORY	DESCRIPTION
Roosting	resting, not moving
Grooming	grooming self, scratching, licking or preening
Alert/Active	head or body raised in an alert position, stretching, yawning, defecating, all other random movements with eyes open or closed
Crawling	moving around on cave walls or on other bats
Flying	taking flight during a sampling session
Allogrooming	grooming other bats

This study was conducted with the approval of and in accordance with the National Parks and Wildlife act 1972. Permit No E23930-01 was issued to enable scientific research to be undertaken in a National Parks Reserve.

2.1 Data collection

Data were collected using the infra red camera system in Bat Cave. This system comprises four cameras, installed at fixed locations throughout Bat Cave during 1995 (see figure 2.1) as part of an expansion of tourist facilities and for scientific research. The cameras themselves are movable about a fixed point, having 357 degree lateral rotation and can move 10 degrees vertically down and 70 degrees upwards. This enables the viewer to see a large proportion of each chamber. The cameras in Bat Cave were designed to ensure that when cameras are moving, noise is kept to a minimum.

Locating cameras in a cave with a resident bat population presented some novel challenges for the designers of this system. To overcome these problems the cameras were enclosed in a glass housing to avoid condensation on sensitive electronics. The cameras have a roof over them to protect from bat guano. The cameras use an active infra red light source supplied by a bank of light emitting diodes (L.E.D's) on the front of each camera (figure 2.2). A remote control panel located in a nearby building controls camera movements (figure 2.3). The panel enables the operator to switch between cameras, move each camera via a joystick and to zoom in and out.

2.2 Temperature and humidity recordings

Temperatures were recorded in each chamber with a camera installed. Needing to read the thermometers under infra red light presented some challenges. The

thermometers had to be mercury to enable them to be read (alcohol thermometers cannot be read under infra red light). Trials indicated that recordings of temperature could not be done simply by hanging thermometers on the walls of the cave. This was due to the dark background and glare. To overcome these problems thermometers were mounted on a white plastic background achieved by cutting used oil canisters (found on site) in half and wiring the thermometers on. Corresponding texta marks on the plastic to the temperature increments made reading easier. Thermometers were hung at a very slight angle to prevent glare. Following installation of thermometers or any visit inside Bat Cave no data were recorded for 12 hours to prevent observer disturbance affecting bat activity.

Temperatures inside Bat Cave were recorded with an infra red laser sighted temperature recorder. Recordings were taken on several trips into Bat Cave. Recordings were made of bats in different positions in clusters eg central or peripheral. External temperature and humidity were recorded with a Mason's wet and dry bulb hygrometer. External recordings were taken outside the interpretation centre at the beginning of each scan or focal sampling session.

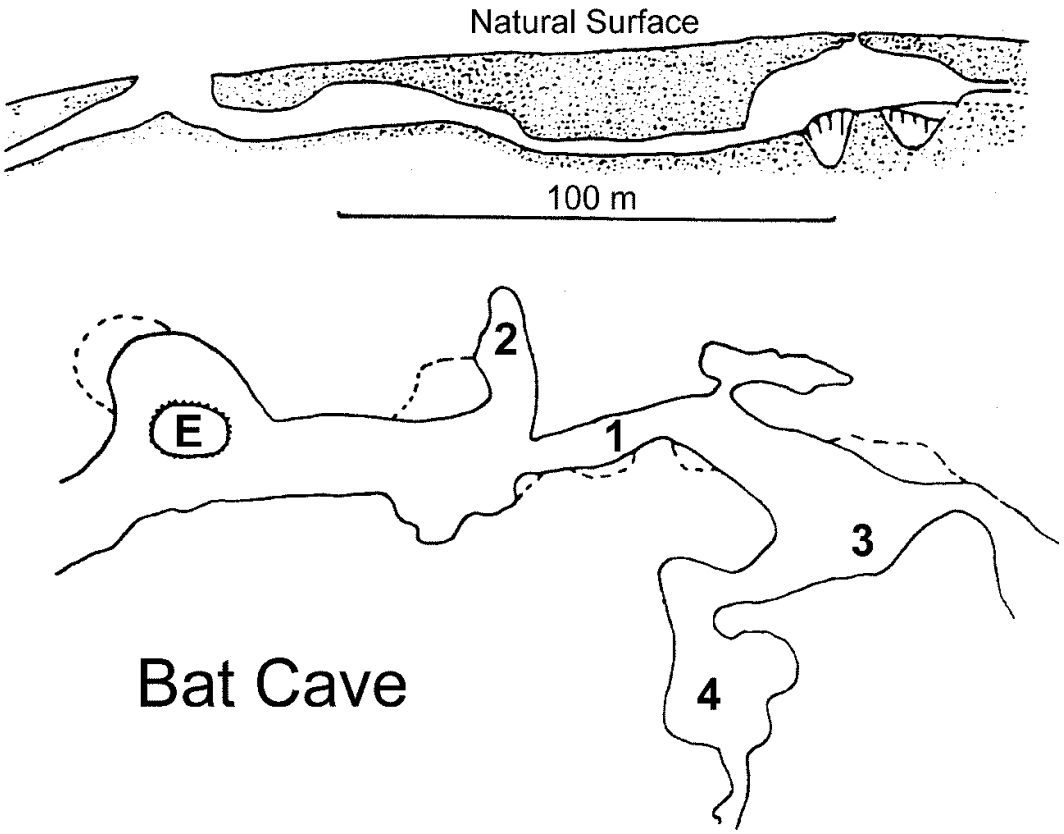

Figure 2.1 Camera and thermometer locations in Bat Cave

1 = Chamber 1, thermometer 1

2 = Chamber 2, thermometer 2

3 = Chamber 3, thermometer 3

4 = Chamber 4, thermometer 4

2.3 Sampling techniques

2.3.1 Scan sampling

Data were recorded using scan sampling (Altmann 1977). I randomly chose five bats with a camera, zoomed in and scored the behavioural state of each one of the five individuals. Five bats constituted a group. Ten replicate scans of each group were conducted during a scanning session. Each scan took two and a half minutes and a new focal group was chosen at ten minute intervals. Less frequent sampling was carried out at times when numbers of bats were low. This normally occurred when the majority of the colony had left to forage, in these instances a new focal group was selected at 15 minute intervals.

The timing of these sampling sessions followed the 'brief' and 'short' conventions outlined by Winchell & Kunz (1993). They found that frequent, brief sampling sessions of ten replicate scans at ten minute intervals reliably quantified the day roosting activity budgets of *P.subflavus* and were the best measure of behaviour. Less frequent sampling sessions, at 15 minute intervals, were advocated for periods when bat numbers were low. Sampling rotated between groups in different chambers, different sized clusters, different cluster configuration etc for each sampling session.

Data were collected in two hour blocks twice a day. Two hour sessions were used to prevent observer fatigue (Martin & Bateson 1993). The two hour blocks were rotated though 24 hours to gain a complete picture of the activity budget. For example a session might run from 8 - 10 am and again at 6 - 8 pm, the next day sessions would then run from 10 am - 12 noon and 8 - 10 pm respectively and so on. Daylight savings fell within the study period and to account for the lost hour, data recording was

swapped to odd hours. Data collection took 7 weeks and totalled 240 hours of observation.

2.3.2 Techniques to identify bats at roost

Identification of bats at roost requires some form of tag to be applied to the bat. Numerous methods have been used to achieve this and a number of important considerations need to be taken into account. The marking technique ultimately used depends on the species and the objectives of the study. Factors such as what period of time the tag is required for, if individual identity is required and how the tag needs to be able to be seen (Kunz 1988) all play a role in the choice of tag. Wing bands, metallic or plastic bands, chemical light tags and even bat necklaces have all been used to identify bats (Kunz 1988).

The use of infra red light to observe the bats in this study meant the tags had to be clearly visible under this light. Banding bats has fallen out of favour due to numerous instances of the tags causing injury and even death (Davis 1960, Dwyer 1965). The main cause of problems appears to be the incorrect application of the tags (Stebbings 1978). Reflective tags show up clearly under infra red light and have been used to study mother pup interactions (McCracken & Gustin 1991) and social organisation (Wilkinson 1985). Reflective tags do not increase the mortality of tagged individuals (M.D. Tuttle pers comm, Kunz 1988).

2.3.3 Focal sampling

To examine any possible differences between male, female and juvenile bats, 45 bats were tagged and monitored using focal sampling (Altmann 1977). Juvenile females were distinguished from adult females by the absence of prominent nipples. This

indicated bats that had not yet given birth. Juvenile bats are normally identified by unfused wing joints. When this study was carried out, juveniles were almost fully grown. Distinguishing them from adults by the wing joint method was unreliable. Juvenile males could not be distinguished from adult males.

Tagging involved a simple mark, capture and release strategy. Tagging was conducted on the 26th of April. Bats were trapped using a harp trap set 30m down inside the entrance of Bat Cave as shown in figure 2.4. Several different types of tag and tagging techniques were trialed in late February and early March. Non toxic paint markings on the forearms were the first tags attempted. Different numbers of marks on the forearm were used to distinguish between the sexes. These tags proved impossible to see as the camera would have needed to be on full zoom to have any chance of the tags being seen. No bats were identified with these tags.

Tags needed to be clearly visible. Trials indicated that reflective tape showed up clearly under infra red light. Sandwich style reflective tape tags were the next tried. These were pinched onto the back of the bat using the adhesive of the tape. These tags showed up clearly on the cameras but were observed being removed within a matter of minutes. To prevent tags being removed so easily or falling off, reflective tags were glued on using “Skin Bond’ glue. Texta marks were used to distinguish between the sexes. These tags were again clearly visible but the glare off the tags made it hard to reliably identify texta marks and distinguish between the sexes. Finally different shaped reflective tags were glued onto the lower back of bats. Male bat were identified by a thin rectangular tag. Adult females received a square tag and juvenile females were assigned a triangular tag. Fur was trimmed to facilitate a strong bond between the tag and skin (see figure 2.5). Focal sampling involved scanning around until a tagged bat was sighted, then zooming in and scoring the behavioural state of the individual bat.

The technique used was similar to scan sampling, the bat's behavioural states were recorded at two second intervals for ten replicate scans of the bat.

2.4 Bat activity

Attempts were made to count the number of bats visible on each camera during each sampling session. Counts were made by panning each camera through its full rotation and counting the number of bats seen. The highest activity level the bats can attain whilst in the cave is to fly around. It is important to gain some idea of the level and frequency of this behaviour. Bats scored as flying during a scan sampling session simply represented bats that took flight whilst sampling. Once the bats have taken off they were scored as flying for the rest of the session.

On each of the four cameras a specific site was chosen that could be readily recognised and returned to, for example, by reference to obvious cave decoration etc. The number of bats flying past each of these points in one minute was recorded during each hour of observation. The arrival and departure times of the colony were also recorded if they occurred during a sampling session.

2.5 Drinking behaviour

M.schreibersii were first noticed to be drinking from a site near camera two shortly after the installation of the cameras. Water permeating through limestone caves has the potential to pick up various minerals most notably calcium. A water sample was collected from the drinking site in Bat Cave. This sample was compared to samples from other caves in the area, Wet and Blanche caves, and from possible alternative drinking sites, Mosquito Creek and Bool lagoon.

Water analysis was carried out by Waite Analytical Services using Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES). Water was analysed for the presence of the following elements: Fe, Mn, B, Cu, Zn, S, Ca, Mg, P, K and Na.

2.6 Survey of overwintering sites

M.schreibersii leave Bat Cave with the onset of winter to disperse out to wintering sites (Palmeirim & Rodrigues 1995). Information on the movements of bent wings, the location and numbers of bats in wintering caves is largely based on anecdotal data. Surveys of possible wintering caves attempted to described the location and movements of *M.schreibersii* through winter.

Caves in the surrounding area were surveyed to monitor the usage pattern of the bent wings of these overwintering sites. Temperature, humidity and the number of bats seen were recorded on each visit. The caves surveyed were: Blanche cave (1), Wet cave (1), Gran Gran cave (2), Graveyard cave (3), Mt Burr cave (4), MonBulla (5), Robertson's cave (1) and Joanna Bat Cave. These caves were within a 150 km radius from Bat Cave. Numbers refer to location of caves on figure 2.6. The location of Joanna Bat Cave is not included on the map as it is on private land and the owner requested its location remain unreported.

2.7 Statistical methods

Data analysis was carried out on the percentage of time allocated to each of the different behavioural states. Replicate scans were considered to be independent samples (Cochran 1963). Homogeneity tests revealed scan and focal sampling data were heteroscedastic. Arcsine transformation was not successful in normalising data. Scan and focal data were analysed using non parametric Kruskal Wallis and Mann Whitney U test to examine the relationship between factors and activity budget. Due to the large number of tests performed the Bonferroni inequality was used to control type I errror rate (Appendix 1) for Mann Whitney U tests. Full description of the results of Mann Whitney U (rank, p value) are in Appendixes 2 & 3.

Bat flight activity data were homogenous when log transformed (see Appendix 5). Data were examined using parametric Scheffe's one way ANOVA and multiple linear regression to explain variation.

CHAPTER 3

Results

3.1 Roosting environment

Data were collected over a seven week period, totalling 240 hours of observations, spanning the 7th of March to the 1st of June. Temperature was recorded in each chamber of Bat Cave at the start of each sampling session from installed thermometers. Internal ambient temperature fluctuated very little. The maternity chamber (Camera 3) had a consistently higher ambient temperature than all other chambers ranging from 20.8 - 25.6 °C (mean +/- SE = 20.95 +/- 0.11, N = 463). Ambient temperatures in chamber 4 (camera 4) ranged from 19 - 21.8 °C (19.07 +/- 0.35, N = 463). Ambient temperatures in chamber 1 (camera 1) ranged from 17 - 19.4 °C (17.4 +/- 0.11, N = 463). Chamber 2 (Camera 2) is located the closest to the entrance of Bat Cave and recorded the lowest ambient temperatures, ranging from 14.1 - 17.3 °C (14.3 +/- 0.37, N = 463).

Internal temperature had a significant effect on the amount of time spent roosting ($\chi^2 = 79.76$, $p < 0.0001$), grooming ($\chi^2 = 66.92$, $p < 0.0001$), active ($\chi^2 = 20.91$, $p < 0.01$) and crawling ($\chi^2 = 74.85$, $p < 0.0001$). Activity generally increased with temperature evidence by increased grooming and active behaviour.

3.2 Flying and allogrooming

The behavioural category allogrooming (see chapter 2) was never found to occur during the study period. It was subsequently not included in analysis. Flying simply recorded the bats that took flight during a scan or focal sampling session. Once a bat took flight they were scored as flying for the rest of the session. This completed the data set and ensured the number of observations and timing remained consistent during a session. Bats taking flight is not a behavioural state and was not included in analysis. Summary percentages as a result do not add up to 100 %. Recordings of bats flying past a chosen point in each chamber aimed to account for and quantify this behaviour (see section 3.6).

3.3 Bat activity budgets

3.3.1 Scan sampling

A total of 638 scan sampling sessions were conducted spanning 196 hours of observation over a seven week period. The overall percentages (mean +/- SE) of time spent in each behavioural state for all days and hours combined were as follows: roosting, 61.6 +/- 1.26 %; grooming, 16.23 +/- 0.8 %; active, 18.95 +/- 0.68 %; crawling, 1.12 +/- 0.12 %.

Roosting was a major part of the activity budget of *M.schreibersii.* The next most frequently observed behaviours (active and grooming) occurred with about the same frequency and were inversely related to levels of roosting (see figure 3.1a). Crawling occurred infrequently over the recording period and was never found to

exceed 3 % of the overall budget (figure 3.1b). Crawling was most often associated with the formation of clusters or following disturbance by other individuals.

3.3.2 Changes in activity budget over study period

The month and week of recording session were examined to look at effects on the pattern of time allocated to different behaviour states over the course of this study. Data recording was only carried out on one day in June. Mean percentages of time spent in each behavioural state in June (week 7) are not available.

Kruskal Wallis analysis indicated that week ($N = 638$, $df = 6$) recording was carried out in had a significant effect on time spent in all behavioural states; Roosting ($\chi^2 = 62.22$, $p < 0.0001$), grooming ($\chi^2 = 54.3$, $p < 0.0001$), active ($\chi^2 = 85.88$, $p < 0.0001$) and crawling ($\chi^2 = 63.66$, $p < 0.0001$), see figure 3.1 a & b. Results of individual Mann Whitney U tests (Bonferroni significance level $p = 0.0002$) between weeks indicated that the bats were roosting significantly less in week 1 than other weeks. Level of grooming were significantly higher in weeks 4 and 5. Levels of active behaviour were highest in weeks 1, 3 and 5. Incidence of bats crawling about the roost was significantly higher in week 1 than any other week.

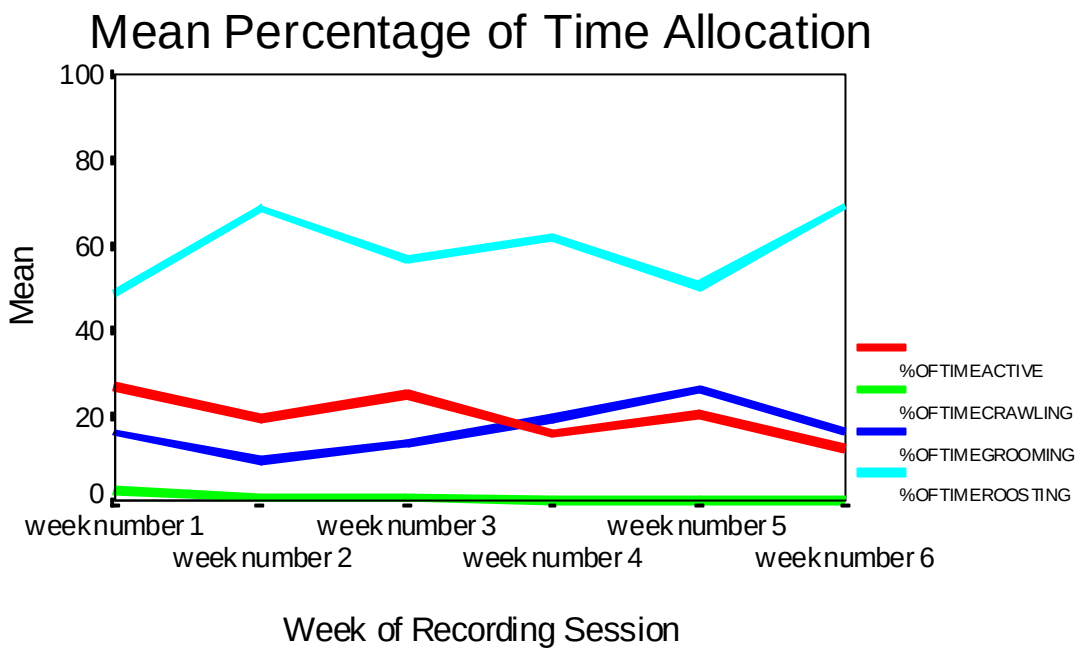

Figure 3.1a) Pattern of time distribution between activities for all weeks and hours combined.

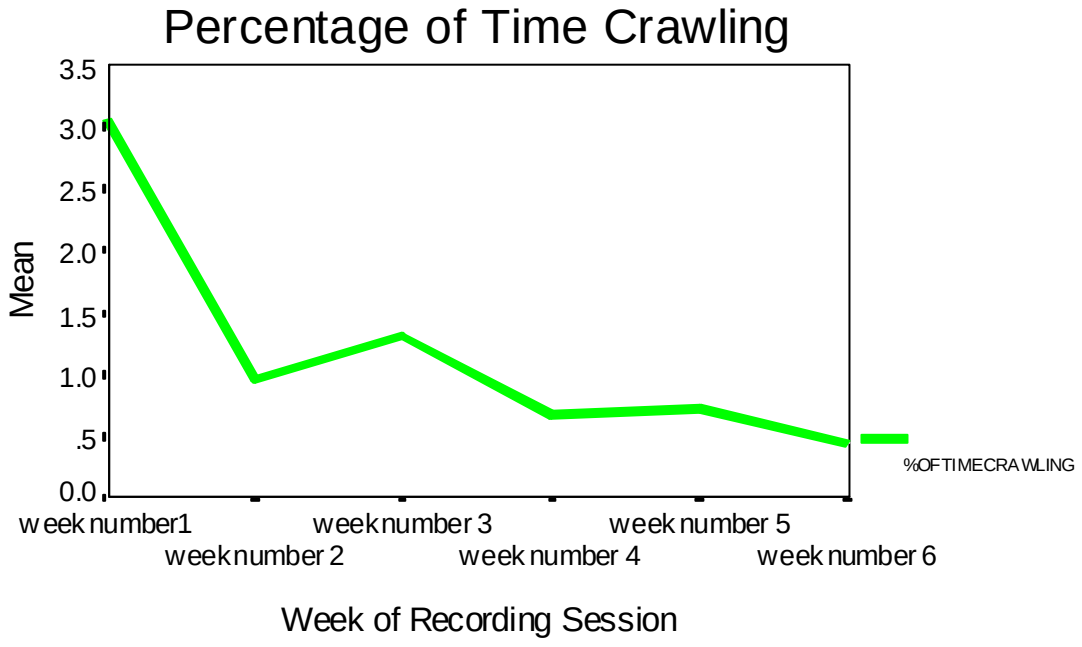

Figure 3.1B) Percentage of time allocated to crawling over all weeks and hours combined, showing pattern not discernible in Fig. 3.1 a

3.3.3 Chamber effects on activity budget

Kruskal - Wallis analysis indicated chamber (N = 638, df = 3) had a significant effect on the activity budgets of *M.schreibersii.* Roosting ($\chi^2 = 140.99$, $p < 0.0001$), grooming ($\chi^2 = 106.35$, $p < 0.0001$), active ($\chi^2 = 128.45$, $p < 0.0001$) and crawling ($\chi^2 = 24.41$, $p < 0.0001$). The percentage of time allocated to each activity (figure 3.2) indicated that the bats were behaving differently in different chambers. Roosting behaviour was highest in chamber 1, levels of active and grooming were highest in chamber 3. The summary percentages (mean +/- SE) for each chamber are presented in Table 3.1.

Comparison between chambers were made using Mann Whitney U tests of significance. Bats roosted more in chambers 1 and 2 than in chamber 3 and more in chamber 4 when compared with chamber 2. Percentage of time grooming was significantly higher for bats in chamber 3 than in chambers 1,2 or 4. Active behaviour of bats was greater in chambers 2 and 3 when compared to chambers 1 and 4. Bats were not found to spend significantly different amounts of time crawling between any chambers (see table 3.8).

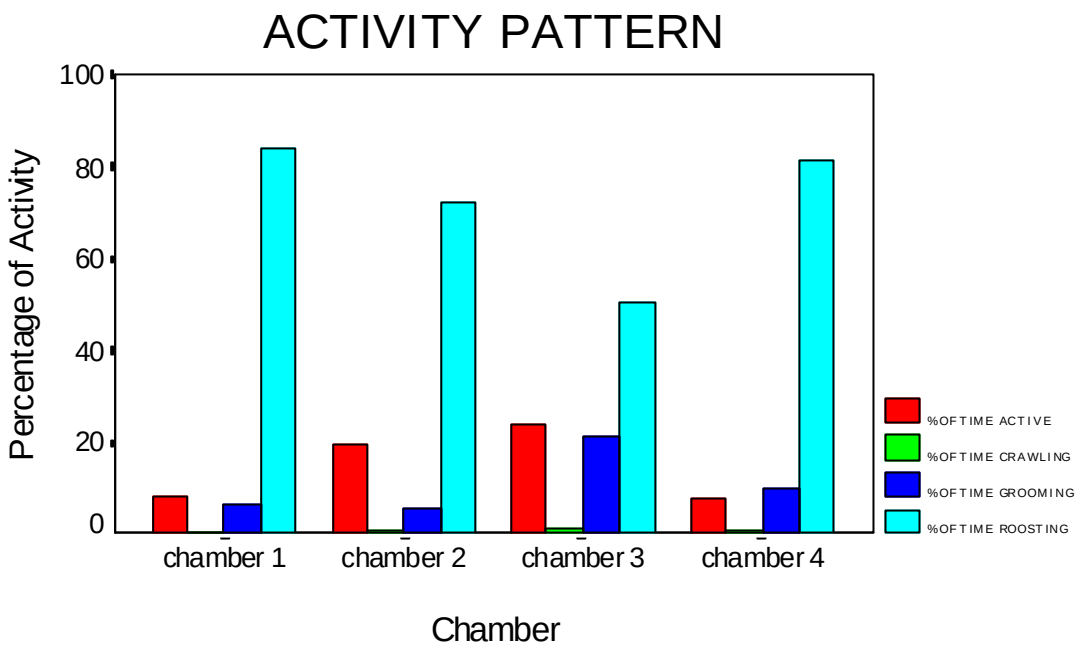

Figure 3.2) Pattern of percentage of time distributed between chambers in Bat Cave for all hours, week combined.

Table 3.1: Summary percentages (mean +/- SE) of time spent in each behavioural activity

CHAMBER	ROOSTING	GROOMING	ACTIVE	CRAWLING
Chamber 1	84.3 +/- 2.9	6.57 +/- 1.58	8.46 +/- 0.38	0.38 +/- 0.19
Chamber 2	72.33 +/- 3.41	5.76 +/- 1.79	19.77 +/- 2.36	0.88 +/- 0.5
Chamber 3	50.58 +/- 1.51	21.23 +/- 1.04	23.79 +/- 0.85	1.39 +/- 0.16
Chamber 4	81.37 +/- 2.23	9.78 +/- 1.74	7.64 +/- 0.98	0.67 +/- 0.25

3.3.4 Cluster configuration

Cluster configuration (N = 636, df = 3) classified as tight, loose, dispersed or lined up, had a significant effect on the percentage of time that bats allocated to roosting ($\chi^2 = 45.44$, $p < 0.0001$), grooming ($\chi^2 = 52.77$, $p < 0.0001$) and active ($\chi^2 = 57.61$, $p < 0.0001$) behaviour. Configuration did not have a significant effect the time bats spent crawling ($\chi^2 = 7.5$, $p = 0.0575$). The distribution of activity for different cluster configuration is summarised in figure 3.3.

Mann Whitney U analysis (table 3.8) within configuration revealed that bat roosting activity was higher for tight, dispersed and lined up clusters when compared with loose. Bats groomed significantly more in loose clusters than dispersed or lined up and grooming was lower in tight clusters than loose. Active behaviour was higher for bats in tight and loose clusters than dispersed (see table 3.3).

3.3.5 Location of sampled group in a cluster

The location of the sampled group in a cluster (central, peripheral or solitary) had a significant effect on the activity budget (N = 636, df = 2). Significant differences were found for the percentage of time spent active ($\chi^2 = 39.54$, $p < 0.001$). There was a small significant effect on the percentage of time spent roosting ($\chi^2 = 16.67$, $p = 0.001$). There was no significant difference between the percentage of time spent grooming ($\chi^2 = 5.67$, $p = 0.06$) or crawling ($\chi^2 = 1.86$, $p = 0.3938$) for location in cluster (see figure 3.4). Summary mean and standard errors are presented in table 3.4. Comparison within location showed peripheral bats spent significantly more time active than those that were solitary (table 3.8).

Temperatures were recorded for bats in different locations in clusters. The results are presented in Table 3.2

Table 3.2 Temperature variations within clusters and for solitary bats in chambers 2 and 3

	VARIATION IN BAT TEMPERATURE (MEAN +/- SE)		
CHAMBER	**CENTRE** N = 20	**PERIPHERY** N = 20	**SOLITARY** N = 20
2	18.7 +/- 0.25	16.4 +/- 0.13	14.4 +/- 0.91
3	27.3 +/- 1.48	24.1 +/- 1.21	22.6 +/- 0.88

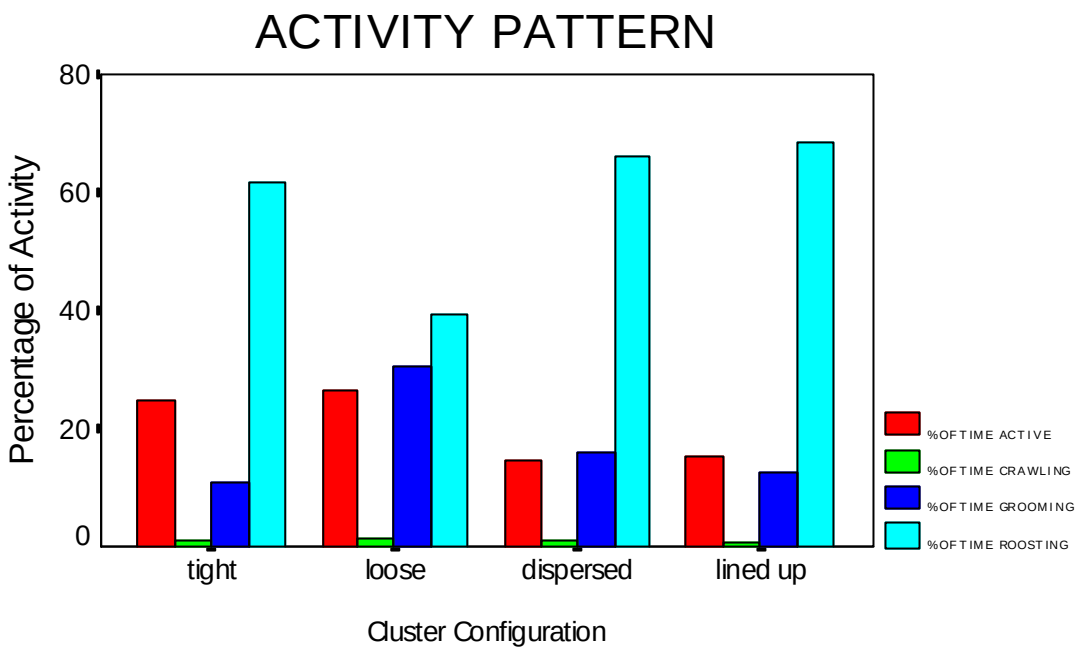

Figure 3.3) Pattern of percentage of time distributed between configurations of clusters, all hours / weeks combined.

Table 3.3: Summary percentages of activity distribution (mean +/- SE) for cluster configurations

CONFIGURATION	ROOSTING	GROOMING	ACTIVE	CRAWLING
Tight	62.83 +/- 3.38	14.63 +/- 2.15	22.07 +/- 2.13	0.27 +/- 0.19
Loose	39.72 +/- 4.38	32.48 +/- 3.38	24.92 +/- 2.36	1.1 +/- 0.33
Dispersed	70.46 +/- 2.37	17.27 +/- 1.71	9.72 +/- 0.93	0.53 +/- 0.17
Lined - up	68.42 +/- 9.08	18.28 +/- 7.21	13.14 +/- 3.91	0.14 +/- 0.14

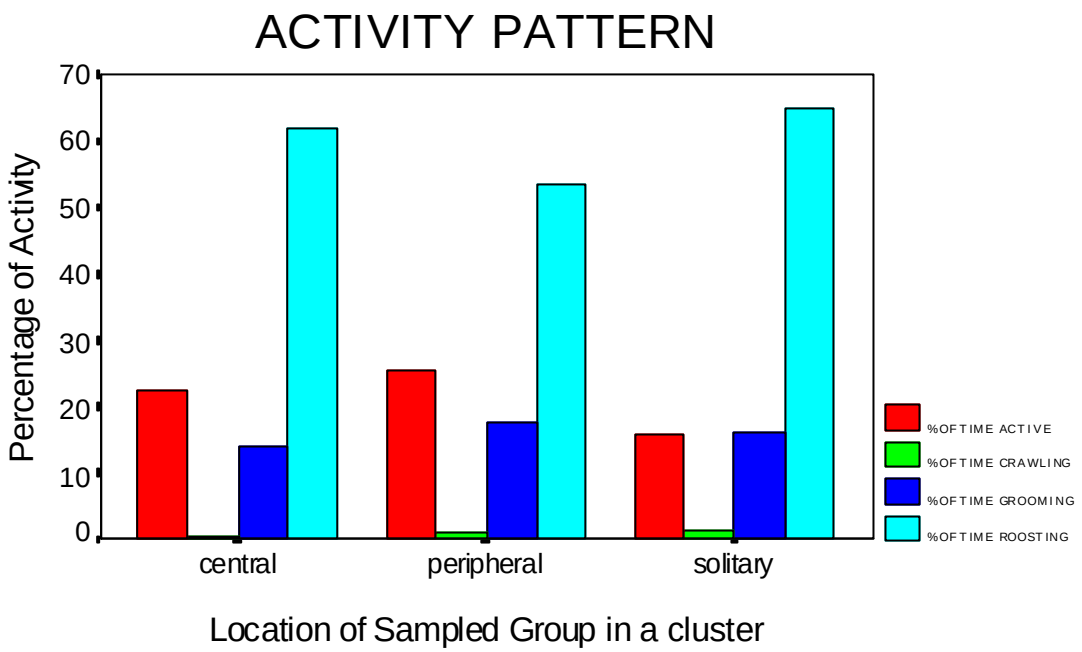

Figure 3.4) Pattern of percentage of time distributed between location of sampled group in a cluster, all hours / weeks combined.

Table 3.4: Summary percentages (mean +/- SE) for location of sampled group

LOCATION	ROOSTING	GROOMING	ACTIVE	CRAWLING
Central	62.08 +/- 3.76	13.94 +/- 2.66	22.53 +/- 1.92	0.68 +/- 0.27
Peripheral	53.68 +/- 2.39	17.65 +/- 1.57	25.44 +/- 1.50	1.07 +/- 0.24
Solitary	64.87 +/- 1.58	15.99 +/- 0.99	15.61 +/- 0.77	1.21 +/- 0.16

3.3.6 Size of cluster

The size of the cluster (N = 636, df = 1) being sampled had a significant effect on the percentage of time bats spent roosting (χ^2 = 22.35, $p < 0.0001$) and active (χ^2 = 58.74, $p < 0.0001$) see figure 3.5. There was no significant difference between grooming ($\chi^2 = 0.01$, $p = 0.91$) and crawling ($\chi^2 = 0.36$, $p = 0.55$). Comparison between the size of clusters (Mann Whitney U - table 3.8) revealed that bats in small clusters (< 12 bats) were found to be roosting significantly more than those in large clusters (> 12 bats). The opposite was revealed for large clusters with bats spending significantly more time active than in small (see table 3.5).

3.3.7 Area of cave cluster sampled

The area of the chamber sampled (high, middle or low) significantly affected bat activity budget (N = 327, df = 2) see figure 3.6. Area affected the amount of time bats spent active (χ^2 = 34.61, $p < 0.0001$) and roosting ($\chi^2 = 15.47$, $p < 0.01$). Area cluster was found did not significantly effect grooming ($\chi^2 = 5.06$, $p = 0.7544$) or crawling ($\chi^2 = 5.67$, $p = 0.8179$). The effect of area on the mean +/- SE of bat activity are summarised in table 3.6.

Comparison between elevations, Mann Whitney U, indicated that bats lower down on the cave wall roosted significantly more than bats high up. The percentage of time spent active was also significantly higher for bats located higher up and in the middle of the chamber wall when compared to bats lower down (see table 3.8).

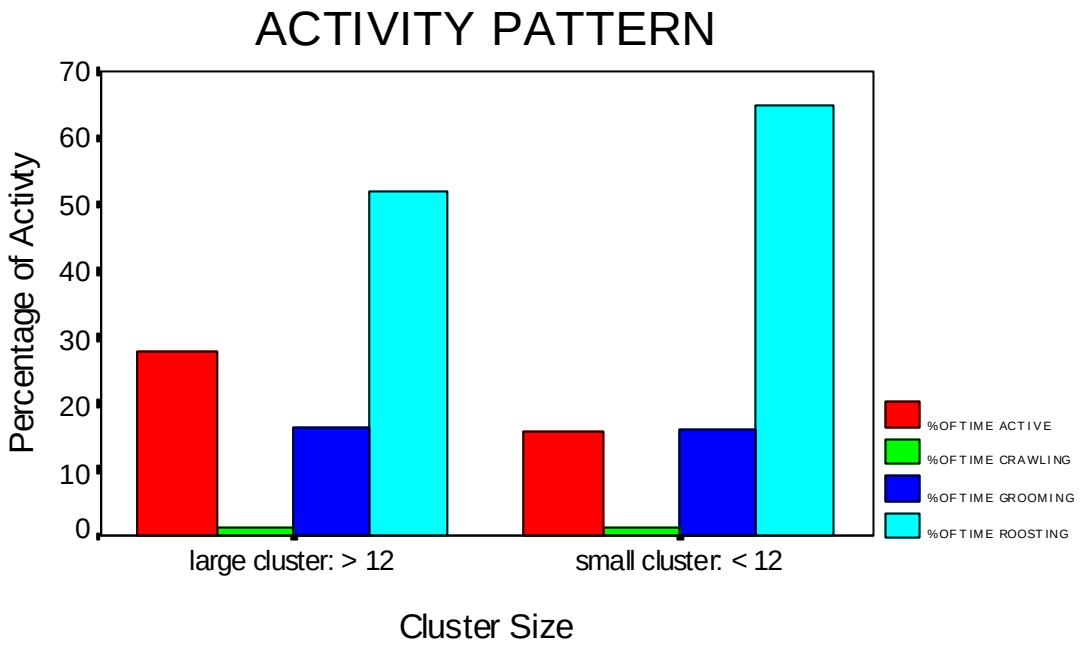

Figure 3.5) Comparison of pattern of time distribution between large clusters (>12 bats) and small clusters (< 12 bats) for all hours / weeks combined.

Table 3.5: Summary percentages (mean +/- SE) for large and small clusters of bats

SIZE	ROOSTING	GROOMING	ACTIVE	CRAWLING
Large > 12 bats	49.68 +/- 3.61	22.87 +/- 2.81	26.57 +/- 2.17	0.28 +/- 0.13
Small < 12 bats	67.82 +/- 2.05	17.78 +/- 1.43	12.10 +/- 0.90	0.61 +/- 0.14

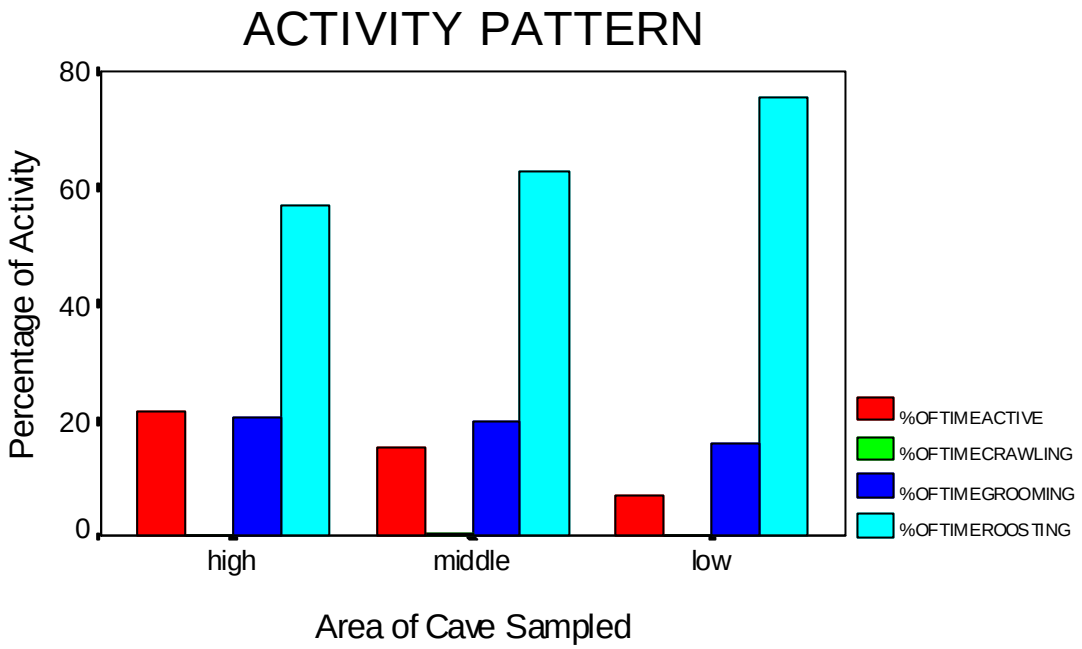

Figure 3.6) Distribution of time for bats sampled at different elevations / areas in Bat Cave, all hours and weeks combined

Table 3.6: Summary percentages of time allocation (mean +/- SE) for different areas of sampled bats

AREA	ROOSTING	GROOMING	ACTIVE	CRAWLING
High	57.05 +/- 3.37	20.56 +/- 2.44	21.31 +/- 1.81	0.38 +/- 0.14
Middle	62.64 +/- 2.59	19.54 +/- 1.74	15.34 +/- 1.26	0.80 +/- 0.21
Low	75.42 +/- 3.74	15.68 +/- 2.98	6.96 +/- 1.33	0.08 +/- 0.08

3.3.8 Period of the day

Each day was divided into four subperiods. These were defined as: 'day' - the period from arrival back and the departure the next night. 'Pre - emergence' as the period 2 hours before bats left to forage. 'Foraging' as the time when the majority of bats had left the cave until they returned and 'Post foraging return' as the 2 hour period following the return of the bats. The arrival and departure times of the colony were used to define these subperiods. Mean arrival and departure times fluctuated each month and the appropriate adjustment in terms of subperiod classification was made. In March mean departure time was 7:30pm, mean arrival time was 5:15 am. In April mean departure time was 5:45pm, arrival time 4:45am (daylight savings adjustment had been made). In May the colony means were departing at 5:15pm and arriving back at 4:45 am. The departure of the bats to forage was closely linked to sunset whereas the arrival times were fairly constant. With shortening day length the time available for foraging reduces gradually. The period of the day that a cluster was sampled had a significant effect on the percentage of time bats spent roosting ($\chi^2 = 137.53$, $p < 0.0001$), grooming ($\chi^2 = 129.23$, $p < 0.0001$), active ($\chi^2 = 63.47$, $p < 0.0001$) and crawling ($\chi^2 = 21.08$, $p < 0.01$). N = 638 df = 3. See figure 3.7.

Mann Whitney U comparisons between day subperiod (table 3.8) revealed roosting behaviour of the bats was significantly higher during the day subperiod than during pre - emergence, foraging or post foraging return. Grooming was significantly lower during the day than any other subperiod. Percentage of time bats spent active was higher during foraging and post foraging return periods than during the day. Percentage of time spent crawling was also significantly higher during foraging subperiod than during the day subperiod (see table 3.7).

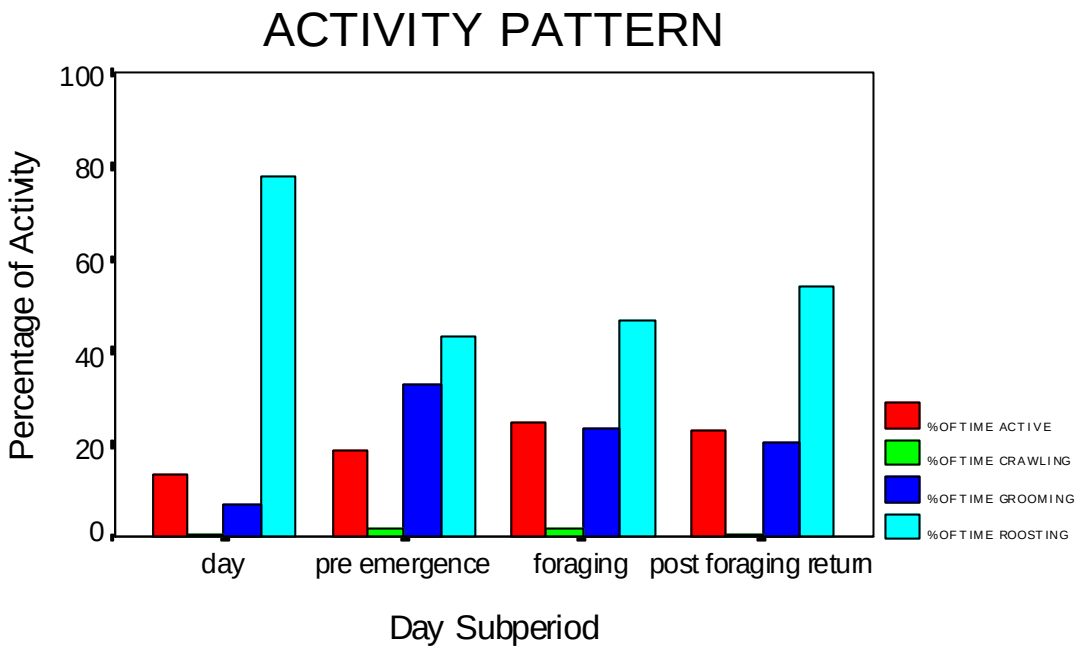

Figure 3.7) Pattern of percentage of time distributed over 24 hours by day subperiod all hours and weeks combined.

Table 3.7: Summary percentage (mean +/- SE) of activity for bats sampled in different subperiods, hours / weeks combined

PERIOD	ROOSTING	GROOMING	ACTIVE	CRAWLING
Day	77.56 +/- 1.37	7.01 +/- 0.68	13.47 +/- 0.85	0.72 +/- 0.16
Pre - emergence	43.07 +/- 5.78	32.92 +/- 4.78	18.67 +/- 2.83	1.69 +/- 0.70
Foraging	46.84 +/- 1.98	23.77 +/- 1.39	24.72 +/- 1.16	1.62 +/- 0.22
Post - foraging	54.22 +/- 3.82	20.44 +/- 2.61	22.91 +/- 2.22	0.69 +/- 0.26

Table 3.8: Summary of Mann Whitney U Analysis Within Factors

FACTOR	ROOSTING	GROOMING	ACTIVE	CRAWLING
Chamber				
1--2	**	NS	***	NS
1--3	***	***	***	**
1--4	NS	NS	NS	NS
2--3	***	***	NS	*
2--4	*	NS	***	NS
3--4	***	***	***	**
Configuration				
1--2	***	***	NS	**
1--3	NS	**	***	NS
1--4	NS	NS	**	NS
2--3	***	***	***	*
2--4	***	***	**	NS
3--4	NS	NS	NS	NS
Size				
1--2	***	NS	***	NS
Location				
1--2	NS	*	NS	NS
1--3	NS	*	**	NS
2--3	**	NS	***	NS
Period				
1--2	***	***	NS	NS
1--3	***	***	***	***
1--4	***	***	***	NS
2--3	NS	NS	*	NS
2--4	NS	NS	NS	NS
3--4	NS	NS	NS	NS
Area				
1--2	NS	NS	*	NS
1--3	***	*	***	*
2--3	**	*	***	*
Month				
1--2	NS	NS	NS	NS
1--3	NS	NS	***	***
2--3	NS	NS	**	*
Week				
1--2	***	***	***	***
1--3	NS	NS	NS	**
1--4	**	NS	***	***
1--5	NS	**	**	***
1--6	***	**	***	***
1--7	***	**	***	*
2--3	**	NS	*	NS
2--4	NS	**	*	NS
2--5	***	***	NS	NS
2--6	NS	NS	***	***
2--7	***	*	***	NS
3--4	NS	NS	**	NS
3--5	NS	***	NS	NS
3--6	**	NS	***	NS
3--7	***	**	***	NS
4--5	*	*	**	NS
4--6	NS	*	**	NS
4--7	**	**	**	NS
5--6	***	***	***	*
5--7	***	**	***	NS
6--7	**	*	**	NS

Key: * ⇨ 0.05

**** ⇨ 0.01**

***** ⇨ 0.0002 (Bonferroni significance level)**

3.4 Focal Sampling of Bat Activity

Focal sampling was conducted during a two week period to examine the difference between the activity budgets of male, adult and juvenile female bats. A total of 163 focal sampling sessions, spanning 44 hours of observation, were conducted between the 27th of April and the 8th of May. Tags remained effective for 13 days. The numbers of tagged bats seen and therefore sampled in focal sampling are described in table 3.9

Table 3.9: Number of tagged bats focal sampled on given day

	NUMBER OF BATS SEEN		
DATE	**MALE**	**ADULT FEMALE**	**JUV. FEMALE**
27/4	5	2	3
28/4	4	0	3
29/4	3	1	4
30/4	5	3	4
1/5	4	2	1
2/5	4	2	1
3/5	5	2	1
4/5	2	2	2
5/5	1	1	0
6/5	0	1	0
7/5	1	1	0
8/5	1	2	0
9/5	0	1	0

There was a significant difference between the percentage of time spent active ($\chi^2 = 7.29$, $p < 0.05$) and grooming ($\chi^2 = 9.97$, $p < 0.01$) between male, female and juvenile female bats ($N = 163$, $df = 2$). Mann Whitney U analysis between the sexes indicated that male bats spent more time crawling and grooming than adult female bats.

Adult female bats also spent significantly more time active than juvenile female bats (see figure 3.8).

3.4.1 Effect of tagging on bats

Focal sampling is dependant on the tagging of individual bats. It is important to establish whether the tags are having any effect on the activity budget. Focal sampling was conducted over a two week period. The activity budget in this period was compared to scan sampling of the week before and the week following focal sampling (see figure 3.9). These periods represented approximately the same sampling time.

Mann Whitney U analysis used the Bonferroni inequality to calculate significance level ($p = 0.00013$). A comparison between scan (weeks 3 & 4) and focal (weeks 4 & 5) sampling revealed that roosting was significantly higher in week 3 than in week 4. Percentage of time active was significantly higher during scan sampling than focal. Roosting and grooming were significantly higher during focal sampling. While time active was lower during focal sampling. Comparison between the weeks of focal sampling revealed no significant differences in time activity budget. At the $p= 0.001$ level, time active was higher in the first week and percentage of time roosting was higher in the second week (see table 3.10).

Table 3.10: Summary percentages of time (mean +/- SE) activity budget of male, female and juvenile female bats, hours / weeks combined.

SEX	ROOSTING	GROOMING	ACTIVE	CRAWLING
Male	38.14 +/- 4.42	39 +/- 4.34	22.69 +/- 2.04	0.49 +/- 0.19
Female	50.46 +/- 4.59	20.93 +/- 4.32	26.91 +/- 2.55	0.07 +/- 0.07

Juvenile female	42.21 +/- 6.48	36.62 +/- 6.36	16.61 +/- 2.53	1.21 +/- 0.58

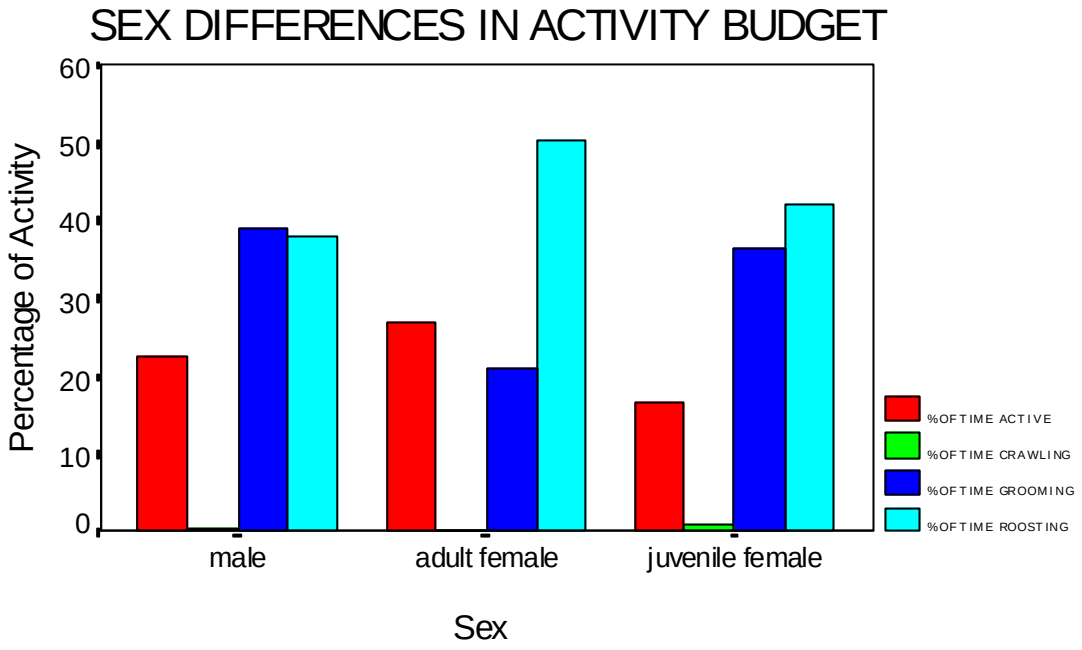

Figure 3.8) Comparison of time budgets for male, female and juvenile female bats from focal sampling sessions, all hours / weeks combined.

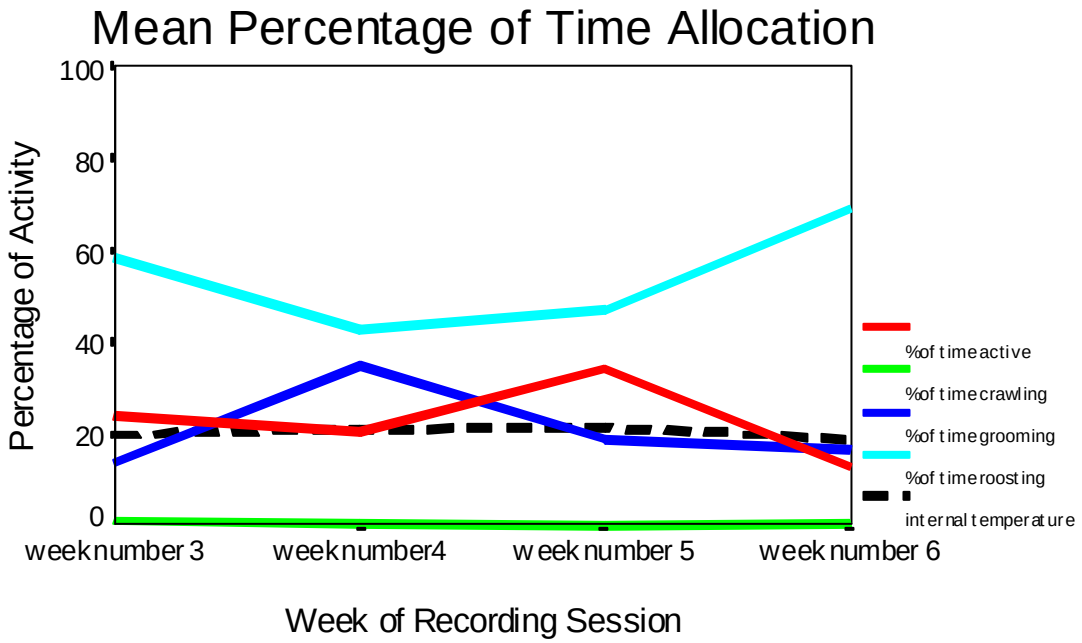

Figure 3.9) Comparison between activity budget of scan and focal sampling session looking at the effect of tagging bats on time budget, hours / days combined. Dotted line indicates mean internal temperature over sampling period.

Table 3.11: Summary of Mann Whitney U tests between Sex and Week

WEEK	ROOSTING	GROOMING	ACTIVE	CRAWLING
3--4	***	**	NS	*
3--5	NS	NS	*	*
3--6	NS	NS	***	**
4--5	NS	NS	**	NS
4--6	***	***	***	NS
5--6	***	NS	***	NS
SEX				
1--2	NS	**	NS	*
1--3	NS	NS	NS	NS
2--3	NS	NS	**	NS

Key: *** ⇒ p < 0.05**
**** ⇒ p < 0.01**
***** ⇒ p < 0.00013 (Bonferroni significance level)**

3.5 Bat flight activity

ANOVA (N = 481) revealed that the number of bats flying was significantly different between chambers ($F = 28.11$, $p < 0.0001$, $df = 3$), period of the day being sampled ($F = 10.54$, $p < 0.0001$, $df = 3$), the month ($F = 34.96$, $p < 0.0001$, $df = 3$) and week that recording session was carried out in ($F = 36.20$, $p < 0.0001$, $df = 6$). Scheffe's test of significance between means indicated that chamber 4 had significantly less bats flying past than chambers 1,3 or 4 (see figure 3.10). Comparison of flight activity by the period of the day sampling was conducted indicated that during the day subperiod bats

flew significantly less than during the foraging (see figure 3.11). The flight activity of *M.schreibersii* was affected season. Flight activity was significantly higher in March than other months. There was no significant difference between the first 4 weeks of recording. Flight activity was significantly lower in week 5 than weeks 1 - 4 and flying in weeks 6 and 7 was significantly lower than all other weeks (see figure 3.12).

Multiple linear regression analysis revealed that week alone explained 22 % of the variation in flight activity while month explained a further 16 %. There remained a further 62 % of variation in flight activity unexplained.

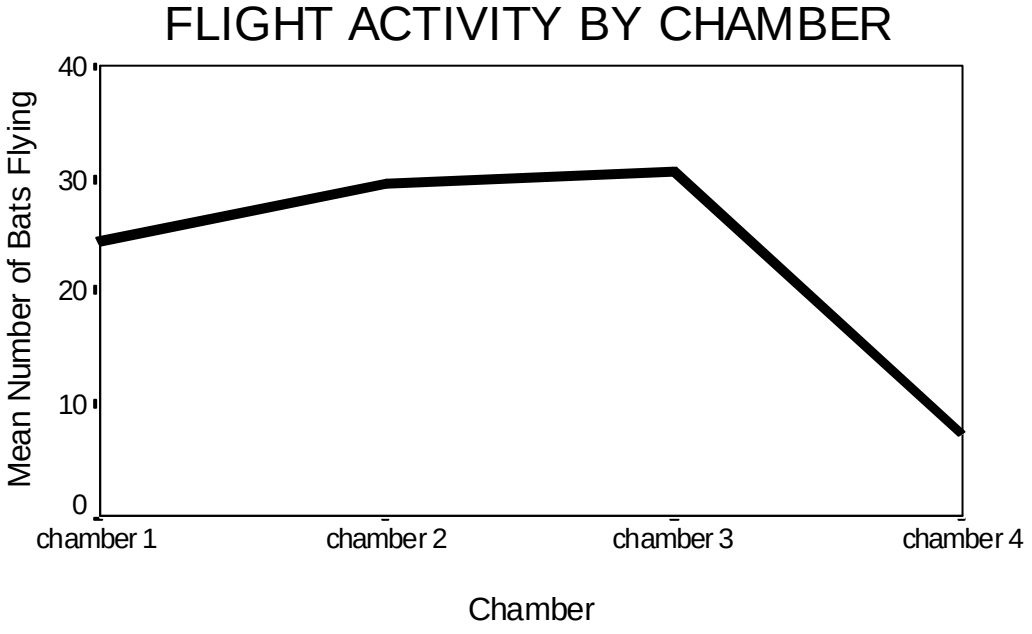

Figure 3.10) Mean number of bats flying past a fixed point for different chambers. All hours and weeks combined.

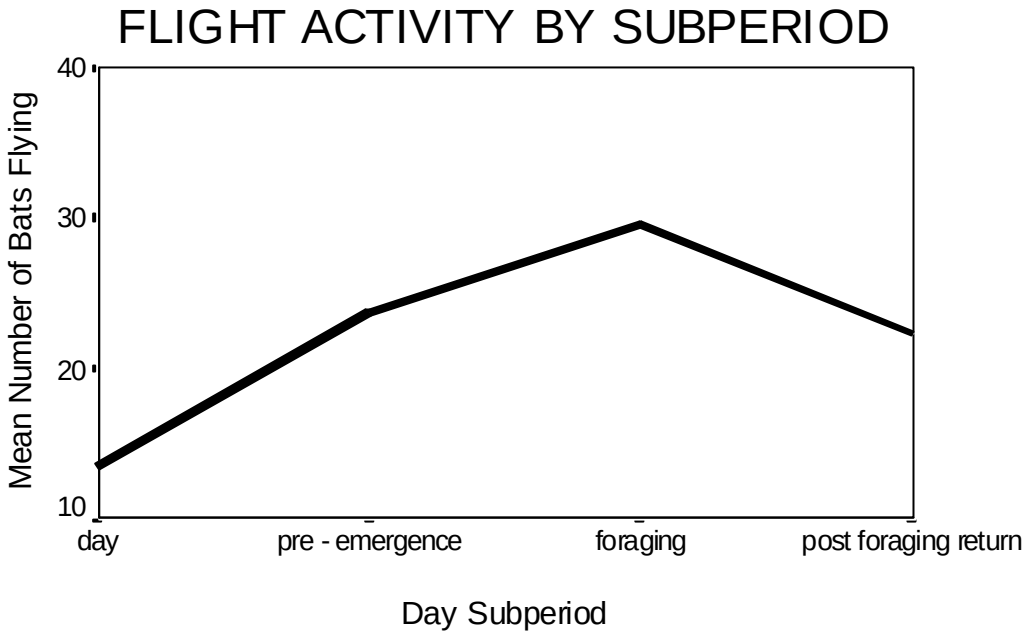

Figure 3.11) Mean number of bat flying for the different period of the day that sampling was conducted. All hours and weeks combined.

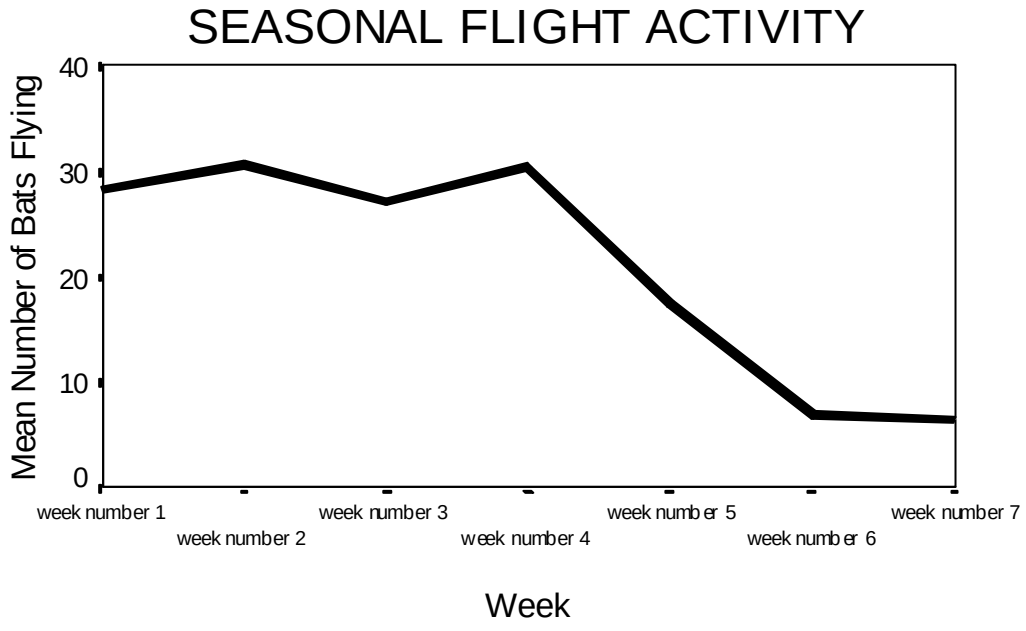

Figure 3.12) Seasonal change in flight activity by week. All chambers and hours combined.

3.6 Bat numbers

Following each sampling session the number of bats visible in chambers 1, 2 and 4 were recorded. The number of bats present in chamber 3 was too large for accurate counts to be made. Bat numbers declined steadily as the study period progressed, due to the dispersal of bats to overwintering caves. This may have been due to the dispersal of bats to overwintering caves. The bat numbers in chambers 1,2 and 4 were considered to be representative of overall bat population size and of the decline in bat numbers (see figure 3.13).

There were less than 50 bats visible in all chambers by the end of the study period. The entire population was observed to eventually leave Bat Cave.

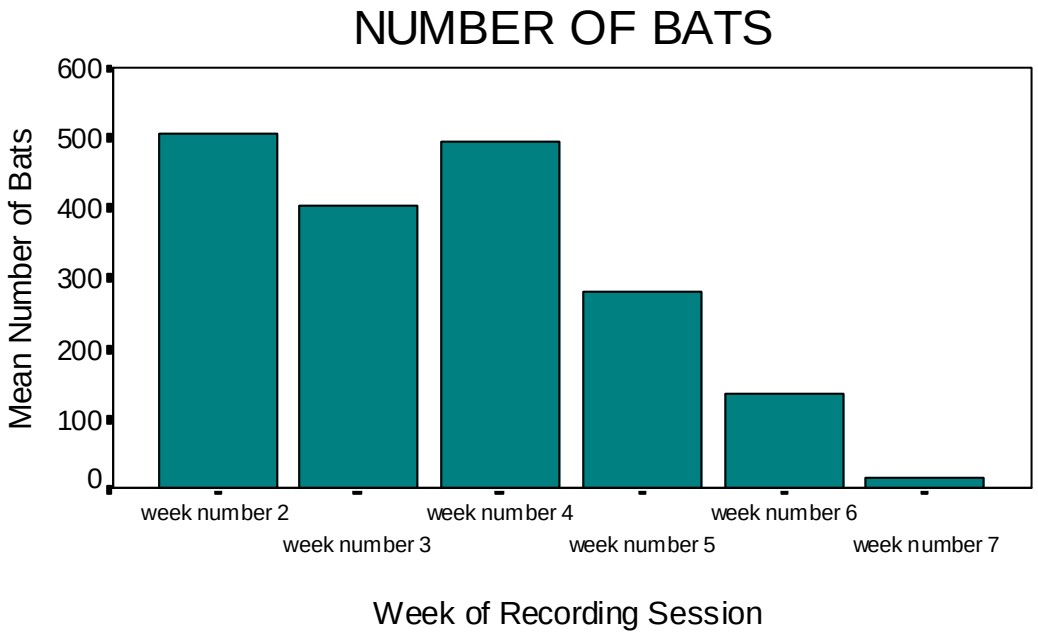

Figure 3.13) The decline in bat numbers with week, as season progressed into winter. Count are of chambers 1, 2 and 4 and are considered representative for entire population.

3.7 Surveys of overwintering caves

Caves surveyed within the National Park were Wet Cave, Blanche Cave and Robertson's Cave. Outlying caves surveyed were Gran Gran Cave, Graveyard Cave, Mt Burr Cave, Mon Bulla Cave and Joanna Bat Cave. The results are displayed in Table 3.12.

Table 3.12) Results from Surveys of Overwintering Caves

CAVE	DATE	TEMP °C	HUMIDITY % RH	NUMBER OF BATS
Wet	15/5	14	65	0
	18/10	12	57	0
Blanche	15/5	15.4	78	1- 200
	18/10	13	59	100
Robertson	15/5	15.5	81	> 5000
	18/10	14.3	69	1 - 200
Gran Gran	15/5	15.1	69	100
	18/10	12	52	1
Graveyard	15/5	16	67	4
	18/10	-	-	-
Mt Burr	15/5	13	75	3 - 4000
	18/10	12	68	0
Mon Bulla	15/5	14.5	61	200
	18/10	13	65	0
Joanna Bat	15/5	16	75	0
	18/10	-	-	-

3.8 Water analysis

A sample of water was collected from the site in chamber 2 where bats were observed to drink. Samples were also taken from other caves on the reserve and from possible alternative drinking sites for comparison. Cave samples were taken from Wet Cave and Blanche Cave. Possible alternative drinking sites identified were Bool Lagoon

(1 = Tea tree Boardwalk, 2 = Hacks Lagoon) and Mosquito Creek. The results of the water sample analysis are contained in Table 3.13. The analysis showed that samples from Bat, Wet and Blanche caves were generally comparable. The main difference being increased sodium levels in the Bat Cave sample. Samples from Bool Lagoon and Mosquito Creek recorded higher levels of all minerals than cave samples and had particularly high quantities of magnesium and sodium.

Table 3.13 Water Sample analysis. Comparison between Bat Cave sample from drinking site, other cave samples and alternative drinking sites (mg/litre)

	Bat Cave	Wet Cave	Blanche Cave	Mosquito Creek	Bool Lagoon 1	Bool Lagoon 2
Fe	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Mn	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.06	< 0.05	< 0.05	0.27	0.43	0.30
Cu	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Zn	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ca	49	42	72	88	129	69
Mg	6	4	1	42	206	57
Na	52	13	14	265	3457	372
K	4	3	2	7	47	14
P	< 1	< 1	< 1	< 1	< 1	< 1
S	4	2	1	22	173	28

CHAPTER 4

Discussion

4.1 Roosting activity budget

The roosting activity budget of *M.schreibersii* can be described as a general period of rest, accounting for around 60% of the time sampled. Time not spent roosting was largely distributed between grooming and general activity. The activity budget of M.schreibersii was influenced by several factors each of which will be discussed in the following sections.

4.1.1 Chamber and internal environment

Activity budgets differed between chambers in Bat Cave. Chamber 3 had a consistently higher ambient temperature than all other chambers, and recorded the lowest levels of roosting behaviour and the highest levels of grooming. Small bats such as *M.schreibersii* continually have to regulate their energy budget in order to maintain homeothermy. Activities within the roost environment incur an energetic cost. These can be ranked from high to low: crawling / grooming / active / roosting as reported for the little brown bat *M.lucifugus* a small temperate zone bat from America (Burnett & August 1981).

In a high temperature environment (such as chamber 3) bats do not have to spend energy in order to maintain a high body temperature. Energetically expensive behaviours such as grooming are therefore more likely to occur at higher temperatures. This hypothesis would predict that the lowest levels of activity should be observed in the coolest chambers. However roosting behaviour (the lowest activity level) was higher in chambers 1 and 4. The temperatures in chambers 1 and 4 had means of 17 and 19°C respectively which approximate the winter thermal preference range of 16 - 18°C, reported for South African *M.schreibersii* by Brown & Bernard (1994). Conditions in

chambers 1 and 4 appear to be preferred for roosting over chamber 2. The cost of such behaviours, through heat loss at lower temperatures such as those found in chamber 2 could be too high.

Burnett & August (1981) found that crawling behaviour was the most energetically expensive activity for *M.lucifugus* and that it accounted for less than 1 % of activity budget. The low incidences of crawling throughout this study concur and suggest that crawling may be too energetically expensive to warrant movement about the roost by this method. It is noteworthy that the highest incidences of crawling were found on chamber 3, which could be explained in terms of the higher temperatures found there.

Direct observations of the colony revealed a noticeable distribution pattern within Bat Cave that exhibited daily and seasonal change. The general trend in early March following the morning return of the colony was for a large proportion of bats to be visible in chamber 3. As the day progressed the colony would spread to other chambers (cameras 1 & 4) in the cave. A large colony formed in chamber 2 in late afternoon. This pattern altered as the season progressed into winter. Bats were found in outlying chambers progressively earlier in the day and fewer large clusters were formed in chamber 3. The large cluster in chamber 2 was not observed from the middle of May onwards.

The variation in chamber use and the different conditions found suggests that *M.schreibersii* are thermoregulating using the internal characteristics of Bat Cave to place themselves in the desired microclimate. Bats found in cooler chambers from early morning could represent those with lower prey capture success therefore needing to maximise energy savings. It would be instructive to know whether the spread to cooler chambers earlier in the season is a direct result of the declining availability of prey and an increased need to conserve energy. Prey levels could be assessed by using sticky traps

(Schedvin 1991). Climate change through the night may affect the costs of foraging even if insect abundance does not change.

4.1.2 Cluster configuration and location of sampled group in cluster

Cluster configuration and the location within clusters affected the activity budget. Bats in loose clusters roosted less and groomed more. Active behaviour was higher for tight and loose clusters than for dispersed. Within different cluster configurations dispersed bats were found to be more active than solitary bats. Bats located in loose clusters appear to have higher maintenance costs than those in other configurations.

Burnett and August (1981) reported that *M.lucifugus* on the periphery of clusters attempted to squeeze into central locations. Central locations were preferred due to the increased maintenance costs of being on the edge. These included increased activity levels and cooler conditions (Burnett & August 1981). While different temperatures existed for *M.schreibersii* in the centre of clusters compared to the edge, no observations of attempts to gain a more central location were seen. This suggests that the benefits of central locations may not be as great for *M.schreibersii*. Body temperatures of *M.schreibersii* on the edge of clusters (see table 3.3) were still higher than solitary bats. This would represent an energetic saving by decreasing the energy required to maintain a high body temperature. The cost of achieving a central location may not be warranted in terms of the benefits it may offer. Being peripheral may still be an advantage over being solitary.

4.1.3 Diel activity

Bats were less active during the day than at night. The majority of the day was spent roosting. Grooming behaviour increased prior to the nightly departure to forage and during the subsequent return to the roost. An increase in grooming before departure has been reported in other species: *M.lucifugus* (Burnett & August 1981), *P.subflavus* (Winchell & Kunz 1996).

Active behaviour increased in bats that remained when the majority of the colony had departed to feed and during subsequent return. This is most likely to reflect an imminent departure and typically consisted of shivering. This behaviour functions to increase body temperature (Kunz 1988) and suggest behaviour functions in thermoregulation. Active behaviour was frequently observed with grooming and in many instances occurred before, during or after a grooming incident.

4.1.4 Cluster size and area

Bats in small clusters were found to apportion more time to roosting than bats in larger clusters. While bats in larger clusters spent more time active. Temperature differences are likely to exist between different sized clusters. Smaller numbers of bats would have higher costs of maintenance required to maintain a higher body temperature. Abandoning attempts to remain warm and hence more active would account for decreased activity levels and observation of bats entering torpor readily in cooler chambers.

Changes in activity budget for bats at different elevations (areas) in Bat Cave can also be explained by temperature changes within chambers. Temperatures were always

higher at the top of chambers than closer to the floor. The temperature difference in cave microclimate would impact on activity levels.

4.2 Between species comparison of activity budget

The behavioural states monitored in this study were similar to those used to quantify the activity budgets of the little brown bat *M.lucifugus* and the eastern pipistrelle bat *P.subflavus.* Both *M.lucifugus* and *P.subflavus* were from colonies in Massachusetts. A comparison of the overall activity budget for the different species is summarised in table 4.1.

Table 4.1: Comparison between activity budget (mean +/- SE) of *M.schreibersii* (this study), *P.subflavus* (Winchell & Kunz 1996) & *M.lucifugus* (Burnett & August 1981)

	SPECIES OF BAT		
ACTIVITY	***M.schreibersii***	***P.subflavus***	***M.lucifugus***
Roosting	61.6 +/- 1.26	77 +/- 1.0	79.2 +/- 0.49
Grooming	16.23 +/- 0.8	7.0 +/- 1.0	14.3 +/- 0.4
Active	18.95 +/- 0.68	16 +/- 1.0	4.7 +/- 0.21
Crawling	1.12 +/- 0.12	< 1.0 +/- 0.0	1.6 +/- 0.1

Clear differences are evident by comparing activity budgets between species. Roosting was around 20 % lower in *M.schreibersii* while they recorded the highest levels of active and grooming behaviour. Crawling behaviour comprised less than 2 % of the activity budget across species. Winchell and Kunz (1996) identified colony size as a possible cause of differences in activity budget between *P.subflavus* and *M.lucifugus.* *P.subflavus* form small maternity colonies of around nine females, colony size peaked at 1000 individuals for *M.lucifugus,* while the Naracoorte population of *M.schreibersii* has

been reported to contain up to 200 000 individuals (B.Clark pers.comm). The higher levels of grooming behaviour seen as colony size increased may reflect an increasing parasite load (Winchell & Kunz 1996). Fastidious cleaning and grooming is required to prevent the parasite load rising and adversely affecting the health of the host bat (Marshall 1982).

The roost microclimate affected the activity budget of all three species of bat. Roost conditions were different for each species and reflects between species variation.

4.3 Focal Sampling of Activity Budget

The results of focal sampling on tagged bats are inconclusive. The higher incidence of grooming during focal sampling and the decrease in levels of roosting from the week before could be indicating that the tags were irritating the bats. This could be adversely influencing the activity budget by causing disproportionately higher levels of grooming. However tagged bats also roosted significantly more than untagged bats did the week following focal sampling. These results are difficult to interpret for a number of reasons. The number of bats sampled (table 3.10) indicates that male bats were seen more often than adult or juvenile females. The fact that more male bats were sampled indicates that males are more likely to be found either solitary or in loose clusters, this confirms observations of male *M.schreibersii* roosting singly by Dwyer (1966).

Tags were placed on the lower back in an attempt to prevent annoyance to the bat and to discourage the ease at which the tag could be groomed off. This meant however that the tags could not be seen in a number of situations. If the tagged bat was in the centre of a cluster or in any location tight up against another bat the tag was obviously not visible. This meant that the majority of tagged bats were either solitary, on the edge of

clusters or in loose clusters. While very few were sampled from the centre of clusters. Scan sampling revealed that the cluster configuration and the location of bats in a cluster affected the activity budget. By sampling tagged bats that were predominantly from, for example, loose clusters rather than tight the results will be biased towards an increase in active behaviour.

Improvements would need to be made in any future attempts to improve the reliability of results from focal sampling. An increased sample size and longer monitoring periods would improve the accuracy of results. Tags could be placed on the head of the bat which would enable them to be seen in any cluster arrangement. These could be made from small pieces of reflective tape tags or alternatively fluorescent paint as used by McCracken & Gustin (1991) to monitor mother pup interaction could be used.

Tagging of bats and focal sampling was still a worthwhile exercise. During the tagging period an adult female was routinely observed in the same location. This bat was found in the middle section on camera 3 for five consecutive days, she was named ‘MF1’ (middle female 1). MF1 had a fortuitous small notch missing from the corner of her tag, presumably the result of a failed attempt to groom off the tag, which distinguished her from other tagged adult females. Repeatedly finding MF1 in the same location raises the possibility that these bats have specific territories or roosting sites that they return to each day. The bats could be roosting in family groups or all females could be roosting together. This is supported by the observation of males roosting singly. These questions could be answered by mist netting a cluster and recording the sex of bats present and DNA analysis could confirm any family linkages. It is possible that this may have simply been a one off observation. It would be interesting to conduct future tagging, with individual identification, so that this behaviour could be examined further.

4.4 Flight activity

Flying is the most energetically costly activity for bats. Flying levels noticeably increased in the pre emergence subperiod and when the majority of bats has left Bat Cave to forage. Bat were often observed circling the entrance to Bat Cave prior to emerging for the night. This behaviour is well documented in many bats species and appears to represent light sampling behaviour. Light sampling is used to fine tune the nightly departure of bats from their roost sites based on outside light intensity levels (Kunz 1982). Emerging too early exposes bats to diurnal predators.

Aside from this light sampling behaviour, bats are still observed to be flying around. Flight activity occurred more often in chambers 1,2 and 3 than chamber 4. The bats may be moving between chambers to achieve the desired microclimate. Flight activity in chamber 3 typically involved circling of the chamber and is most likely in response to being dislodged from a roost site.

4.5 Movement to overwintering caves

The number of bats present in Bat Cave declined dramatically over the study period. Monitoring of caves in the nearby area confirmed that Blanche, Robertson, Gran Gran, Graveyard, Mt Burr and Mon Bulla caves are overwintering sites for *M.schreibersii.* Numbers of bats found suggest that Mt Burr and Robertson caves are the most important overwintering sites of those surveyed. Overwintering sites are typified by lower temperatures than those found in Bat Cave and moderate humidity. Dispersal away from Bat Cave may represent declining prey availability in the area. Once prey numbers decline bats are no longer able to compensate for the energy burnt in flight (Fenton 1983) and alternative strategies such as dispersal to cooler sites and torpor must be employed.

Temperatures in overwintering caves were comparable to those found close to the entrance of Bat Cave. A trip into Bat Cave confirmed that large numbers of bats were in fact using this region as a wintering site during early May. These bats left however by mid May. Bats in overwintering caves were always found in close proximity to the entrance of the cave. These regions are always the coolest part of caves and probably represent the conditions needed for torpor.

Baudinette et al (1994) concluded that *M.schreibersii* gather in the large numbers found in Bat Cave in order to achieve the desired conditioning of caves. This effect has also been reported in breeding caves of the American free tailed bat, *T.brasiliensis.*(Davis et al 1962). These conditions are not required during winter and separation of the colony may be necessary to achieve cooler conditions. All overwintering caves surveyed had a different internal structure than Bat Cave, typically being shallow with no large chambers. These conditions would not facilitate heat trapping like the dome chambers in Bat Cave (Baudinette et al 1994). The cooler temperatures would facilitate conditions for torpor.

The number of bats seen in surveyed caves did not represent the majority of the Naracoorte population. More extensive surveys throughout the South East and into Victoria and possible New South Wales (Dwyer 1966) are required to identify other overwintering sites.

4.6 Water analysis

Water analysis was carried out on a sample from the drinking site in chamber 2. Samples were also tested from nearby caves on site and possible alternative drinking sites. Reasons why Bool Lagoon and Mosquito Creek samples record such high levels are unclear but could represent fertiliser run off. The seasonal rise and fall of water levels in

Bool Lagoon could contribute towards concentrating samples, particularly sodium. It is worth noting that Bool Lagoon and Mosquito Creek are unconfirmed as drinking sites for *M.schreibersii.* Using a hand held bat detector the presence of bats at Bool Lagoon and close to Mosquito Creek was confirmed but drinking was never observed.

Water is obviously an important requirement for *M.schreibersii.* In particular the availability of calcium has been suggested as a constraint on reproduction, litter size and bone development in bats (Barclay 1995). Calcium levels are low in insect prey (Maxon & Oring 1980, Turner 1982). Drinking from inside Bat Cave provides a readily available and low energy method of supplementing water intake and may improve calcium and other mineral intake. Bats were also observed to lick the surface of the cave roof during drinking episodes using it as a type of 'salt lick'. Calcium and other minerals could be obtained in a more concentrated form this way.

Future work is required to establish the importance of drinking from Bat Cave to the resident bats. It would be instructive to identify if it was the sole source of water, apart from insect prey, for *M.schreibersii*. Monitoring Bool Lagoon and Mosquito Creek with night vision equipment could confirm if drinking behaviour was occurring.

4.7 Future Considerations

4.7.1 Energetic costs of activity

Analysis of time activity budgets are well suited to provide information on the energetic cost of roost behaviours. Accurate estimation of the costs of different roosting behaviours requires laboratory derived measurements for each activity. The majority of work looking at energetics in bats has been based on estimates and comparisons derived

from other taxa (Kunz 1988). Burnett and August (1981) used calculations of time budget in *M.lucifugus* and assigned an assumed energetic costs to the different activities. Calculating the energetic costs of behaviours in the field is commonly done using doubly labelled water to measure energy metabolism and water flux (Bell et al 1986).
Future calculations of energy budgets would require measures to account for the different thermal conditions faced by individual bats at different locations in clusters and different heights in the cave.

4.7.2 Bat Numbers

The large numbers of *M.schreibersii* in Bat Cave precluded accurate counts of population size. While numbers are reported to reach 200 000 bats at peak summer occupation it is unclear how this figure is reached. Accurate determination of colony size is important to monitor the health of the bat population at Naracoorte. Population size would also determine the onset of dispersal to overwintering sites. Accurate counts could be related to temperature changes and prey availability and would indicate any critical levels that trigger dispersal.

The large population size prevented measurement by counting alone. Bat numbers could be accurately recorded using a series of infra red beams. Beam counters have been used to monitor bats flying inside caves as an indicator to day activity (Fullard & Barclay 1980, Kunz 1988). A variation on these techniques could be used to count bats at Naracoorte. A grid of infra red beams could be set up over the entrance to Bat Cave. Using a data logger the number of times the beam was broken, which would indicate a bat flying through, could be recorded. *M.schreibersii* were often observed flying both in and out through the course of a night. A number of bats could be tagged with

radiotransmitters to monitor the number of returns into the cave. If it was determined that the average was 4 trips in and out, a simple division by 4 would indicate the population size.

4.7.3 Parasite Load

During the application of reflective tags, ticks were noticed on several bats. Bat are well documented to host a wide range of ectoparasites including fleas, hemipterans, ticks and nycteribiids. Most cause little or no harm to the host bat although ticks have been reported to cause small lesions (Kunz 1988). Parasite load can have important implications for the host bat in terms of increased levels of grooming (Marshall 1982). This would ultimately influence the activity budget of the bat and increase the energetic cost of maintenance.

Little is known about the number and species composition of parasites on bats. Taxonomic classification and counts of ectoparasites on *M.schreibersii* could be obtained simply by collecting specimens from Bat Cave. Specimens are usually collected, quickly killed and examined using a dissecting microscope (Whitaker 1988). Live specimens can be examined using similar techniques but require cooling or anaesthetising. Techniques that are commonly employed in studies of bird parasite loads may have potential to be used in bat studies. It would be interesting to compare the parasite load of bats located in different chambers in Bat Cave and for bats . This would establish whether there is any correlation between choice of roost at different temperatures and parasite load.

CHAPTER 5

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APPENDIX 1

Bonferroni Inequality: "Approach for adjusting the selected alpha level to control overall type 1 error rate. The procedure involves computing the adjusted rate as α divide by the number of statistical tests to be performed and then using the adjusted rate as the critical value in each separate test" (Hair, Anderson Tatham and Black 1995)