# CHAPTER 1

# GENERAL INTRODUCTION

Tropical ecosystems are exceptionally rich with exclusive reservoirs of earth's biodiversity (Appanah & Ratnam, 1992; Sodhi *et* al., 2004). Compared to tropical Africa and South America, tropical Asia is the most highly populated regions of the world (Appanah & Ratnam, 1992). To cater for these vast populated region, agriculture and deforestation has become a main agenda, unfortunately at the expense of the ecosystem. Rapid rate of forest reduction heightens the importance of managing tropical rainforests (Adekunle, 2006). Although most research is actively being carried out in the Neotropics due to better resources and funding, it is the tropical regions in the Paleontropics that need the most attention for research due to its rich biodiversity and increased risk of habitat destruction and species extinction.

The tropical region supports the highest diversity of bat fauna known (Kunz, 1982). More than half the total diversity of flora and fauna in this planet is contained in the lowland evergreen tropical rain forests. There has been many studies in Peninsular Malaysia focusing on bats at lowland dipterocarp forest (Francis, 1990, 1994; Kingston, 2001; Kingston *et al*., 2003; Fletcher, 2006; Sheema, 2006; Struebig *et al*., 2008) but very few in other habitats such as mangrove forest (Joann, 2006), limestone forest (Mohd. Azlan, 2005; Struebig *et al*., 2009) or the upper hills (Fletcher *et al*., 2004). However, the remaining lowland primary rain forest in Malaysia is no longer adequately represented due to various land conversions and timber harvesting (Ashton, 2008). The paradigm is now shifting to the

hill forest, where there is still knowledge deficiency. Research is scarce in these areas due to the rough terrains, but nevertheless researchers have to race with bulldozers in order to discover the realm of the hills, and hopefully help to protect what needs to be protected. This study intends to document insectivorous bats in the forest hills of Peninsular Malaysia. Today, morphologically similar species are being labeled as cryptic species (Anwarali Khan, 2008), meaning that more profound research is required in documenting local bat diversity in Malaysia (Baker & Bradley 2006). So far there have been no studies comparing the geographic distribution of insectivorous bat assemblages in different parts of the Peninsular.

The Theory of Island Biogeography (MacArthur & Wilson, 1967 quoted by Ashton, 2008) predicts that a reduction of a continuous habitat area of 90% will lead to extinction of 50% of its inhabiting species if there were no active management to sustain the populations. However, it does not predict how long it will take for this new equilibrium to be achieved. The virgin jungle reserve (VJR) network was institutionalized about 50 years ago as a conservation effort by the Malaysian government. These patches of primary forest are meant to be natural arboreta that controls for the exploited and siviculturally-managed surrounding forest (Sam, 2001). According to Whitmore (1984), most species survive logging by persisting in un-logged pockets from which they re-establish, so long as such pockets occur within their dispersal range. Here it is hoped that the VJRs can take on the role of such un-logged pockets. However, the overall effectiveness of VJRs is still unclear as we lack sufficient scientific information for evaluation (Sam, 2001; Lee et al., 2002).

It is often easier to detect changes in species distribution rather than evaluating the factors behind the changes, because there are many confounding factors affecting these changes (Abdul Rahman *et al*., 2002; Kessler, 2009). Especially within a tropical forest ecosystem where its complexity creates various aspects that can contribute to changes in species composition (Sundarapandian & Swamy, 2000). Some of which are; soil, temperature, elevation and slope aspect. These factors often affects the distribution and growth of trees within a forest, which directly or indirectly affects organisms associated with trees (Moning *et al.*, 2009), because trees are seen as proxy for overall biodiversity (Ashton, 2008). The vast niche diversity of bats is forced by their unique echolocation call and wing morphology, creating the need for resource partitioning and habitat selection (Patriquin & Barclay, 2003). Micro habitat selection such as ridge, slope or valley may help explain these diversity patterns of bat communities within the forest. This is based on the understanding that each species have a unique wing shape that creates variety in foraging pattern, flight style (Vaughan *et al*., 2000) and maneuverability (Patriquin & Barclay, 2003). Echolocation call frequency however complements this unique wing morphology in detecting prey and for navigation (Aldridge & Rautenbach, 1987). Species with low frequency and narrow-band calls thrive best in open environment, where else species with broad-band calls thrive best in highly cluttered environment (Aldridge & Rautenbach, 1987). It is hoped that by studying the distribution of species abundance, the maximum amount of information about a community's diversity can be obtained (Magurran, 2004).

Two hypotheses suggested in the Research Agenda for Biodiversity which was jointly launched by The International Union of Biological Sciences (TUBS), Scientific Committee on Problems of the Environment (SCOPE) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Solbrig, 1991) is adopted in this study. The hypotheses are; 1) spatial heterogeneity of the regional landscape has no effect on coexisting species in a local community, and 2) that removal and addition of ecosystem components that produce changes in spatial configuration of landscape elements will have no significant effect on the disturbance response behavior of an ecosystem over a range of time and space scales (Boyle, 1992). We test this hypothesis by looking at the distribution of insectivorous bat assemblages in relation to various spatial aspects such as geography, space as well as distance and topography. Therefore, the first objective of this study is to look at the distribution of insectivorous bat assemblages at various states in Peninsular Malaysia (geography). The second objective is to assess the impact of primary habitat reduction on insectivorous bat assemblages (space) and the third objective is to examine if habitat selection by bats is effected by topography. It is hoped that this study will be able to fill the knowledge deficiency of bats in these areas and enhance communication by linking knowledge and action in conservation biology (Shanley & Lopez, 2009; Sunderland *et al.*, 2009).

**CHAPTER 2**


**INSECTIVOROUS BAT ASSEMBLAGES IN PENINSULAR MALAYSIA**


**2.1 INTRODUCTION**


There are 4600 living species of mammals (Hickman, 2003), 1111 of which are Chiropterans (Simmons, 2005). Bats belong to the order Chiroptera, which is the largest mammalian order after Rodentia (Vaughan *et al*., 2000). Bats have successfully colonized every continental region on earth except the poles (Findley, 1983). There are two suborders of bats; Megachiroptera or megabats with 166 species which can only be found in the Old World, and Microchiroptera or microbats with 759 species that are more geographically diverse (Kunz & Pierson, 1994).


2.1.1 Ecology of bats


The reason for their success are mainly due to their large geographical ranges, the diversity of habitats, various foraging strategies and the tendency to exhibit a variety of roosting behaviour (Ganon & Willig, 1995). Bats occupy virtually every trophic level, from primary consumer to tertiary consumer levels, feeding mainly on fruit, insects, nectar, pollen, fish, blood and vertebrates (Medellin *et al.*, 2000). The morphology of a species that contribute to flight maneuverability and echolocation frequency tends to influence the feeding habits. Bat ecology is strongly related to aerodynamics and wing

morphology, commonly measured by aspect ratio and wing loading (Crome & Richards, 1988) as well as wing-tip index (Arita & Fenton, 1997). Each species has a unique wing shape that varies according to foraging pattern, flight style (Vaughan *et al.*, 2000) and maneuverability which influences their habitat choice (Patriquin & Barclay, 2003) and roost selection (Sedgeley & O'Donnell, 1999). Echolocation call complements wing morphology in detecting and locating prey as well as for navigation (Aldridge & Rauntenbach, 1987).

Bat roosting requirement are determined by the physiological demands of the adults or young, predation pressure, sociological considerations or by morphology (Findley, 1993). A good roost provides adequate protection allowing bats to rest and satisfy their social needs for successful reproduction (Tan *et al.*, 1999). Many megabats and most microbats prefer concealed places when roosting and have very specific roosting requirements (Crampton & Barclay, 1996; Mirowsky, 1997; Lee & McCracken, 2004; Fletcher, 2006). Foliage, caves, rock crevices, hollow trees, fallen trees and human made structures such as buildings are some of the common bat roost. Some bat species are more common in old-growth forests due to the impressive tree sizes, abundance of old or dead trees that had time to develop broken tops, creeks, hollows, and scaling bark, which can in turn serve as roosting sites (Thomas, 1992). A good roost offers protection from predators and provides ambient temperature especially for maternity roosts (Sedgeley & O'Donnell, 1999; Sedgeley, 2001; Fletcher, 2006), therefore factors such as height from the ground, temperature, humidity and sunlight are considered before a roost is selected. These kinds of specificity displayed by bats increase their sensitivity to any habitat changes, making

them vulnerable to disturbances and may restrict them to certain habitats. Where roost opportunities are limited, the diversity of bats may be affected (Fenton, 1982). Some species of bats are known to hibernate and some migrate (Kunz & Pierson, 1994). Bats in Malaysia however may undergo short (local) migration, but there have not been much study on it.

Bats are known to exhibit varying degrees of dispersal and roost fidelity based on their social system (Gopukumar *et al.*, 2005). Depending on the species, colony size may vary from a few individuals to millions (Kunz, 1982). Some non-colonial species tend to aggregate only during maternity periods. Males usually roost in solitary, occur in small groups at maternity sites or roost in mixed gender groups during the maternity period (Kunz & Pierson, 1994).

The ecological roles of bats as pollinators and pest controllers have long been studied (Altringham, 1996). Plant species that are economically important depend on frugivorous bats for propagation (Tuttle, 1983). By consuming large proportions of insects every night, insectivorous bats help maintain a balanced food chain in the ecosystem. They are also well studied for their medical benefits to humans. For example, scientists have discovered that vampire bat saliva is better at keeping blood from clotting than any known medicine, and this may one day help prevent heart attacks and strokes (Locke, 2003).

2.1.2 Study of bats

There have been numerous studies on the distribution and habitat ecology of bats done in various parts of the world (Arita & Fenton, 1997; Kalko & Handley, 2001; Meyer *et al*., 2008). The tropical region however, is known to support the highest diversity of bat fauna (Kunz, 1982). Tropical insectivorous bats are interesting because a large number of the species can be found at a single location (Heller & Volleth, 1995). Although Findley (1993) showed a large difference of bat species in various parts of the tropics, communities of tropical insectivorous bats are similar in species richness (Heller & Volleth, 1995). Explaining global variation in local species richness requires historical, systematic and biogeographic studies (Ricklefs, 1987; Xiang *et al.*, 2004; Chown & Convey, 2007; Anwarali Khan *et al*., 2008), but ecological studies are still the root of these fields.

A number of bat inventories have been done in Southeast Asia (e.g. Hill, 1974; Medway, 1983; Francis, 1990; Heaney & Rickart, 1990; Francis, 1994; Zubaid, 1993; Abdullah *et al.*, 1997; Kock & Dobat, 2000; Fletcher *et al.*, 2004; Pottie *et al.*, 2005; Fukuda *et al.*, 2009; Leong & Lim, 2009). Since then many improved methods have been developed to optimize the capture rate of bats such as the improved harp trap (Francis, 1989; Berry *et al*., 2004) and the tunnel trap (Sedlock, 2001).

2.1.3 Bats of Peninsular Malaysia

In 1940, Chasen listed 84 species in the first published faunal list of bats from Malaysia (Ellerman & Morrison-Scott, 1955), and in 1997, Payne and Francis published 92 species of bats in Borneo. The most recent estimate of bat species in Malaysia is 125 (Simmons, 2005), listing the country as a centre of bat diversity in the old world (Kingston *et al*., 2006). Although Chiroptera is the second largest mammalian order in the world, it is however the largest mammalian order in Peninsular Malaysia. Krau Wildlife Reserve in Pahang is likely the most extensively studied site for bat diversity in Peninsular Malaysia (Anwarali Khan, 2008). With 69 species, Krau is reported to hold the highest diversity of bats known for a single site in the world (Kingston *et al*., 2006). The long-term study in this area has contributed significantly to understanding further the habitat ecology of several key species in primary lowland forests (Kingston *et al*., 1999; Fletcher, 2000; 2006; Kingston *et al*., 2000; Kingston *et al*. 2003a, b; Thabah *et al*., 2006).

However, Whitmore (1984) predicted that by the early 1990s there will be no virgin lowland rain forest left in Malaysia outside of conservation areas. Most lowland forests have been explored to exhaustion or converted for agriculture and infrastructure development, shifting the attention towards hill forests (Phillips, 1986; Kasran, 1988; Appanah & Rasol, 1991), particularly the extensive forests in northern Peninsular Malaysia. Despite extensive research, our knowledge of the extent of the world's biological diversity remains incomplete (Magurran, 2004), and the effects of habitat and spatial distance on the distribution of bats in Malaysia are yet to be comprehensively

studied. Understanding patterns such as species composition and population turn over in relation to spatial and temporal factors in intact habitats are a pre-requisite to understanding how disturbance will affect these systems.

Communities are assemblages of organisms belonging to different species living together in the same area. Studies of bat assemblages help reveal the effects bats have on each other and how they have come to adapt to each other's presence. Many studies have conducted bat surveys at specific locations (Kingston *et al*., 2003a; Fletcher, 2004; Struebig *et al*., 2008; Struebig *et al*., 2009); but none were conducted in different sites in Peninsular Malaysia within the same study. Comparing bat diversity and abundance with previous studies in different locations may hold biasness as sampling methods and total effort may differ (Mohd-Azlan *et al*., 2005). The objective of this study was to assess the distribution of insectivorous bat assemblages at selected forest patches throughout Peninsular Malaysia. All species found in Malaysia are thought to be distributed throughout the Peninsular (West Malaysia) (Kingston *et al*., 2006) or confined to Borneo (East Malaysia) (Payne & Francis, 1997). This study examined the hypothesis that insectivorous bat assemblages in a hill dipterocarp forest would not differ geographically, because there are no known extreme seasonal or climatic conditions in the Peninsular to cause such significant differences in distribution.

## 2.2 METHODS

### 2.2.1 Study sites

This study was conducted between September 2007 and June 2009 at six different sites selected throughout Peninsular Malaysia (Figure 2.1). Certain criteria were applied during site selection, they were: 1) the forest type must include lowland and hill dipterocarp forest, 2) at elevations between 100–1500 m asl, and 3) all sites contains a virgin jungle reserve surrounded by forest areas that have been logged at least 15 years ago (Table 2.1). In the typical designation of hill dipterocarp forests the elevation ranges from 300 to 760 m (Whitmore, 1990), and while many lowland forest tree species are still found in the hill forests, many species which occur in hill forests are absent in the lowlands (Wyatt-Smith, 1961). In Peninsular Malaysia, hill forests can be distinguished from typical lowland forests by the presence of the dominant tree species, *Shorea curtisii*, or locally known as *Seraya* (Whitmore 1984). Since it was not possible to select study sites with the exact same elevational range, the sampling points were chosen to have a gradual incline to include hill forest.
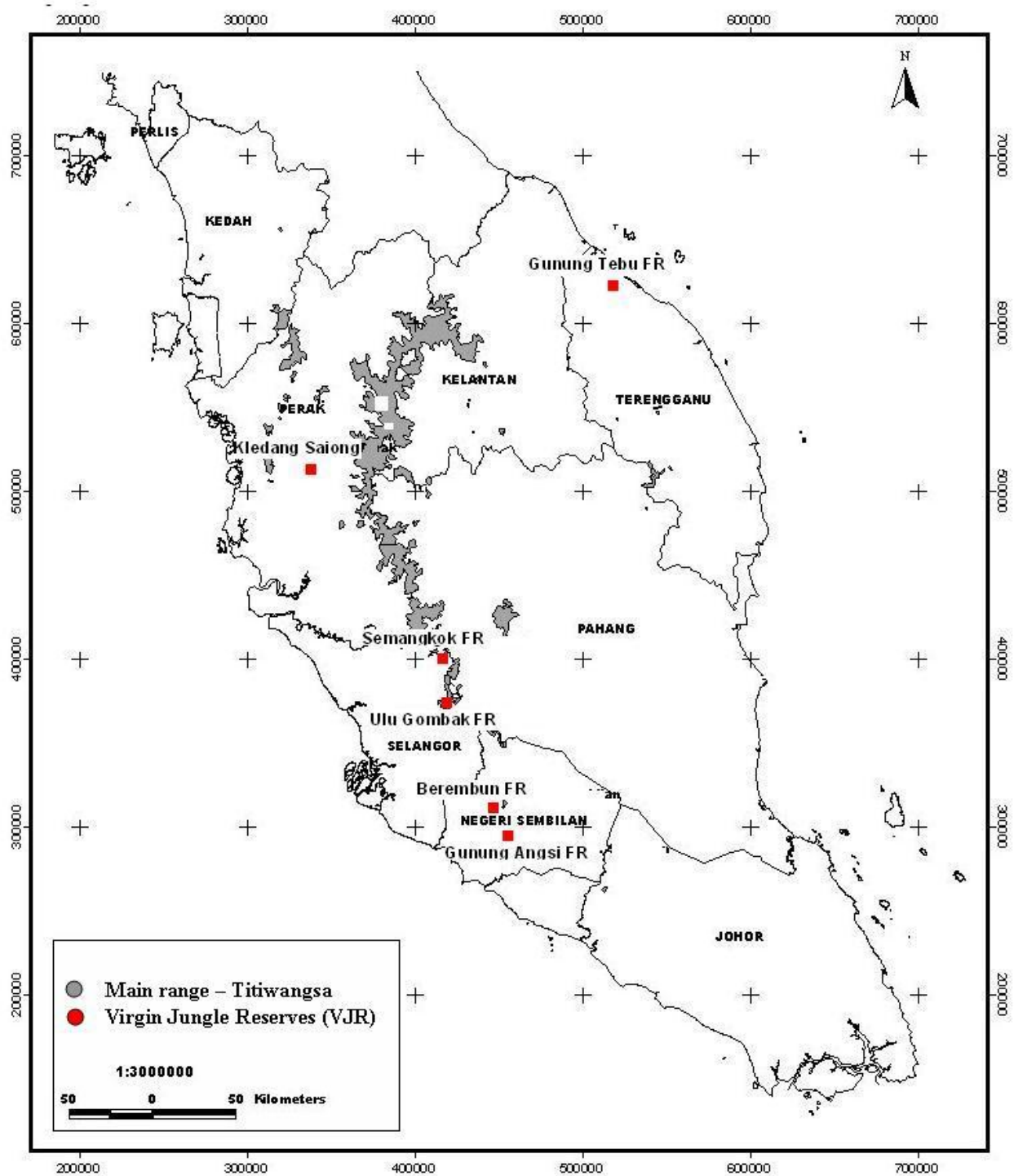
Figure 2.1 Location of the six study sites in Peninsular Malaysia

Table 2.1 Details of the study sites in Peninsular Malaysia.

| Forest Reserve | State | Elevation of study site (metres above sea level) | Forest Type |
|---|---|---|---|
| Semangkok<br>3º 40'N, 101º 40'E | Selangor | 379 – 472 | Hill dipterocarp forest |
| Ulu Gombak<br>3˚ 47' N, 101˚19' E | Selangor | 457 – 1,128 | Hill dipterocarp forest, upper dipterocarp forest, lower montane forest |
| Kledang Saiong<br>3˚ 03' N, 102˚ 37' E | Perak | 100 – 600 | Lowland, hill dipterocarp forest |
| Berembun<br>2° 46'N, 102° 06'E | Negeri Sembilan | 200 – 700 | Lowland, hill dipterocarp forest |
| Gunung Angsi<br>2° 39'N, 102° 06'E | Negeri Sembilan | 200 – 500 | Lowland, hill dipterocarp forest |
| Gunung Tebu<br>4˚ 41' N, 103˚35' E | Terengganu | 244 – 472 | Lowland, hill dipterocarp forest |

2.2.1(a) Semangkok Forest Reserve

Semangkok Forest Reserve (FR) is located in Kuala Kubu Bharu, Selangor. It is 60 km to the North of Kuala Lumpur (Kominami *et al.*, 2000) and is next to the Kuala Kubu Bharu – Fraser Hill road. *Shorea curtisii* is the dominant tree species in the ridges of Semangkok FR (Tange *et al.,* 1998). Aside from the road adjacent to the forest, there were no signs of disturbance or encroachment in Semangkok FR. Sampling in the reserve was conducted from 19–29 November 2007.

2.2.1(b) Berembun Forest Reserve

Berembun FR is located on the outskirts of Seremban, Negeri Sembilan. There was a small Orang Asli settlement around the reserve and they usually forage in the forest for *petai* (*Parkia speciosa*) and rattan as their livelihood. Sampling in Berembun FR was conducted from 12–24 May 2008.

2.2.1(c) Gunung Tebu Forest Reserve

Gunung Tebu FR is located in Besut, Terengganu. The forest reserve is very secluded from any disturbance. The area is only accessed by army personnel for training purposes. Sampling in Gunung Tebu FR was conducted from 9–18 June 2008.

2.2.1(d) Ulu Gombak Forest Reserve

Ulu Gombak FR is located in Hulu Gombak, Selangor. There were signs of encroachment: clearings and planted fruit trees. The forest reserve is also adjacent to the Karak Highway, which links the east and west coast of Peninsular Malaysia. Sampling in Ulu Gombak FR was conducted from 4–15 August 2008.

2.2.1(e) Kledang Saiong Forest Reserve

Kledang Saiong FR is located in Jelapang, Perak. This forest reserve is surrounded by housing development and small industries. There is also a golf course adjacent to the forest. Besides the heavy development that is on-going around it, there were no signs of encroachment within the forest reserve. Sampling in Kledang Saiong FR was conducted from 14–22 January 2009.

2.2.1(f) Gunung Angsi Forest Reserve

Gunung Angsi FR is located in Rembau, Negeri Sembilan. There is a village adjacent to the forest. Aside from that there is a small rubber plantation at the entrance coupled with some farming activities. There were also signs of encroachment in Compartment 12 which is a VJR, resulting in a patch of cleared and open area. Sampling in Gunung Angsi FR was conducted from 8–21 June 2009.

2.2.2 Sampling design

In order to capture and identify forest-interior insectivorous bats across Peninsular Malaysia, nine 300 m transect lines were set up within each study area. Transect were established 200–500 m apart. Four-bank harp traps (Francis, 1989) (ca. 2 m width and 3 m height) were set up along each transect for three consecutive nights. Traps were set up on clear pathways approximately 1 m above ground level, with trees and undergrowth on either side as well as above the trap.  Each night, three traps were set up on each three transects; making nine traps in total. Each trap was set 50–75 m apart. They were moved to the next three transect lines on the fourth day (Francis, 1989). The annual mean rainfall

and temperature data from the nearest meteorological station for each site was obtained from the Malaysian Meteorological Department.

## 2.2.3 Field Sampling

Captured bats were held in catch bags before biometric data such as weight (g) and forearm length (mm) were obtained. Body mass was recorded to an accuracy of 0.1 g with a 30 g Pesola$^{®}$ spring balance to determine the average mass of each species. The forearm length was measured to 0.1 mm accuracy with calipers (Bontadina *et al*., 2002). Individuals were further inspected to determine the age by looking at the structure of the $5^{th}$ digit (finger) bones. A solid knob would indicate an adult, where else juveniles have cartilaginous epiphyseal plates, which if seen above a light source will appear like rings. Reproductive stages of females: lactating, post-lactating, recently post-lactating, late-lactating, pregnant and non-reproductive were also assessed. Aluminium wing bands were placed on the right forearm of females and left forearms of males to account for recaptures. Individuals were identified up to the species level using morphology keys by Payne and Francis (1997) as well as Kingston *et al*. (2006). All bats were released after the required information was obtained.

## 2.2.4 Statistical analysis

The total number of bats caught and species identified were compared across sites. For alpha diversity which is defined as inventory diversity by Jurasinski *et al*. (2009), I

compared Simpson's diversity index (Simpson, 1949) and Pielou's Evenness (Pielou, 1966), for all six sites. Bat composition was also compared among bat families. A species rank abundance graph was created to display the species composition at each site (Struebig *et al.,* 2009).

A rarefied species accumulation curve on the mean of accumulating individuals was created for each site to determine if all species in the site had been sampled adequately (Kingston, 2009). Extrapolated species richness was calculated to estimate the number of species in each site. The Chao estimator was used to take into account the number of species with abundance instead of just the incidence of the observed species (Chao, 1984; Chao *et al*., 2006). Sampled species richness was then divided by the estimator for each site to calculate the percentage of total richness estimated by Chao (Tylianakis *et al*., 2006). The analysis was completed using R Statistical computing and the Vegan package (R Development Core Team, 2009; Oksanen *et al*., 2009)

Multiple Response Permutation Procedure (MRPP) was used to look at the differences in community of bats between each site (McCune & Grace, 2002). MRPP supports a multivariate test of the null hypothesis of no significant difference between groups of samples (Lamb *et al*., 2003). It was carried out using PC-ORD statistical software (McCune & Mefford, 1999). To display the differences of species composition between the study sites, a distance matrix was calculated using Sorenson distance for species presence/ absence and Steinhause distance for species composition.

To examine the possible drivers of variation on bat composition, the effects of mean annual temperature (C°) and rainfall (mm) between sites were tested. A Pearson's Product

Moment Correlation Coefficient was derived to measure the strength of linear dependence between those three environmental variables with bat abundance. The analysis was done using R Statistical computing (R Development Core Team, 2009; Oksanen *et al.*, 2009)

**2.3 RESULTS**

2.3.1 Bat assemblages

A total of 958 individuals of 27 insectivorous species from five families were captured over 486 trap nights across all six sites. Although more than half of the species caught in this study belonged to the Hipposideridae and Rhinolophidae family (Figure 2.2a), Hipposideridae had a higher percentage in terms of abundance (Figure 2.2b). Gunung Angsi FR in Negeri Sembilan and Gunung Tebu FR in Terengganu had the highest number of captures with 29.33% and 27.45% of the total, respectively (Figure 2.3). Ulu Gombak FR in Selangor had the fewest captures with only 6.68 % of the total. Although Berembun FR in Negeri Sembilan had a low capture rate of less than 100 individuals, it recorded a relatively high number of species (Figure 2.3). Semangkok FR in Selangor had a higher Simpson's (1-D) diversity index with 0.8977, where else Kledang Saiong FR had a higher evenness (Table 2.2).
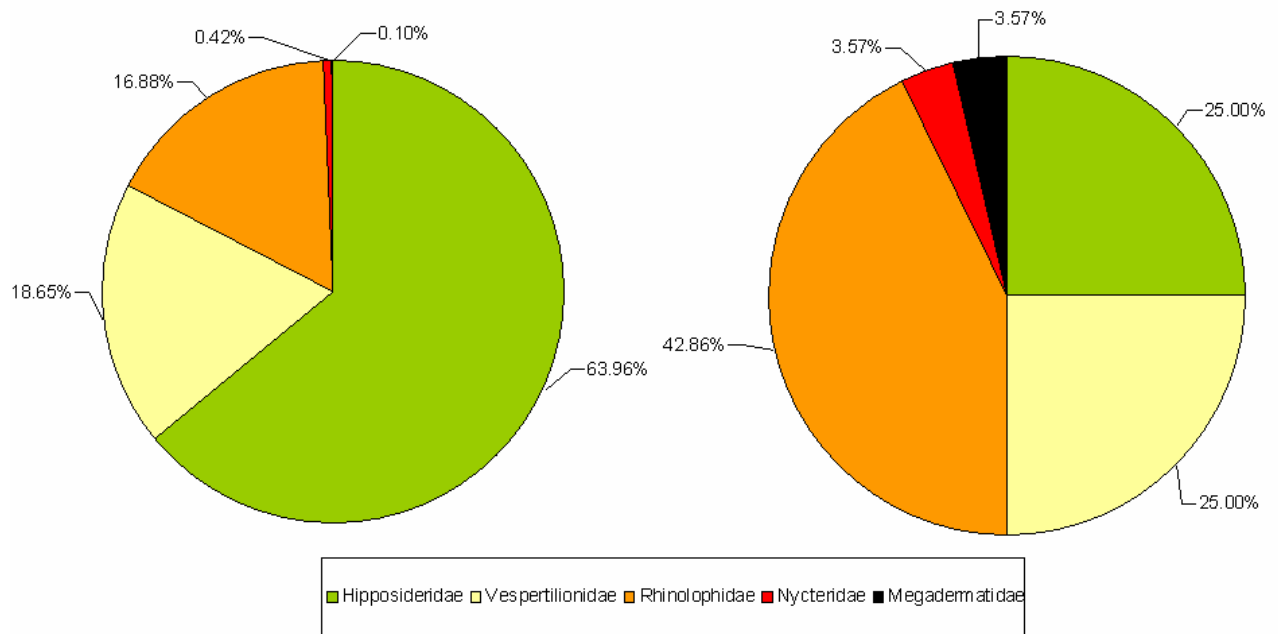
Figure 2.2 Family compositions of insectivorous bats caught at six forest reserves in Peninsular Malaysia; (a) number of species by family and (b) number of individuals by family.
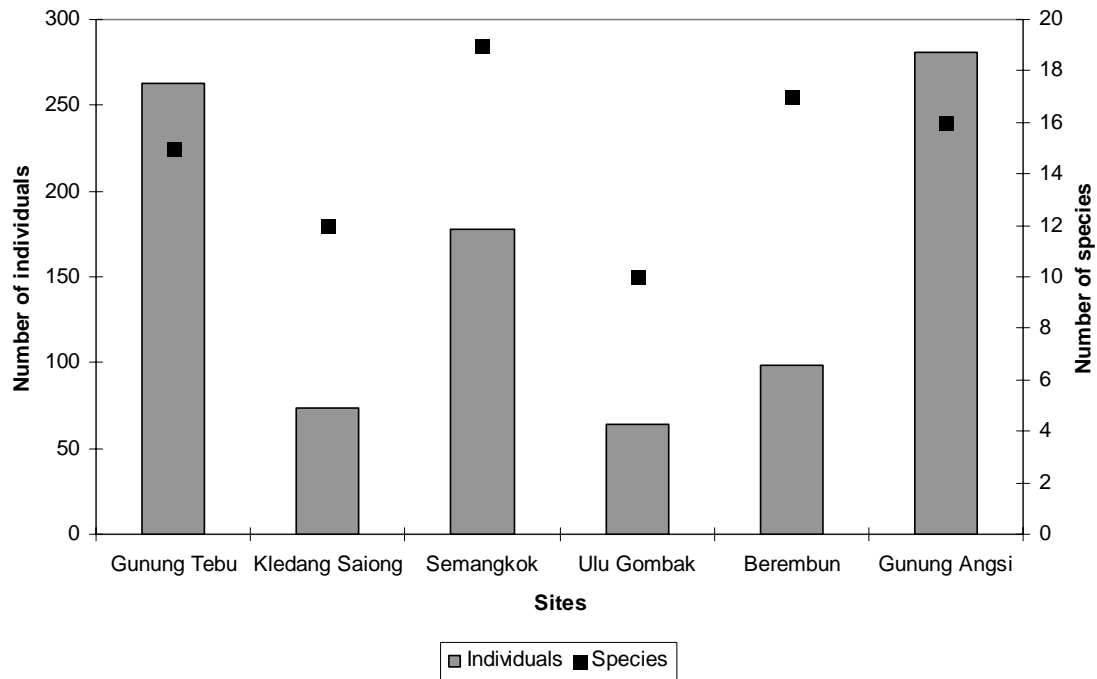
Figure 2.3 Bat abundance and number of species captured in six forest reserves in Peninsular Malaysia.

Table 2.2 Simpson's diversity index (1-D) and Pielou's Eveness index for six forest reserves in Peninsular Malaysia.

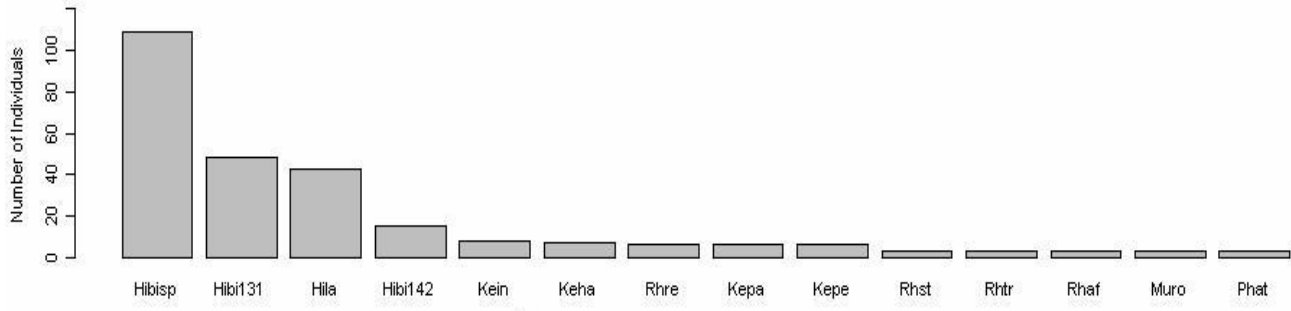|  | Gunung Tebu FR | Kledang Saiong FR | Semangkok FR | Ulu Gombak FR | Berembun FR | Gunung Angsi FR |
|---|---|---|---|---|---|---|
| Simpson's Index (1-D) | 0.7611 | 0.8433 | 0.8977 | 0.7944 | 0.8534 | 0.7139 |
| Pielou's Eveness Index | 0.7016 | 0.8580 | 0.8505 | 0.8145 | 0.8209 | 0.6852 |

2.3.2 Bat species composition

*Hipposideros bicolor 131*, *H. bicolor* sp., *Rhinolophus stheno*, *R. trifoliatus* and *Kerivoula hardwickii* were the only species present at all sites (Table 2.3). Cave-roosting species especially those from the Hipposideridae family (e.g. *Hipposideros bicolor* sp., *H. larvatus*, *H. cervinus*) and also *Rhinolophus affinis* dominated the sampling sites (Figure 2.4). This is very apparent in Gunung Angsi where *H. bicolor* sp. contributed 50.53% of the total bat capture. Species from the Vespertilionidae family were the least widely distributed in this survey. *Kerivoula papillosa,* a tree/foliage-roosting species, was abundant at all the sites except in Ulu Gombak FR.
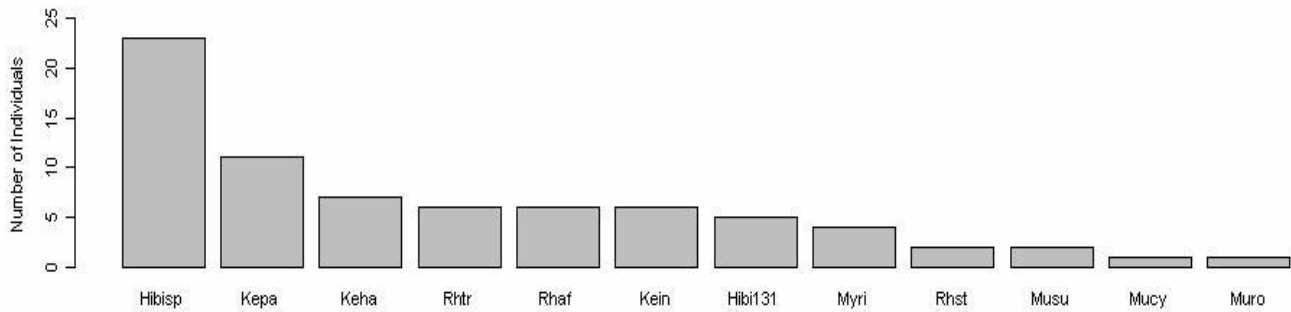
Table 2.3 List of bat family and species caught in six sites across Peninsular Malaysia and the International Union for Conservation of Nature and Natural Resources (IUCN) status for each species (IUCN, 2009). [*Hipposideros 'bicolor' comprises of two phonic types with mean echolocation call frequencies of 131 kHz and 142 kHz. They were distinguished in the hand by forearm length *H.bicolor 131* > 45 mm and *H.bicolor 142* < 43 mm. Individuals with forearm 43 – 45 mm is identified as *H.bicolor* sp.]. Species classification is according to Kingston *et al*. (2006) (see Appendix A).

| Family | Species | Code | Semangkok F.R. | Berembun F.R. | Gunung Tebu F.R. | Ulu Gombak F.R. | Kledang Saiong F.R. | Gunung Angsi F.R. | IUCN status |
|---|---|---|---|---|---|---|---|---|---|
| Hipposideridae | *Hipposideros bicolor* Temmninck *131** | Hibi131 | ● | ● | ● | ● | ● | ● | LC |
| | *Hipposideros bicolor* Temmninck *142** | Hibi142 | ● | ● | ● | ● | | ● | LC |
| | *Hipposideros bicolor* Temmninck *sp** | Hibisp | ● | ● | ● | ● | ● | ● | LC |
| | *Hipposideros cervinus* Gould | Hice | ● | ● | | ● | | ● | LC |
| | *Hipposideros larvatus* Horsfield | Hila | ● | ● | ● | | | | LC |
| | *Hipposideros sabanus* Peters | Hisa | ● | | | | | | LC |
| | *Hipposideros galeritus* Cantor | Higa | ● | ● | | | | ● | LC |
| Rhinolophidae | *Rhinolophus stheno* Andersen | Rhst | ● | ● | ● | ● | ● | ● | LC |
| | *Rhinolophus lepidus* Andersen | Rhre | ● | ● | ● | | | ● | LC |
| | *Rhinolophus sedulus* Andersen | Rhse | ● | | | | | | NT |
| | *Rhinolophus trifoliatus* Temminck | Rhtr | ● | ● | ● | ● | ● | ● | LC |
| | *Rhinolophus affinis* Horsfield | Rhaf | | ● | ● | | ● | ● | LC |
| | *Rhinolophus pusillus* Temminck | Rhpu | | | ● | | | | LC |
| | *Rhinolophus luctus* Temminck | Rhlu | | ● | | ● | | ● | LC |
| Murininae | *Murina suilla* Temminck | Musu | ● | | | | ● | | LC |
| | *Murina cyclotis* Dobson | Mucy | | | ● | | ● | ● | LC |
| | *Murina rozendaali* Hill and Francis | Muro | | | ● | ● | ● | | VU |
| Kerivoulinae | *Kerivoula papillosa* Temminck | Kepa | ● | ● | ● | | ● | ● | LC |
| | *Kerivoula hardwickii* Horsfield | Keha | ● | ● | ● | ● | ● | ● | LC |
| | *Kerivoula pellucida* Waterhouse | Kepe | ● | ● | ● | ● | | ● | NT |
| | *Kerivoula intermedia* Hill and Francis | Kein | ● | ● | ● | | ● | ● | NT |
| | *Phoniscus atrox* Miller | Phat | | | ● | | | | NT |
| Vespertilioninae | *Glischropus tylopus* Dobson | Glty | ● | | | | | | LC |
| | *Tylonycteris robustula* Temminck | Tyro | ● | | | | | | LC |
| | *Myotis ridleyi* Thomas | Myri | | | | | ● | | NT |
| Megadermatidae | *Megaderma spasma* Linnaeus | Mesp | | ● | | | | | LC |
| Nycteridae | *Nycteris tragata* Andersen | Nytr | ● | | | | | ● | NT |

*LC – Least concern; NT – Near threatened; VU – Vulnerable*
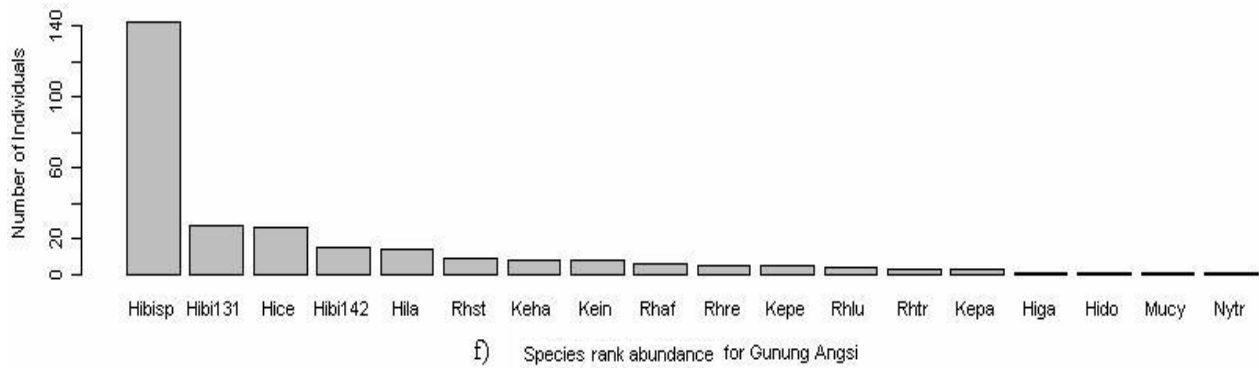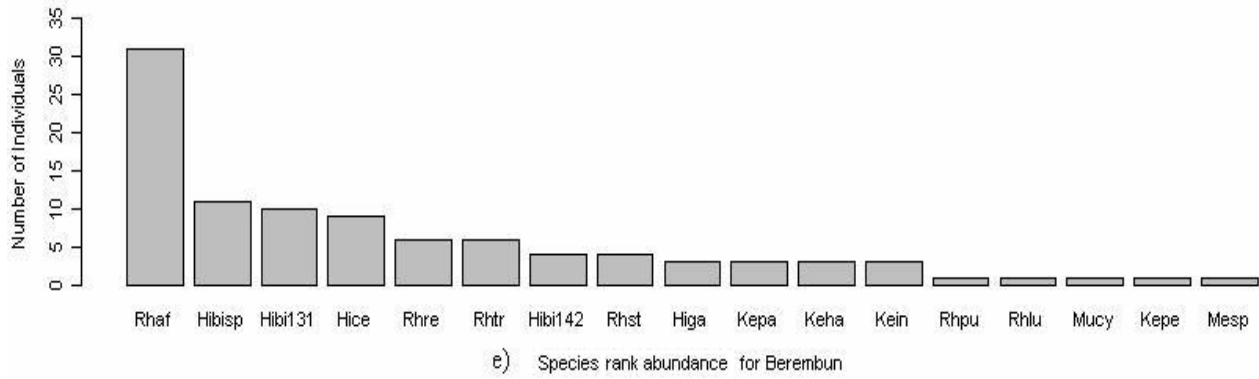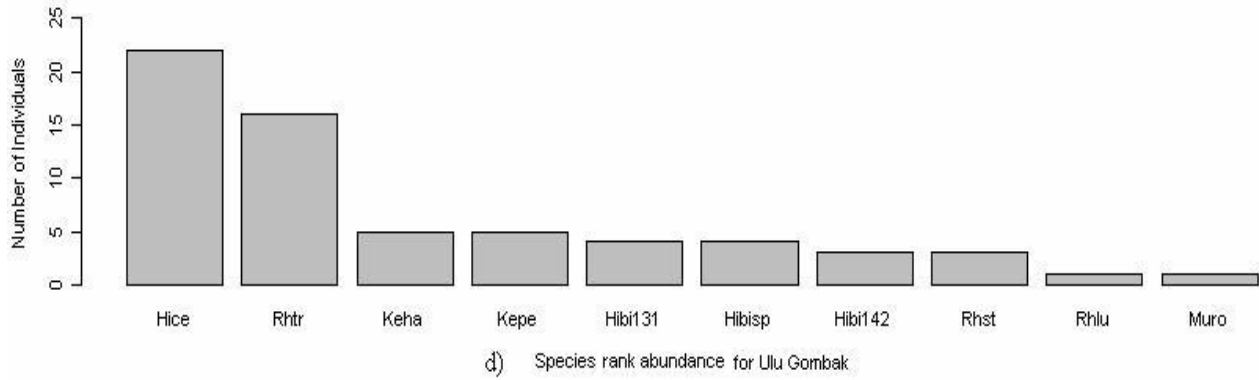
Figure 2.4 Species rank abundance for (a) Gunung Tebu Forest Reserve in Terengganu; (b) Kledang Saiong Forest Reserve in Perak; (c) Semangkok Forest Reserve in Selangor; (d) Ulu Gombak Forest Reserve in Selangor; (e) Berembun Forest Reserve in Negeri Sembilan, and (f) Gunung Angsi Forest Reserve in Negeri Sembilan. See Table 2.3 for species codes.

Figure 2.4, continued



d)  Species rank abundance for Ulu Gombak



e)  Species rank abundance for Berembun



f)  Species rank abundance for Gunung Angsi

A rarefied species accumulation curve with 100 permutations showed that none of the sites, except Gunung Tebu FR had a curve nearing an asymptote (Figure 2.5). An increasing trend in the graph indicates that not all species in the area were caught during this study. Although the curve in Berembun FR continued to increase, an extrapolated species richness using Chao estimates projected the same number of species caught (Table 2.4). Chao estimates indicated that the bats at four of the six sites had been well sampled.

2.3.3 Bat distribution

The annual mean rainfall (2786 ± 420 mm) and temperature (27.03 ± 0.69 °C) for all six forest reserve shows that Gunung Tebu FR has the highest annual mean rainfall (Figure 2.6a) but lowest annual mean temperature (Figure 2.6b). Comparing number of bat captures obtained between sites and the respective climatic conditions, rainfall ($r = 0.5954, p = 0.2124$) and temperature ($r = -0.1791, p = 0.7342$) had a non-significant correlation.
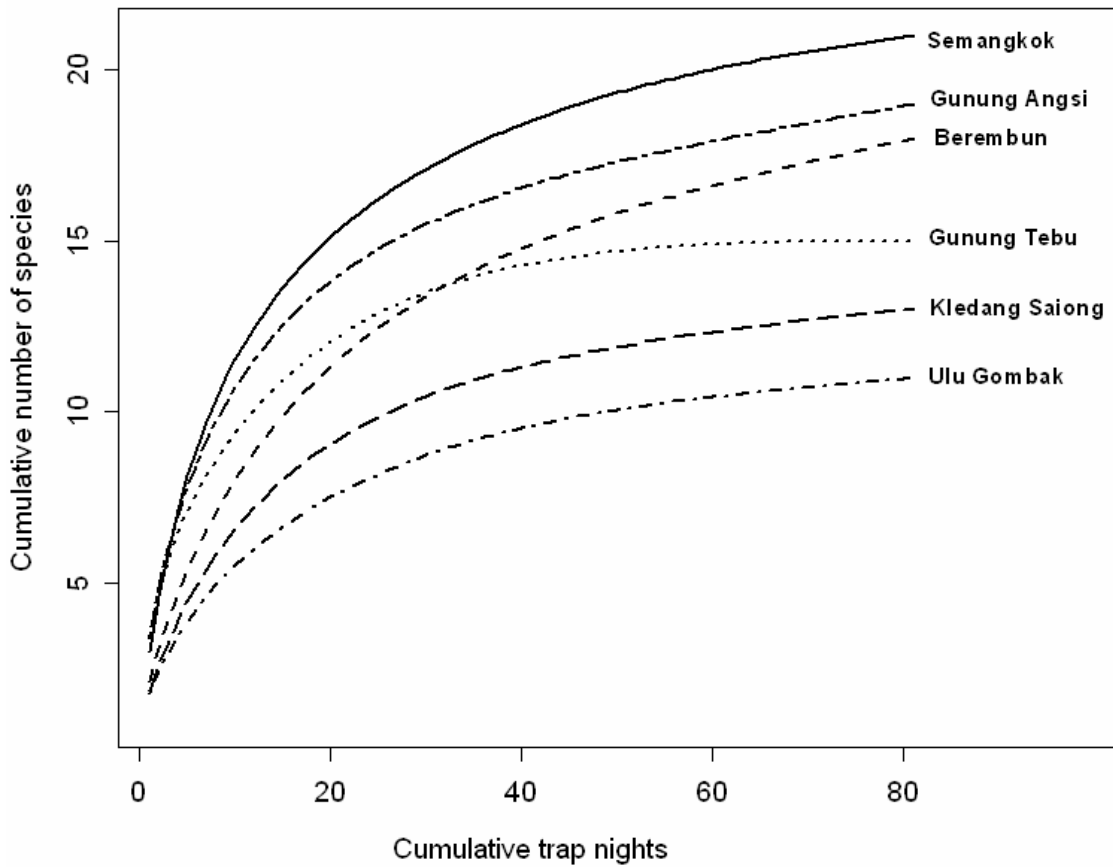
Figure 2.5 Species accumulation curve for six forest reserves in Peninsular Malaysia using rarefaction method.

Table 2.4 Extrapolated species richness with Chao estimates in six sites (S.E. - standard error)

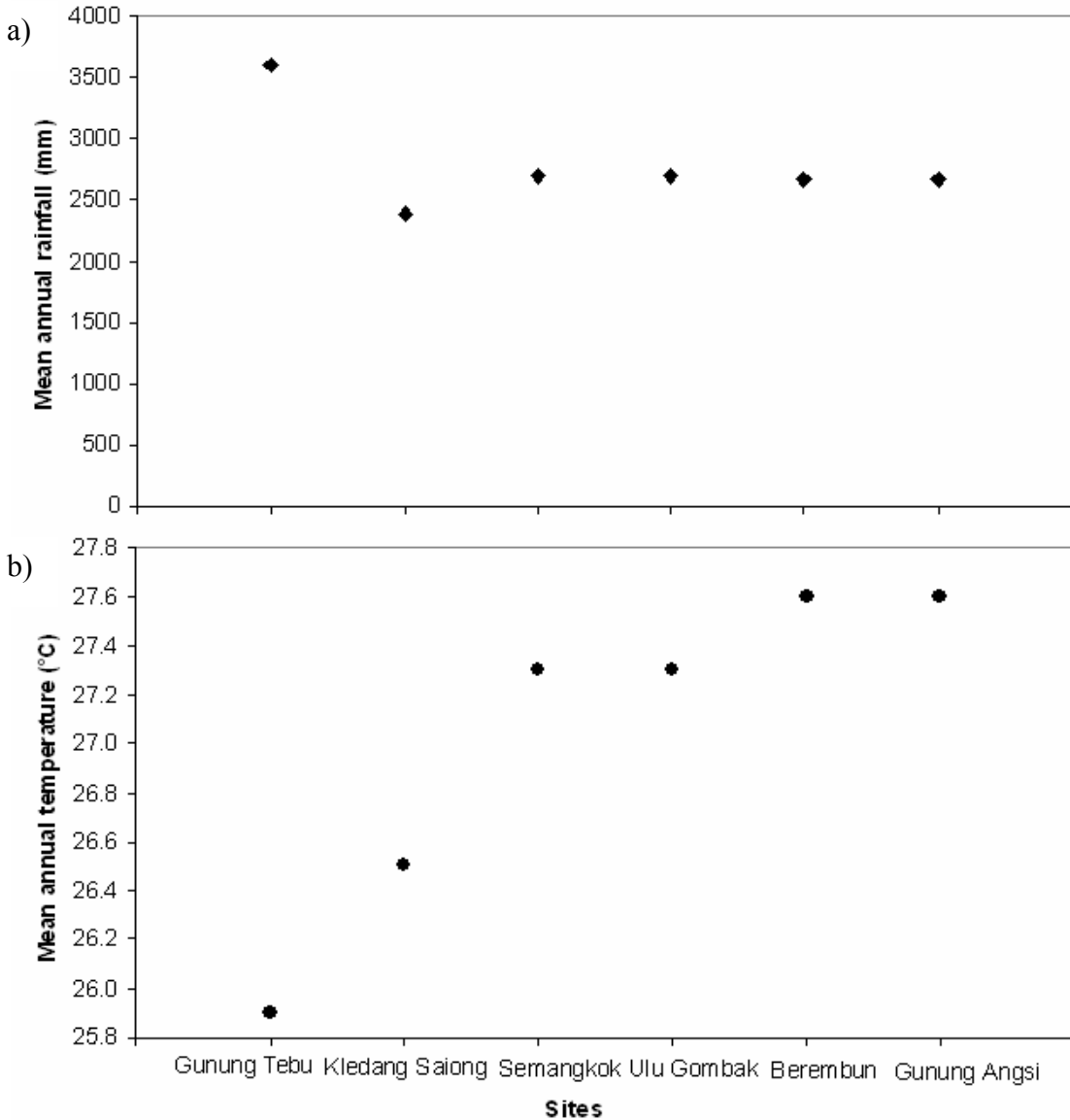| Site | Species | Chao | Chao.SE | % of total richness estimated |
|---|---|---|---|---|
| Semangkok FR | 20 | 21.13 | 1.7689 | 94.7 |
| Berembun FR | 17 | 17 | 0 | 100.0 |
| Gunung Tebu FR | 14 | 14 | 0 | 100.0 |
| Ulu Gombak FR | 10 | 18 | 11.6619 | 55.6 |
| Kledang Saiong FR | 12 | 12.67 | 1.3053 | 94.7 |
| Gunung Angsi FR | 18 | 26 | 11.6619 | 69.2 |

Figure 2.6 (a) Annual mean rainfall (mm) and (b) annual mean temperature (°C) compared with number of bats caught for the six study sites. Climate data obtained from the nearest meteorological station: Kledang Saiong – Lubuk Merbau Station, Perak; Semangkok and Ulu Gombak - Kuala Kubu Bharu Station, Selangor; Berembun and Gunung Angsi – Seremban Hospital Station, Negeri Sembilan; Gunung Tebu – Kuala Terengganu Airport Station, Terengganu. *Source: Malaysian Meteorological Department.*

When comparing differences of bat species composition between sites, most sites showed that communities were not similar (Table 2.5). This dissimilarity of species composition between different sites is further displayed in a cluster dendogram for species presence/absence (Figure 2.7) and proportion (Figure 2.8). Berembun FR and Gunung Angsi FR both in Negeri Sembilan had similar species but they were very dissimilar in the proportional representation of each species. The proportions for each species were more similar between Gunung Tebu FR and Gunung Angsi FR.

Table 2.5 Block Multiple Response Permutation Procedure (MRPP) results Chance-corrected within-group agreement (A) describes within-group homogeneity. If all observed items are identical within groups, A=1, which is the highest possible value. If there is less agreement within groups than expected by chance, A < 0. The higher the *A* value the more identical the sites are in terms of bat communities. p< 0.05 indicates that the pair is significantly not similar.

| Sites compared | | | A | p |
|---|---|---|---|---|
| Semangkok | vs. | Gunung Tebu | 0.1442 | 0.0006 |
| Semangkok | vs. | Gunung Angsi | 0.0271 | 0.0329 |
| Semangkok | vs. | Ulu Gombak | 0.1027 | 0.0003 |
| Semangkok | vs. | Kledang Saiong | 0.0863 | 0.0008 |
| Semangkok | vs. | Berembun | 0.0655 | 0.0052 |
| Gunung Tebu | vs. | Gunung Angsi | 0.0155 | 0.1548 |
| Gunung Tebu | vs. | Ulu Gombak | 0.2210 | 0.0002 |
| Gunung Tebu | vs. | Kledang Saiong | 0.1681 | 0.0006 |
| Gunung Tebu | vs. | Berembun | 0.1521 | 0.0012 |
| Gunung Angsi | vs. | Gombak | 0.0345 | 0.0141 |
| Gunung Angsi | vs. | Kledang Saiong | 0.0294 | 0.0253 |
| Gunung Angsi | vs. | Berembun | 0.0154 | 0.1236 |
| Ulu Gombak | vs. | Kledang Saiong | 0.0595 | 0.0021 |
| Ulu Gombak | vs. | Berembun | 0.0163 | 0.1107 |
| Kledang Saiong | vs. | Berembun | 0.0039 | 0.3051 |
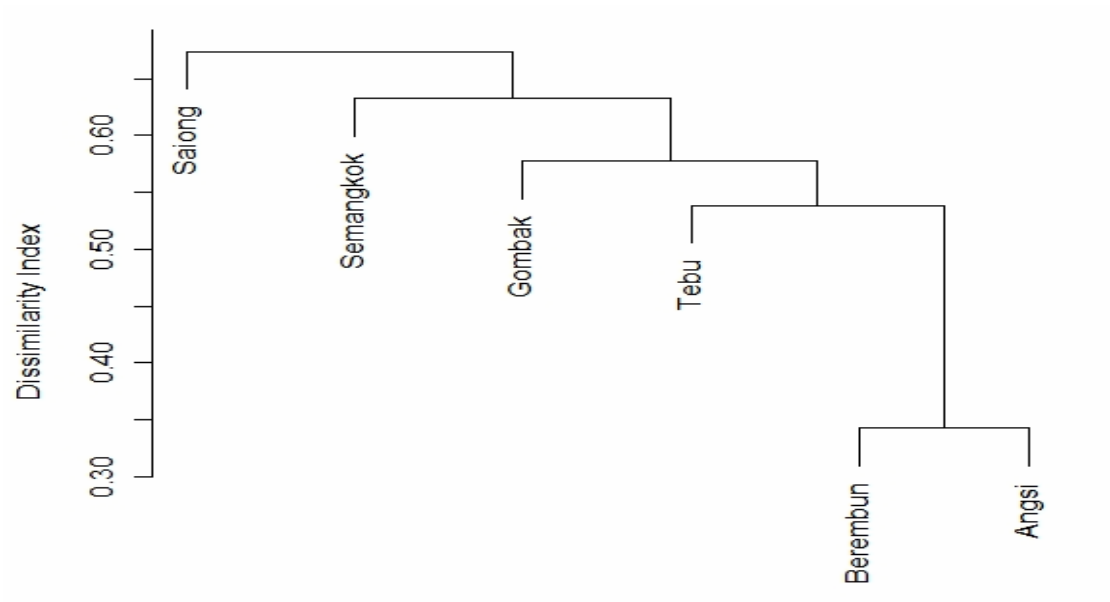
Figure 2.7 Cluster dendogram using Sorenson dissimilarity index of bat species presence/absence.


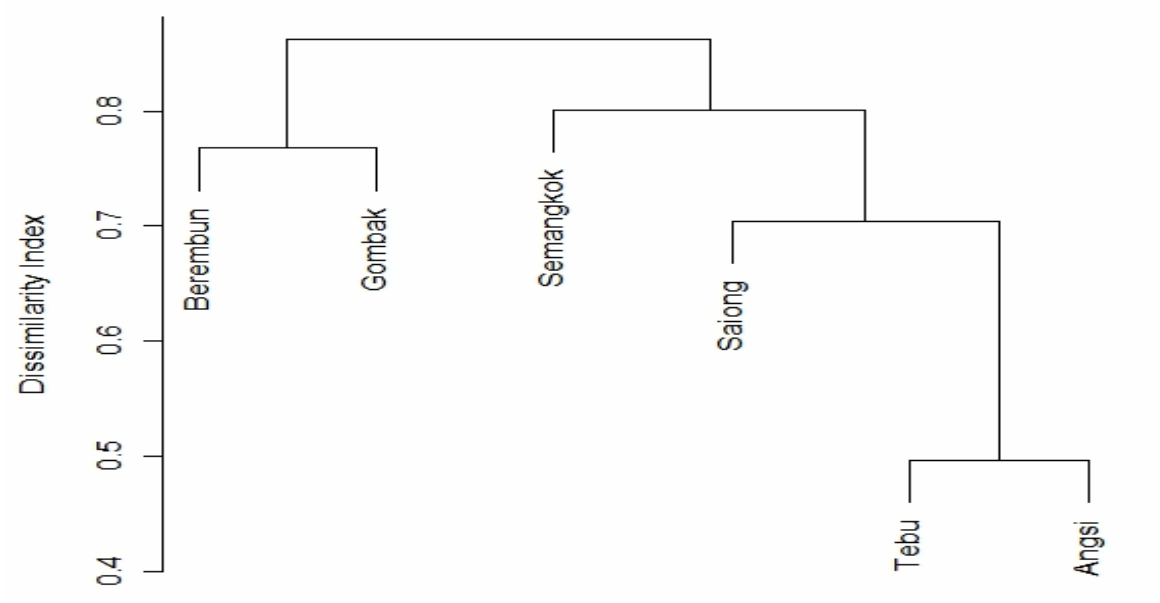
Figure 2.8 Cluster dendogram using Steinhaus dissimililarity index of proportion of bat species caught in the six study sites.

**2.4 DISCUSSION**

2.4.1 Bat assemblage

A lowland forest in Malaysia has been recorded to contain 69 species of both Megachiropterans and Microchiropterans within a 620 km$^2$ forest, which is the highest diversity of bats recorded in the Old World (Kingston *et al.,* 2006). This study however had recorded only 27 species of Microchiropterans, but it is difficult to compare as there are very few published insectivorous bat surveys in the hill forests of Peninsular Malaysia (e.g. Fletcher *et al.*, 2004; Struebig *et al*., 2009) as opposed to the lowland forests (e.g. Francis, 1990; Zubaid, 1993; Francis, 1994; Zubaid 1994; Kingston *et al*., 2000, Sheema, 2006). However if lowland and hill forests were to be compared, species diversity would be expected to decrease to a certain extent with increasing elevation (Heaney & Rickart, 1990; Fletcher *et al*., 2004). The assumption is based on the understanding that species tend to be most abundant around their environmental optimum (Fukami & Wardel, 2005). Therefore as elevation increases, temperature and insect availability decreases (Lawton *et al.*, 1987; Wolda, 1987; Stevens, 1992; Grindal & Brigham, 1999), which will eventually lead to a decrease in bat species diversity due to the inability to adapt to low temperatures and increased competition for scarce food resources (Fenton, 1990; Whitaker *et al*., 2000; Armstrong, 2004; Meyer *et al*., 2004; Akasaka *et al*., 2009).

Palaeotropical bat assemblages are dominated by members of the families Rhinolophidae and Hipposideridae, and the Vespertilionidae subfamilies Kerivoulinae and Murininae (Struebig *et al*., 2009). This study showed that Hipposideridae and Rhinolophidae were

highly represented in the insectivorous bat fauna of Peninsular Malaysia. Species from these families are primarily cave-dwellers; therefore bats from these families are more versatile as they do not rely on the forest entirely. Gunung Angsi FR and Gunung Tebu FR have a similar elevational range of 200–500 m asl although each is on either side of the main range. A large portion of the bats captured in these two sites consisted of *Hipposideros bicolor* sp. most probably because traps were coincidentally placed in their flight path. This species roosts gregariously in big groups in either rock boulders or caves, and commute to their foraging areas in large groups (Kingston *et al.*, 2006). Although there were no caves sighted in the vicinity of the sampling areas, the possibility of a nearby cave cannot be dismissed. There were however, large boulders near the transect line.

2.4.2 Bat species composition

It is interesting to note that *Rhinolophus trifoliatus* is one of four species that were found in all six sites. This species is known to roost within the forest interior, usually under leaves of palms and small trees (Kingston *et al.*, 2006, Fletcher, 2006). Although Medway (1983) did record them roosting in caves, Fletcher (2006) observed that roosts selected by this species were close to one another, indicating a small home range. The presence of this species would be a good indicator that the forest is able to sustain forest specialist. Forests are particularly crucial to forest dwelling species not only for food but also for shelter (Findley, 1993; Patriquin & Barclay, 2003; Henderson *et al.*, 2008). However, although they were present in all the sites, they were not abundant. Only Ulu Gombak FR had a relatively high number of this species. Also interesting to note is

*Kerivoula papillosa*, another tree/foliage roosting species which was abundant in all the sites but absent in Ulu Gombak FR. *Kerivoula hardwickii* was also found in all sites, but not much is known about its habits and roosting ecology. However, morphological features such as body size and wing morphology fits the characteristics found in other tree/foliage roosting species in the family (Sedgeley & O'Donnell, 1999). These results indicate that although the abundance of each species may vary across sites, the family composition of bats remained somewhat similar. There are many factors such as location and disturbance of a particular site that might influence the composition of bats. For example, species such as *Glischropus tylopus* and *Tylonycteris robustula*, commonly known as bamboo bats, were the only species from the Vespertilioninae family that was recorded in Semangkok FR. These species are often found roosting together and associated with bamboo in forested areas (Kingston *et al*., 2006). Information such as this provides a general description of the forest condition.

The low number of tree/foliage roosting species in Gunung Tebu FR may indicate that it might not be an ideal forest for roosting. The high abundance contributed by the cave-roosting bats however may imply that the forest could be an important foraging ground. These cave roosting bats are able to fly greater distances, often foraging in forest areas for food but roosting elsewhere (Systun *et al*., 2001). The primary concern should be given to tree/foliage roosting species which are present and abundant in some sites but lacking in others. Their specialized wing morphology and echolocation signal restricts them to cluttered environments hence making it difficult to be flexible ecologically (Kingston, 2003b). Their distinct features make them more susceptible to disturbance

than other bat species. However, some species such as *Phoniscus atrox* and *Myotis ridleyi* may not be detected as often as other species due to specific habitat requirements or lack of trapping effort (Anwarali Khan *et al*., 2008). It is however important to monitor and note the presence of these Nearly Threatened (NT) species for conservation measures.

The trapping effort at each site was standardized to reduce bias. With the trap effort applied for this study, only Gunung Tebu FR was closely reaching an asymptote, indicating that the community has been sampled adequately (Kingston, 2009). Nevertheless, the Chao results indicated that most sites were well sampled. However, Ulu Gombak FR and Angsi FR had a big standard error indicating < 90 % of the total estimated richness, indicating that they were under sampled (Moreno & Halffter, 2000 cited by Kingston, 2006). This results show that 81 harp trap nights are insufficient to sample the entire bat community in a hill forest, but is enough for representative sampling. Although the longer a survey is conducted the more species are detected (Preston, 1948), a line needs to be drawn between sufficient effort and tradeoffs in getting reliable community species richness (Magurran, 2004). Sampling bat assemblages in hill forests is more demanding in terms of time, logistics, manpower and finances (Gillison & Liswanti, 2004). Kingston *et al*. (2003a) indicated that the effort needed to capture 27 of the 28 insectivorous bats in an undisturbed Malaysian lowland dipterocarp forest is 350 harp trap nights. However there has not been any conclusive study on the effort needed for sampling bats in a hill forest. The effort needed for bat sampling varies according to the environment and bat assemblage being surveyed (Weller & Lee, 2007).

2.4.3 Bat distribution

Humidity has been reported to affect the activities of insects (Mostafa *et al*., 2005; Moriyama & Numata, 2006), and there is a positive relationship with large-ranged Geometridae moths (Brehm *et al*., 2007). High temperatures and high nocturnal insect availability influence the foraging activity of bats; therefore the daily mean humidity may affect insect abundance which in turn affects bat capture rates (Meyer *et al*., 2004). The influence of foliage and canopy cover is also important to shield roosts from sunlight and maintain an ambient temperature (Sedgeley, 2001). Temperature does play a greater role in temperate forests compared to tropical forests because of the different seasonality. Although the results of this study show that rainfall and temperature had a non-significant correlation with bat abundance, it is interesting to note that Gunung Tebu FR had the highest mean rainfall among all sites as well as high bat abundance.

The dissimilarities between sites are depicted clearly in the dissimilarity dendogram where species presence/absence were very similar between Gunung Angsi FR and Berembun FR but were very different in species proportion. Species similarity may be due to relatively close geographical distance between the two sites. These sites were dominated by two different families; Gunung Angsi FR is dominated by *H. bicolor* sp. and Berembun FR by *R. affinis*. Gunung Angsi FR had almost three times the number of bats captured in Berembun FR. There may be two different caves that are dominated by these two families. This type of niche partitioning might be a way of reducing competition for resources (Arlettaz, 1999; Whitaker, 2004). As for similarities in species proportion, Gunung Angsi FR was more similar to Gunung Tebu FR. Although transects

were laid out at similar elevational ranges for all sites, it was impossible to choose study sites with perfectly similar in elevational range. Among all sites, Gunung Tebu FR and Gunung Angsi FR were most similar in elevation. These similarities are explained by the MRPP. The MRPP showed that these sites were not significantly dissimilar, meaning that the sites had similar species composition.

All forests are important habitat for bats. However, to assist in conservation efforts the quality of bat communities within a forest conveys much about the value of the forest. High abundance can sometimes be contributed by a single species as a result of traps placed in their pathway. The IUCN Red List has recently amended the status of five species identified in this study; *Nycteris tragata, Rhinolophus sedulus, Kerivoula pellucida* and *Phoniscus atrox* from Low Risk (LR)/least concern (lc) in 2007 to Near Threatened (NT) and *Murina rozendali* to Vulnerable (VU) in 2008 (IUCN, 2009). Although NT species such as *M. rozendaali* and *Kerivoula intermedia* were recorded in a few sites, rare and nearly threatened species such as *Phoniscus atrox* and *Myotis ridleyi* were only recorded in Gunung Tebu FR and Kledang Saiong FR respectively. Studying the species composition within each site will help identify the value of the forest to the bat community, whether for roosting or foraging. Identifying rare and threatened species in the process can help highlight as well as protect the habitat they thrive in.

The study concludes that insectivorous bat assemblage of Peninsular Malaysia comprises mainly of Hipposideridae and Rhinolophidae. The six sites were similar in species composition but varied highly in their relative species abundance. There was however no sign that any insectivorous bat species were geographically restricted and neither were

there extreme climatic conditions recorded in any of the study sites, which supports the initial hypotheses of this study. This indicates that every forest patch in Peninsular Malaysia is an important refuge for bats. Similarities or dissimilarities of species composition between sites may be due to factors such as elevational range and its surroundings. Understanding population distribution within and between sites may increase our knowledge on the habitat requirements of bats. These are useful for making more informed conservation management decisions (Francis, 1990). Linking knowledge (research) and action (implementation) will no doubt reap the full benefits of science (Shanley & Lopez, 2009).

# CHAPTER THREE

# SIZE EFFECT OF VIRGIN JUNGLE RESERVES ON INSECTIVOROUS BAT

# ASSEMBLAGES

## 3.1 INTRODUCTION

3.1.1 Forestry in Peninsular Malaysia

In 2007, the total forested area in Peninsular Malaysia amounted to 5.84 million ha or about 32% of the land area. These forested areas comprise of 4.25 million ha of inland forest, 0.21 million ha of swamp forest, 0.10 million ha of mangrove forest and 1.28 million ha of other forest types (Ministry of plantation industries and commodities, 2008) Dipterocarp forest which represents the bulk of the inland forested land is mainly comprised of species from the genera *Anisoptera, Dipterocarpus, Dryobalanops, Hopea, Shorea* and *Parashorea* (Thang, 1997).

At the end of 2001, 10.64 million ha were set aside as Production Forests and 3.81 million ha were designated as Protected Forest, making up the total of 14.45 million ha (44.0%) of Permanent Reserve Forest (PRFs) (Mohd Paiz & Wan Mohd Shukri, 2003).

Virgin Jungle Reserves (VJRs) are one of the eleven components under the Permanent Reserve Forest (PRF) and are under the control of their respective State Forestry

Departments. The idea of VJRs was established in 1947 (Laidlaw, 1999) as a network of small, protected patches of natural forest located within a commercial production forest (Wyatt-Smith, 1950) (see Appendix B). They serve as natural arboreta, controls for the exploited and siviculturally-managed forest, seed stands for timber trees, genetic pools for forest species and also for educational and recreational purposes (Sam, 2001). Virgin Jungle Reserves have also helped forest dwellers survive the pressures caused by decades of forest conversion (Borhan & Cheah, 1986). To date, a total of 120 VJRs covering an area of 111 800 ha have been established in Peninsular Malaysia (Chan, 2002). There have been many arguments regarding the most effective size of VJRs (Borhan & Cheah, 1986; Kochummen *et al*., 1990) and their optimal location from the boundary of a forest reserve (edge, middle, etc.) (Laidlaw, 1999; Lee *et al*., 2002). However, the overall effectiveness of VJRs is still unclear as we lack sufficient scientific information for evaluation (Sam, 2001; Lee *et al*., 2002).

Sustainable forestry is a concept hoped to bridge the gap between forest products and conservation. Therefore the 1984 National Forestry Act was promulgated to strengthen the country's capacity to implement Sustainable Forest Management (SFM). It incorporates conservation of biological diversity with the sustainable utilization of forest resources (Chan, 2002). Criteria and Indicators (C & I), which are information tools in the service of forest management (Prabhu *et al.* 2001), are among the foremost mechanism for defining and promoting sustainable tropical forest management (Sheil *et al*. 2004). Jones (2004) suggested that ecological indicators should measure ecological health rather than the productivity of a system. Common ecological indicators are birds

(Wong, 1985), ants (Andersen, 1997; Andersen *et al.*, 2002; Wike & Martin, 2005) and butterflies (Maes & Van Dyck, 2005; Kittur *et al.*, 2006).

3.1.2 Bats and the forest

It has also been established that bats are important organisms in the forest. Their ecological roles as pollinators and pest controllers (Altringham, 1996) help economically important plant species to propagate (Tuttle, 1983), and also maintain a balanced food chain in the ecosystem by consuming large portions of insects every night. Tuttle (1983) also claims that the seed dispersal activities of bats can be critical to reforestation of clear-cut areas. In return for their ecological functions to the ecosystem, the forest plays a crucial role in their life cycles, especially for forest-dwelling bats that not only depend on the forest for food but also for shelter (Findley, 1993; Patriquin & Barclay, 2003; Henderson *et al.*, 2008). Some bat species are more common in old-growth forests due to the impressive tree sizes and the abundance of old or dead trees that have developed broken tops, creeks, hollows, and scaling bark, which can in turn serve as roosting sites (Thomas, 1992). Some bats tend to display very specific roosting requirements (Mirowsky, 1997; Lee & McCracken, 2004; Fletcher, 2006). These kinds of specificity increase their sensitivity to habitat changes and make them vulnerable to extinction.

Understanding and predicting how well flora and fauna respond to habitat disruption has been a major challenge for biologists (Bernard & Fenton, 2007). There have been many studies looking at the effects of fragmentation (Laidlaw, 1996; Sodhi, 2002; Bernard & Fenton, 2007; Henderson *et al.*, 2008; Uehara-Prado and Freitas, 2009; Struebig *et al.*,

2009). These studies can be very valuable as there may only be fragments of tropical forest left in the future (Zubaid, 1993). At some point, VJRs can also be considered as fragmented forests due to the past and current development activities surrounding it. The patchiness that logging creates may influence habitat use by foraging bats either directly, by effecting their flight patterns or indirectly by altering prey availability (Patriquin & Barclay, 2003; Lee & McCracken, 2004). Therefore, this study intends to look solely on insectivorous bats because many species especially forest dwelling species are sedentary and long lived, so their foraging behavior should reflect conditions in an area small enough to study thoroughly, as shown by Fleming *et al.* (1977). These species are sensitive to their roosting needs; studying their assemblages in these areas will help predict forest health and assess the effects of logging on their populations.

After logging is complete in a forest, researchers generally pay close attention to the recovery of flora, but a study of the state of the fauna in logged areas is also essential. Whitmore (1984) suggested that the restocking of a forest after logging is not done by immigrants from outside the area but by those moving out of forest pockets such as VJRs. Therefore this study intends to determine if larger pockets have an effect on bat re-colonization. Thus the objective of this study is to look at the impact of different sizes of VJRs on the logged-over forests surrounding it by assessing the insectivorous bat assemblages with a standard sampling method. We assumed that each VJR is a fragment of primary forest surrounded by secondary logged-over forest. This paper hypothesizes that bat abundance and diversity would increase with increasing VJR size. To assess the bat populations in secondary logged-over forest surrounding the VJRs, bat assemblages in fixed distances within and away from the VJRs will also be compared.

**3.2 METHODS**

3.2.1 Study site

The study was conducted between September 2007 and June 2009 at six different sites selected throughout Peninsular Malaysia. Several criteria were applied during the selection process, they were: 1) forest type was restricted to lowland and hill dipterocarp forest, 2) at an elevation between 100–1500 m above sea level (asl), 3) all sites contain a virgin jungle reserve that is surrounded by forest areas that has been logged at least 15 years ago, and 4) granite geological structure. One VJR was chosen to represent each of the size classes: <50 ha, 51–100 ha, 101–300 ha, 301–700 ha, 701–1000 ha and >1000 ha (Table 3.1).

Table 3.1 Details of selected Virgin Jungle Reserves in Peninsular Malaysia. *Source: State Forestry Department*

| Forest Reserve (FR) | State | VJR size (ha) | VJR size class | Site Elevation (m asl) | Adjacent logged forest (years after logging) |
|---|---|---|---|---|---|
| Semangkok | Selangor | < 50 | Class I | 300–600 | > 30 years |
| Gunung Tebu | Terengganu | 51–100 | Class II | 244–472 | > 40 years |
| Gunung Angsi | Negeri Sembilan | 101–300 | Class III | 200–500 | > 40 years |
| Ulu Gombak | Selangor | 301–700 | Class IV | 457–1,128 | > 40 years |
| Kledang Saiong | Perak | 701–1500 | Class V | 100–600 | > 30 years |
| Berembun | Negeri Sembilan | > 1500 | Class VI | 200–700 | > 40 years |

3.2.1 (a) Semangkok Forest Reserve

Semangkok Forest Reserve is located in Kuala Kubu Bharu, Selangor. The 28 ha VJR located in Compartment 30 was established in 1959. The adjacent logged-over forest in Compartment 27 is 110 ha and was logged between 1973 and 1977. The study area selected is a Seraya (*Shorea curtisii*) rich forest and the undergrowth is dominated by Bertam palm, forming a closed sub-canopy (Putz, 1978). Transects and plots were established within 400–600 m above sea level (asl).

3.2.1 (b) Gunung Tebu Forest Reserve

Gunung Tebu Forest Reserve is located in Besut, Terengganu. The 50 ha VJR located in Compartment 4 was established in 1973. The adjacent logged-over forest in Compartment 3 was logged in 1966. This steep and rocky study area consists of Meranti Keruing and Ridge forest. Characteristic species include *Gluta elegans, Shorea guiso, Parashorea lucida* and *S. hypochra*, which reflects a somewhat seasonal climate (Putz, 1978). Transects and plots were established between 60–450 m asl.

3.2.1 (c) Gunung Angsi Forest Reserve

Gunung Angsi Forest Reserve is located in Rembau, Negeri Sembilan. Established in 1959, the 143.3 ha VJR is located in Compartment 12. The adjacent logged-over forest in Compartment 13 was logged between 1963 and 1975. The study area selected consists of lowland and hill Dipterocarp forest. Transects and plots were established between 200–600 m asl.

3.2.1 (d) Ulu Gombak Forest Reserve

Ulu Gombak Forest Reserve is located in Hulu Gombak, Selangor. The 449 ha VJR is located in Compartment 22. The adjacent logged-over forest in Compartment 21 is 653 ha and was logged between 1955 and 1963. The study area selected consists of lowland and hill Dipterocarp forest. The valleys are dominated by *Saracca taaipingensis* (Syn: *Saraca cauliflora*) (Puntz, 1978). Transects and plots were established between 450–670 m asl.

3.2.1 (e) Kledang Saiong Forest Reserve

Kledang Saiong Forest Reserve is located in Jelapang, Perak. The VJR located in Compartment 70 is 814 ha and was established in 1962. The adjacent logged-over forest in Compartment 61 and 63 are 340 ha and were logged between 1973 and 1975. The study area selected consists of lowland and hill Dipterocarp forest. *Shorea maxwelliana*, *S. multiflora* and *S. ovata* are among the common trees in the area (Putz, 1978). Transects and plots were established between 200–550 m asl.

3.2.1 (f) Berembun Forest Reserve

Berembun Forest Reserve is located in Seremban, Negeri Sembilan. The 1834 ha VJR located in Compartment 32 was established in 1993. The adjacent logged-over forest in Compartment 31 is 155 ha and was logged in 1966. The study area selected consists of lowland and hill Dipterocarp forest. Transects and plots were established between 245–610 m asl.

3.2.2 Sampling design

In order to compare forest interior insectivorous bats across different sizes of VJRs in Peninsular Malaysia, nine 300 m transect lines were set up within each study site. Three transects were established at 200 m within the boundary of the VJR, three transects at 200 m and another three transects > 600 m away from the VJR boundary. Each three sets of transects were established 200–500 m apart.

Due to the limitations of the harp trap capture method, sampling was restricted to insectivorous bat species that are readily captured in the forest under-storey. Three four-bank harp traps (Francis, 1989) (ca. 2 m width and 3 m height) were set up along each transect for three consecutive nights, with each trap at least 50–75 m apart. They were set up approximately 1 m above ground level on clear pathways with trees and undergrowth on both sides.  Each night, three traps were set up on each of the three transects, making nine traps in total. They were moved to the next three transect lines on the fourth day (Francis, 1989). A rain gauge was placed at the entrance to each study site to measure daily rainfall.

3.2.3 Field Sampling

Captured bats were held in catch bags before biometric data such as weight (g) and forearm length (mm) were obtained. Body mass was recorded to an accuracy of 0.1 g with a 30 g Pesola® spring balance to determine average mass of each species and the

forearm length was measured to 0.1 mm with calipers (Bontadina *et al*., 2002). Aluminum wing bands were placed on the right forearm of females and left forearms of males to account for recaptures. Species were identified using Payne and Francis (1997) and Kingston *et al*. (2006). All bats were released after required information was gathered.

3.2.4 Habitat survey

A habitat survey was conducted to examine forest regeneration as a possible driver of observed variation in bat species diversity among VJRs. At each transect, a parallel 20 x 80 m plot was established. Each 20 x 80 m plot was subdivided into 20 x 20 m subplots and then further subdivided into 10 x 10 m quadrates. Within each plot, trees $\geq$ 5 cm were measured (diameter at 1.3 m height (dbh) or diameter above buttresses) with a diameter tape. All trees $\geq$ 5 cm dbh were measured for height using Tru pulse 200$^®$ lite laser distance and a measuring pole. Height is measured here to give a picture of the tree strata or foliage height in the plot (Whitmore, 1984).

3.2.5 Statistical analysis

The total number of bats caught and the species identified were compared across different VJR size classes. Nine transects in each study site were pooled to make up one sampling unit. Alpha diversity derived from Simpson's diversity index (Simpson, 1949) and Pielou's evenness (Pielou, 1966) was compared for all sites. Simpson's index was chosen

because it provides a good estimate of diversity with a relatively small sample size (Magurran, 2004).

A rarefied species accumulation curve was also created for each site to determine if all species in the site had been sampled adequately (Kingston, 2009). Although the sampling effort was equal for all sites, but the size of the study sites varied greatly, thus making the efforts unequal. The rarefaction method allows comparisons between the numbers of species found in two regions when the sampling efforts differed. To estimate the number of species at each site and to compare them to those captured, an extrapolated species richness using Chao estimator was derived. The sampled species richness was then divided by the estimator for each size class to calculate the percentage of total richness estimated by Chao (Tylianakis *et al*., 2006). The Chao estimator was used because it takes into account the number of species with abundance instead of just incidence of observed species (Chao, 1984; Chao *et al*., 2006). A rank abundance curve was computed to display the contrasting patterns of species richness in each site (Magurran, 2004). To further display the differences of species composition between each size class, a distance matrix was calculated using Sorenson distance for species presence/absence.

As for plots set up within and distances away from the VJRs, the objective was to look at bat species composition at different areas of the forest reserve. A block Multiple Response Permutation Procedure (MRPP) was used to look at the differences in community of bats between distances within each size class (Mielke, 1984). This is a nonparametric method for testing group differences (McCune & Grace, 2002). In order to exclude rare species that might and might not have been captured due to various reasons,

only the proportion of dominant species (≥ 5% of the population) within distances of each size class is used to calculate a dissimilarity matrix with Steinhaus distance. The relationship of these dominant species within distance sample of each size class is displayed in species space using Non-metric multidimensional scaling (NMDS) (Struebig *et al.,* 2009). According to McCune & Grace (2002), NMDS is generally the most effective ordination method for ecological community data. The software used for this analysis was R Statistical Computing (R Development Core Team, 2009).

Mean basal area per tree within each site was calculated from the dbh to estimate the density between and within the sites:

$$Basal\ area\ per\ hectare = (3.142 \times dbh)^2 / 40\ 000$$

Basal area provides a good description of the forests because it is more closely proportional to leaf area and foliage mass (McCune & Grace, 2002) and it may be a better indicator for monitoring the extent of relative disturbance levels in the site (Seng *et al.*, 2004). Basal area and tree height will be able to provide an overall picture of the density and cluteredness of the forests. To look at the correlation between height and basal area on bat abundance and diversity among sites, a Pearson's product moment correlation coefficient was derived.

**3.3 RESULTS**

3.3.1 Differences in bat community among VJR size classes

A total of 27 insectivorous bat species (Table 3.2) were identified from 958 individuals. They were captured over 486 trap nights. Gunung Angsi FR in Negeri Sembilan (Class III) had the most number of captures with 29.33% (Figure 3.1). Ulu Gombak FR in Selangor (Class IV) had the least capture with only 6.68 % of the total captures. There is a discontinuity between the two increasing trend of the < 50 ha, 51–100 ha, 101–300 ha size classes (Category 1 - Class I, Class II, Class III) and the 301–700 ha, 701–1500 ha, > 1500 ha size classes (Category 2 - Class IV, Class V, Class VI) as seen in Figure 1. Although Class VI had only one third of the captures in comparison to Class III, but with 16 and 17 species respectively, the species richness between these two classes is almost similar. However Class VI had a high evenness index and Class III had the lowest (Figure 3.2). Even though Class I had the highest species richness, Class II had the highest Simpson's (1-D) diversity index with a value of 0.8988. The low Simpson index indicates that although Class I was rich in species; they were not highly proportionate in abundance and is thought to be less diverse.

Table 3.2 List of bat family and species caught in six sites across Peninsular Malaysia, < 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI. [*Hipposideros 'bicolor'* comprises of two phonic types with mean echolocation call frequencies of 131 kHz and 142 kHz. They were distinguished in the field by forearm length *H.bicolor 131* > 45 mm and *H.bicolor 142* < 43 mm. Individuals with forearm 43–45 mm is identified as *H.bicolor* sp.] Species classification is according to Hill (1983) and Kingston *et al*.(2006).

| Family | Species | Code | Virgin Jungle Reserve size class (ha) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | < 50 | 51 - 100 | 101 - 300 | 301 – 700 | 701 - 1500 | > 1500 |
| Hipposideridae | *Hipposideros bicolor 131* Temmninck | Hibi131 | ● | ● | ● | ● | ● | ● |
| | *Hipposideros bicolor 142* Temmninck | Hibi142 | ● | ● | ● | ● | | ● |
| | *Hipposideros bicolor sp* Temmninck | Hibisp | ● | ● | ● | ● | ● | ● |
| | *Hipposideros cervinus* Gould | Hice | ● | ● | | ● | | ● |
| | *Hipposideros larvatus* Horsfield | Hila | ● | ● | ● | | | |
| | *Hipposideros sabanus* Peters | Hisa | ● | | | | | |
| | *Hipposideros galeritus* Cantor | Higa | ● | ● | | | | ● |
| Rhinolophidae | *Rhinolopus stheno* Andersen | Rhst | ● | ● | ● | ● | ● | ● |
| | *Rhinolopus lepidus* Andersen | Rhre | ● | ● | ● | | | ● |
| | *Rhinolopus sedulus* Andersen | Rhse | ● | | | | | |
| | *Rhinolopus trifoliatus* Temminck | Rhtr | ● | ● | ● | ● | ● | ● |
| | *Rhinolopus affinis* Horsfield | Rhaf | | ● | ● | | ● | ● |
| | *Rhinolopus pusillus* Temminck | Rhpu | | ● | | | | |
| | *Rhinolopus luctus* Temminck | Rhlu | | ● | | ● | | ● |
| Murininae | *Murina suilla* Temminck | Musu | ● | | | | ● | |
| | *Murina cyclotis* Dobson | Mucy | | | ● | | ● | ● |
| | *Murina rozendaali* Hill and Francis | Muro | | | ● | ● | ● | |
| Kerivoulinae | *Kerivoula papillosa* Temminck | Kepa | ● | ● | ● | | ● | ● |
| | *Kerivoula hardwickii* Horsfield | Keha | ● | ● | ● | ● | ● | ● |
| | *Kerivoula pellucida* Waterhouse | Kepe | ● | ● | ● | ● | | ● |
| | *Kerivoula intermedia* Hill and Francis | Kein | ● | ● | ● | | ● | ● |
| | *Phoniscus atrox* Miller | Phat | | | | ● | | |
| Vespertilioninae | *Glischropus tylopus* Dobson | Glty | ● | | | | | |
| | *Tylonycteris robustula* Temminck | Tyro | ● | | | | | |
| | *Myotis ridleyi* Thomas | Myri | | | | | ● | |
| Megadermatidae | *Megaderma spasma* Linnaeus | Mesp | | ● | | | | |
| Nycteridae | *Nycteris tragata* Andersen | Nytr | ● | | | | | ● |
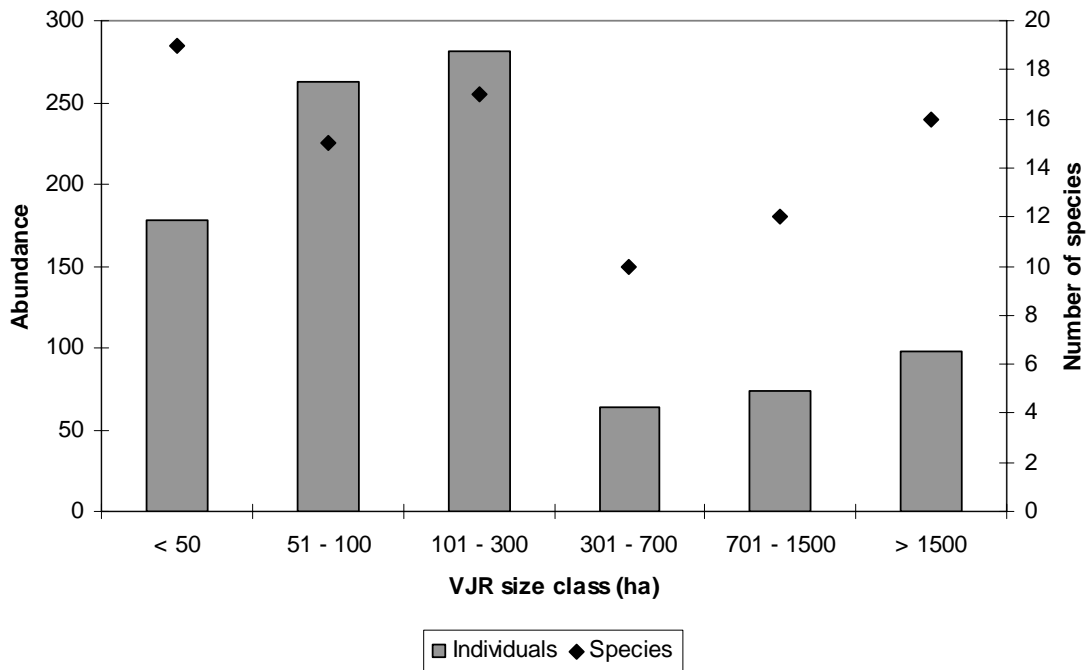
Figure 3.1 Bat abundance and species richness at six VJR size classes in hectare (< 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI)
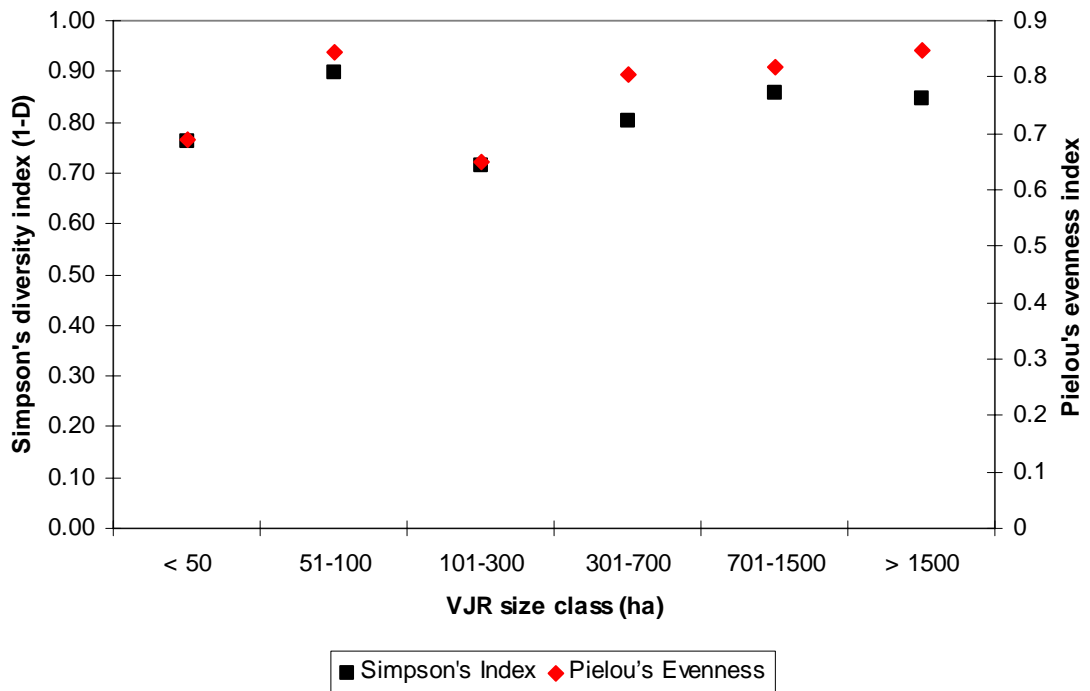


Figure 3.2 Simpson's Diversity Index (1-D) and Pielou's evenness index at six VJR size class in hectare (< 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI).

A rarefied species accumulation curve with 100 permutations showed that none of the sites, except Class II had a curve nearing an asymptote (Figure 3.3). Although the curve in Class VI continued to increase, an extrapolated species richness using Chao estimates estimated the exact number of species caught (Table 3.3). Class III and Class IV however had the biggest standard error with < 90 % of the total estimated richness indicating the possibility that these two areas were under sampled (Moreno & Halffter, 2000).

As for species composition, all the sites were dominated by either Hipposiderids or Rhinolophids (Figure 3.4). Most of the species in these families are primarily cave-dwellers. Steep slopes on the graph signify assemblages with high dominance while shallower slopes (almost straight line) at the tail of the graph imply higher evenness (Magurran, 2004). Class I, Class IV and Class V did show high abundance of tree/foliage roosting species such as *Kerivoula papillosa* and *Rhinolophus trifoliatus.*
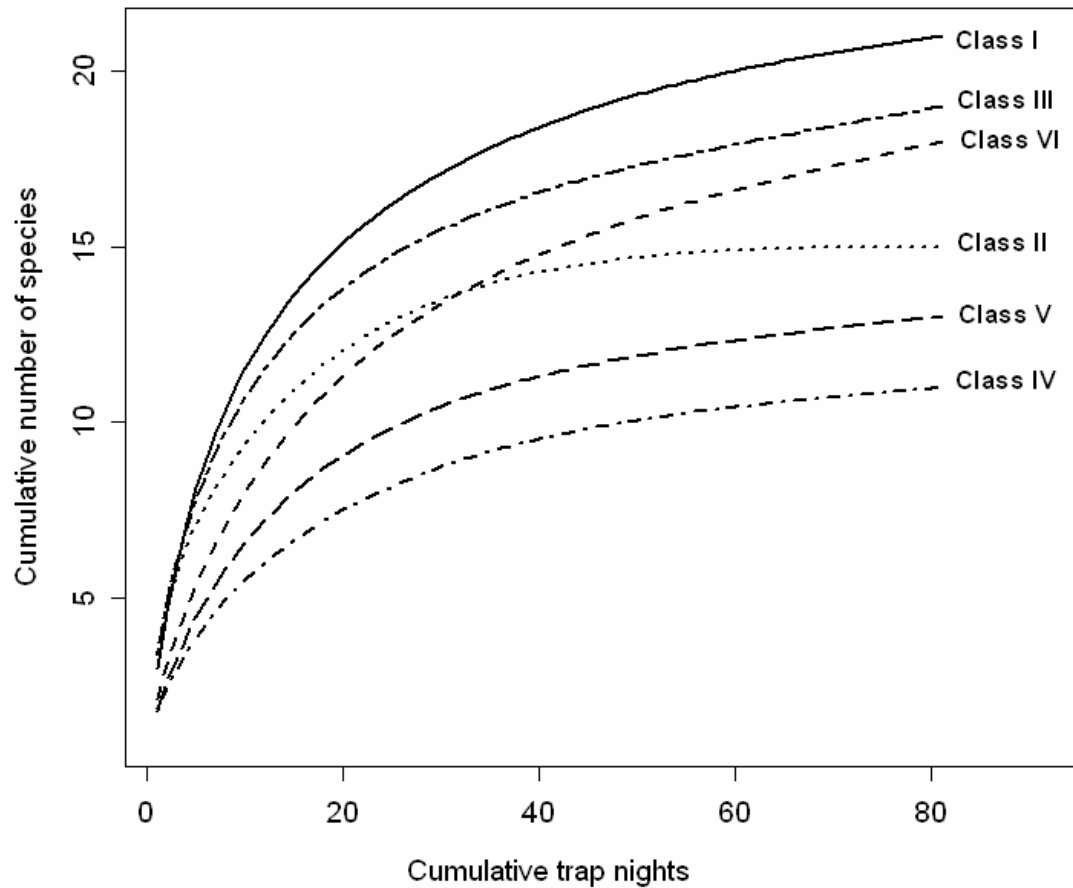
Figure 3.3 Species accumulation curve for six forest reserves in Peninsular Malaysia using rarefaction method (< 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI).

Table 3.3 Extrapolated species richness with Chao estimates in six study sites (SE. - standard error)
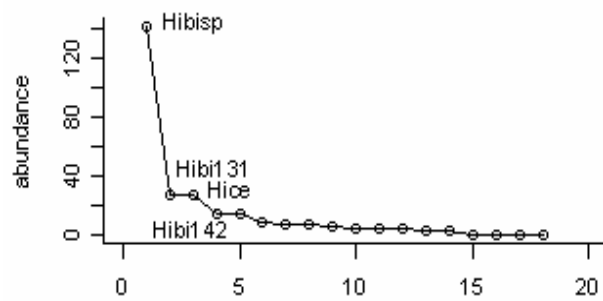
| VJR size class (ha) | VJR class | Species | Chao | Chao.SE | % of total estimated richness |
|---|---|---|---|---|---|
| < 50 | Class I | 20 | 21.13 | 1.769 | 94.7 |
| 51–100 | Class II | 14 | 14 | 0 | 100.0 |
| 101–300 | Class III | 18 | 26 | 11.662 | 69.2 |
| 301–700 | Class IV | 10 | 18 | 11.662 | 55.6 |
| 701–1500 | Class V | 12 | 12.67 | 1.305 | 94.7 |
| > 1500 | Class VI | 17 | 17 | 0 | 100.0 |
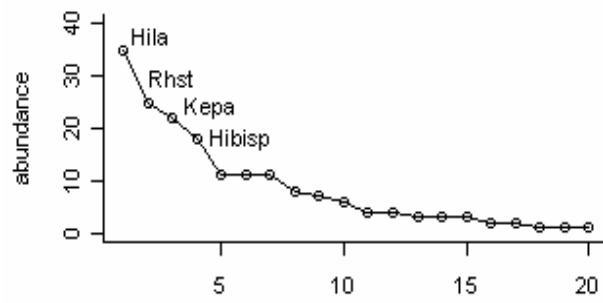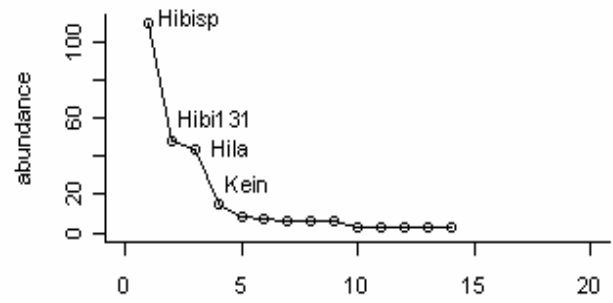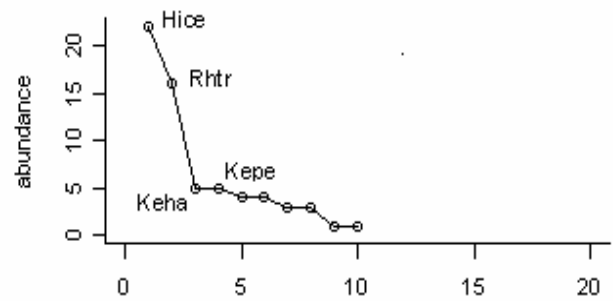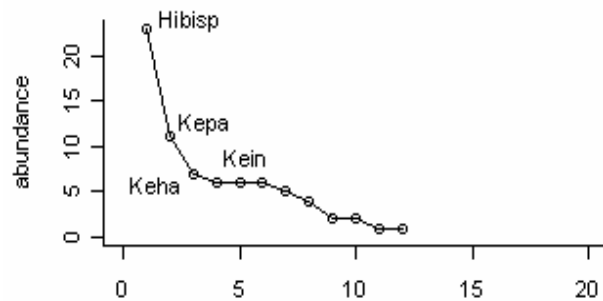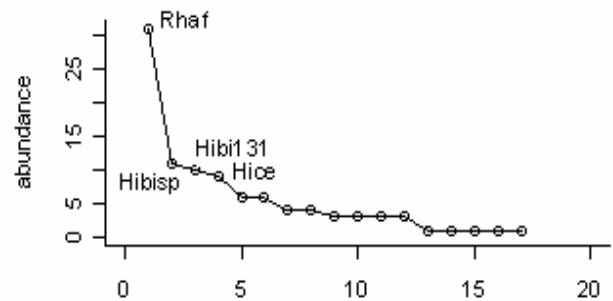
Figure 3.4 Species rank abundance curve with labels of the four most abundant species at six VJR size class in hectare (a) Class I - < 50 (b) Class II - 51–100 (c) Class III - 101–300 (d) Class IV - 301–700 (e) Class V - 701–1500, and (f) Class VI - >1500. See Table 3.2 for species codes.

A cluster dendogram (Figure 3.5) derived from a Sorenson's distance from the species presence/absence data shows that most sites are not clustered together. Only Class III and Class V share similar species, indicating that each site has a distinct bat assemblage.

The habitat variables measured and considered to represent the forest stand were mean dbh (cm) and height of the trees (m). Total basal area per hectare was derived from the tree dbh in each site to predict forest density. A high total basal area per hectare and a high mean dbh would indicate that the area has many big trees; which means that a lower number of trees per hectare would be expected. None of the habitat variables had significant correlation with bat abundance and Simpson's diversity index (Table 3.4).

3.3.2 Differences of bat community between distances

Class VI had the highest proportion of bat abundance within the VJR (Figure 3.6). Figure 3.7 shows that as size class increases, the population of bats 200 m away from the VJR increases too but the proportion of bats furthest away from the VJR (> 600 m) decreases. When the data from all VJRs were pooled together to see the dissimilarity between distances, the block Multiple Response Permutation Procedure (MRPP) (Table 3.5) shows that species composition within and distances away from the VJR were not significantly dissimilar ($p > 0.05$).
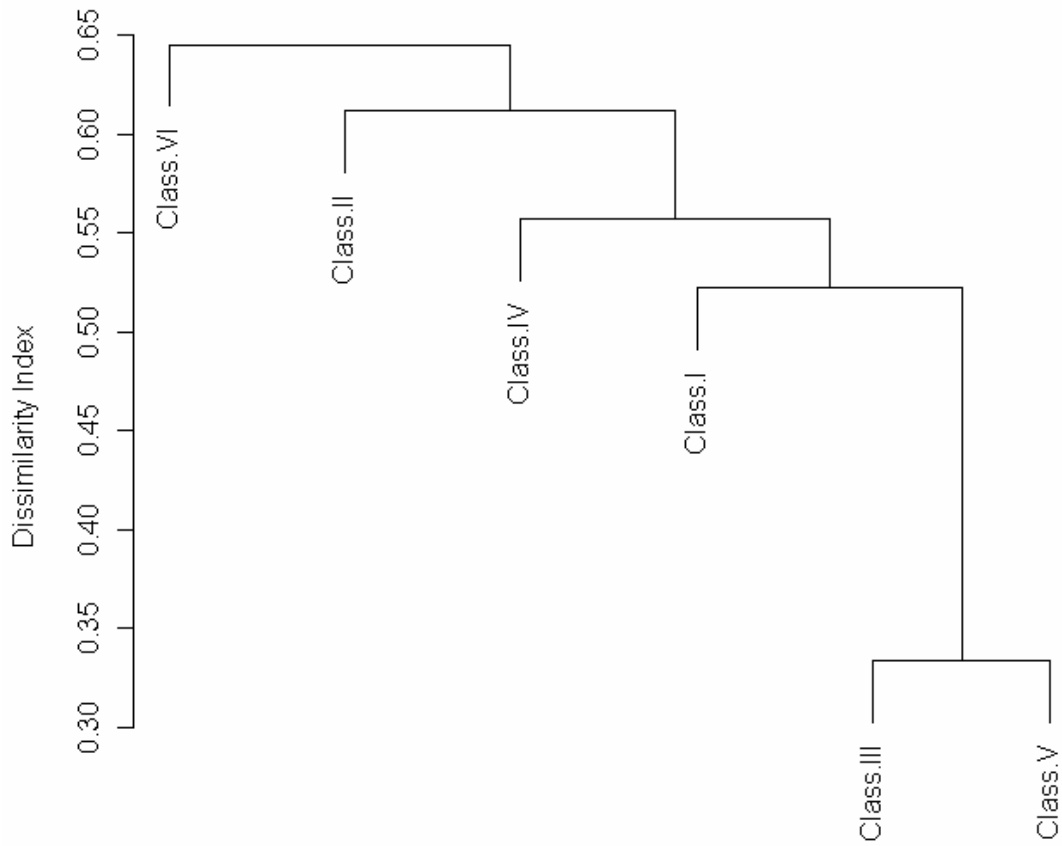
Figure 3.5 Cluster dendogram using Sorenson dissimilarity index of species presence-absence six size classes (in hectare) at the ridge (< 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI).

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Table 3.4 Pearson's correlation (r) of habitat variables with bat abundance and Simpson's Diversity Index (1-D).

|  | Mean Dbh | | Mean Height | | Total basal area | |
|---|---|---|---|---|---|---|
|  | r | p | r | p | r | p |
| Abundance | 0.3329 | 0.5191 | -0.0300 | 0.9550 | -0.3018 | 0.5610 |
| Simpson's Diversity Index (1-D) | 0.1919 | 0.7157 | 0.6082 | 0.2676 | 0.1820 | 0.7299 |
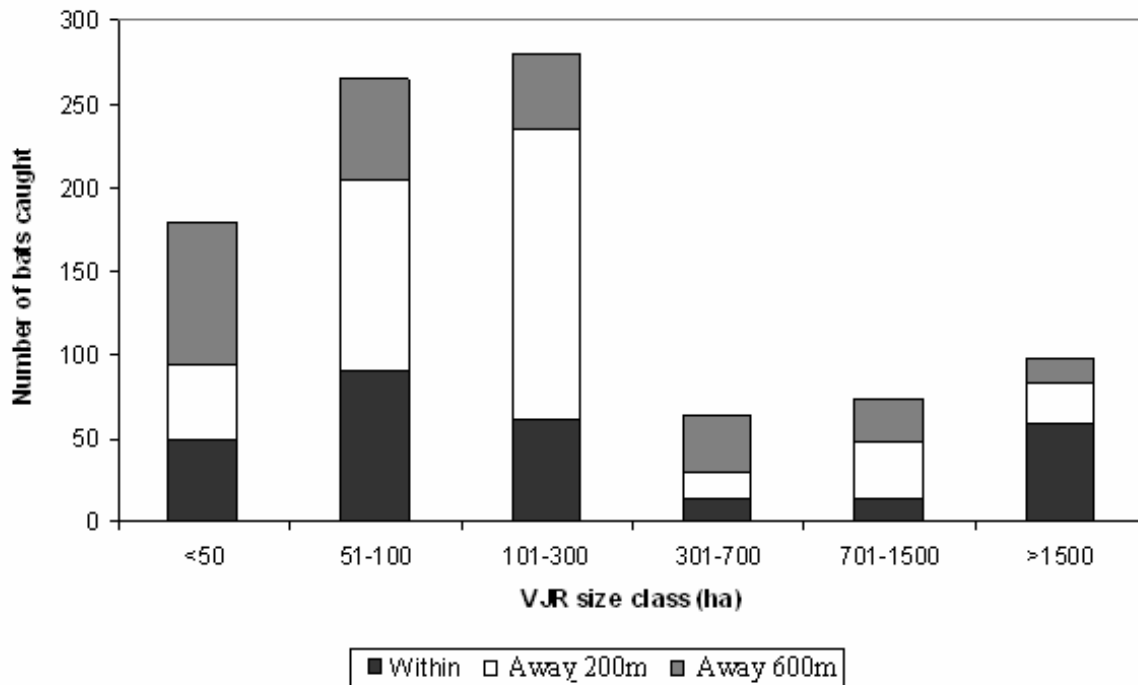


Figure 3.6 Number of bats caught within the Virgin Jungle Reserve (VJR), 200 m away and > 600 m away from the VJR in each size class in hectare (< 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 – Class VI).

Table 3.5 Block Multiple Response Permutation Procedure (MRPP) for comparison between species composition within and distances away from the VJR. Chance-corrected within-group agreement (*A*) describes within-group homogeneity. If all observed items are identical within groups, *A*=1, which is the highest possible value. If there is less agreement within groups than expected by chance, $A < 0$. The higher the *A* value the more identical the sites are in terms of bat communities. $p > 0.05$ indicates that the pair is dissimilar.

| Distances within VJR size compared | | | *A* | *p* |
|---|---|---|---|---|
| Within | vs. | 200 m away | 0.0072 | 0.8095 |
| Within | vs. | > 600 m away | 0.0086 | 0.9039 |
| 200 m away | vs. | > 600 m away | -0.0025 | 0.5002 |

To further analyze the species composition similarity, species that are classified as rare (< 5% of the population in each site) that may or may not have been captured due to various reasons, were excluded (Table 3.6). Hipposideridae is the only family that is present in all six size classes with *Hipposideros bicolor 131* and *Hipposideros bicolor* sp. present in all six sites. *Rhinolopus lepidus,* although present in four of the six size classes, only had a large population (≥ 5 %) in Class VI. Species from the Vespertilionidae family, *Glischropus tylopus* and *Myotis ridleyi,* were more habitat sensitive because they were only present in < 50 ha class and 701–1500 ha class respectively and were absent in the other classes.

Most of these dominant species were distributed without any relationship to their location within and away from the VJRs (Figure 3.7). The only difference is the proportion caught at these different distances. *Rhinolophus lepidus* had only a small percentage caught in traps placed 200 m away from the VJR. However, there were species such as *Glischropus tylopus* that was not caught in traps > 600 m away from the VJRs and *Myotis ridleyi* was only captured within the VJRs. Class II had a similar distribution regardless of distances within or away from the VJR

The distribution of species is further explained by a cluster dendogram derived from a Steinhaus distance (Figure 3.8). Clustering occurred mainly by size classes and not so much by distance, such as 200 m and > 600 m in Class V, Within and 200 m in Class II, Within, 200 m and > 600 m in Class I and Within and > 600 m Away in Class IV.

Table 3.6 Families and species that contribute ≥ 5 % to the population in at least one site size class are listed. Shaded values indicate site in which the species contributed ≥ 5 % to the population (< 50 – Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI).

| Family | Bat species ≥ 5% of the population | Proportion of individuals at each VJR size class (%) | | | | | |
|--------|------------------------------------|----------|-----------|------------|-----------|----------|------------|
| | | Class I | Class II | Class III | Class IV | Class V | Class VI |
| Vespertilioninae | *Glischropus tylopus* | 6.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Myotis ridleyi* | 0.00 | 0.00 | 0.00 | 0.00 | 5.41 | 0.00 |
| Hipposideridae | *Hipposideros bicolor 131* | 6.70 | 18.49 | 10.00 | 6.25 | 6.76 | 10.20 |
| | *Hipposideros bicolor 142* | 3.91 | 5.66 | 5.36 | 4.69 | 0.00 | 4.08 |
| | *Hipposideros bicolor sp* | 6.15 | 41.13 | 50.71 | 6.25 | 31.08 | 11.22 |
| | *Hipposideros cervinus* | 1.12 | 0.00 | 9.29 | 34.38 | 0.00 | 9.18 |
| | *Hipposideros larvatus* | 21.79 | 16.23 | 5.00 | 0.00 | 0.00 | 0.00 |
| Kerivoulinae | *Kerivoula hardwickii* | 10.06 | 2.64 | 2.86 | 9.38 | 9.46 | 3.06 |
| | *Kerivoula intermedia* | 2.23 | 3.02 | 3.21 | 0.00 | 8.11 | 3.06 |
| | *Kerivoula papillosa* | 11.73 | 2.26 | 0.71 | 0.00 | 14.86 | 3.06 |
| | *Kerivoula pellucida* | 0.56 | 2.26 | 1.79 | 6.25 | 0.00 | 1.02 |
| Rhinolophidae | *Rhinolopus affinis* | 0.00 | 1.13 | 2.14 | 0.00 | 8.11 | 31.63 |
| | *Rhinolopus lepidus* | 1.68 | 2.26 | 1.79 | 0.00 | 0.00 | 6.12 |
| | *Rhinolopus stheno* | 13.97 | 1.13 | 3.21 | 4.69 | 2.70 | 4.08 |
| | *Rhinolopus trifoliatus* | 4.47 | 1.13 | 1.07 | 25.00 | 8.11 | 6.12 |
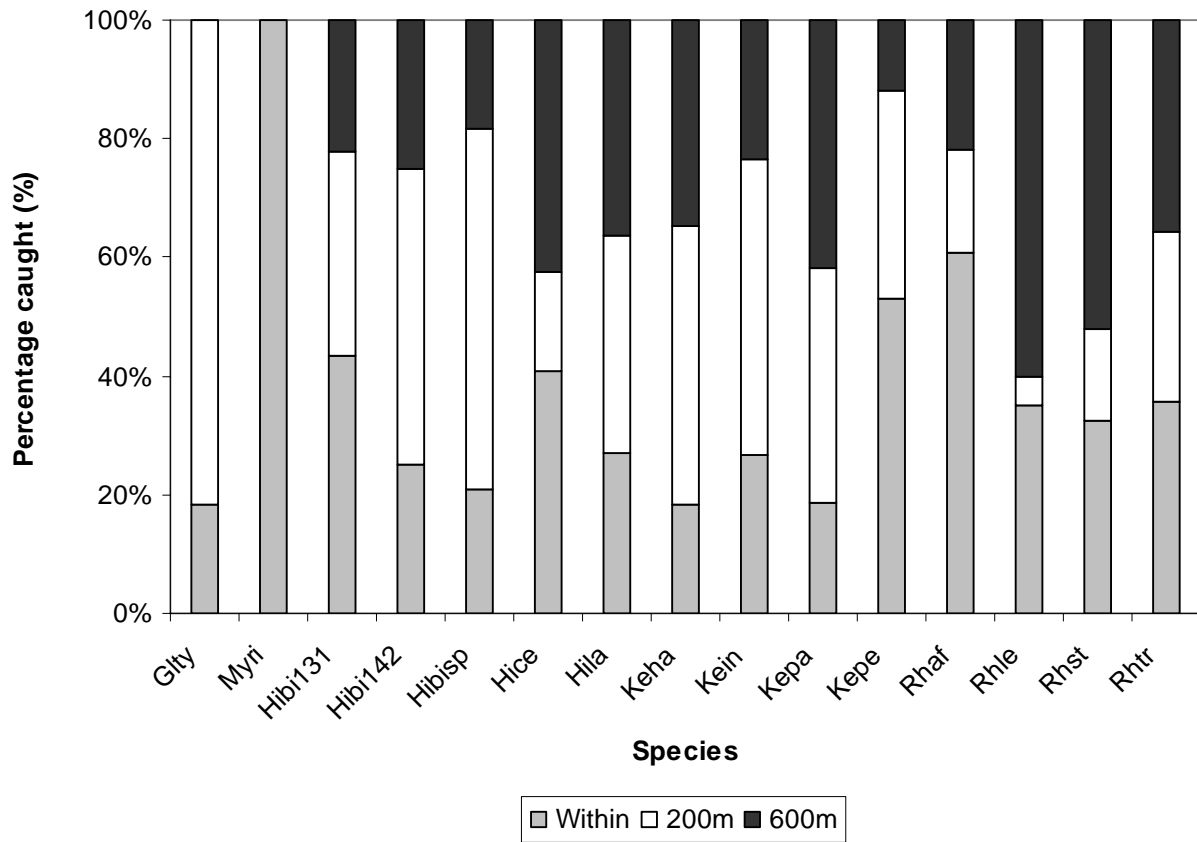
Figure 3.7 Species that contribute ≥ 5 % of the total population in each site and the proportion (%) caught within the Virgin Jungle Reserve (VJR), 200 m away and > 600 m away from the VJR. See Table 3.2 for species codes.
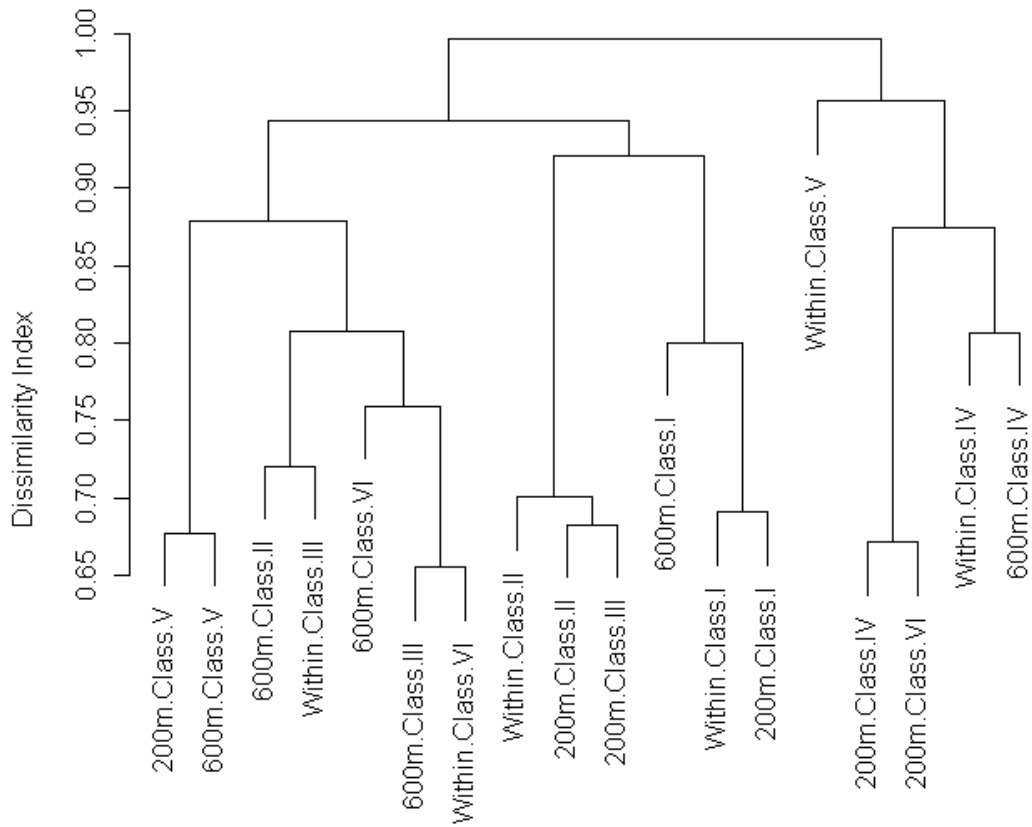
Figure 3.8 Cluster dendogram using Steinhaus dissimilarity index of dominant species proportion in six size classes (in hectare) at the ridge (50 – Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI).

The NMDS ordination graph (Figure 3.9) displays how these species are distributed with regards to distances within each VJR size class in terms of degree of similarity between them. Species depicted as closest to a site are expected to have a higher abundance in those sites (Kindt & Coe, 2005). *Kerivoula pellucida* is closest to Class IV because it was present in high abundance ($\geq 5$ %) within the VJR and absent outside the VJR. Most similar sites were closer together regardless of distance, indicating species composition is distributed according to site location rather than distances within a site. Species such as *Myotis ridleyi* are secluded as they were only present in one site.

3.3.3 Differences in habitat variables

Total basal area per hectare (Figure 3.10a) and mean tree height (Figure 3.10b) within and distances away from the VJRs are almost similar in Class I site. This reflects a similar habitat structure regardless of distance. The Class II and IV size class showed a higher total basal area per hectare and mean tree height in the 200 m away plots.
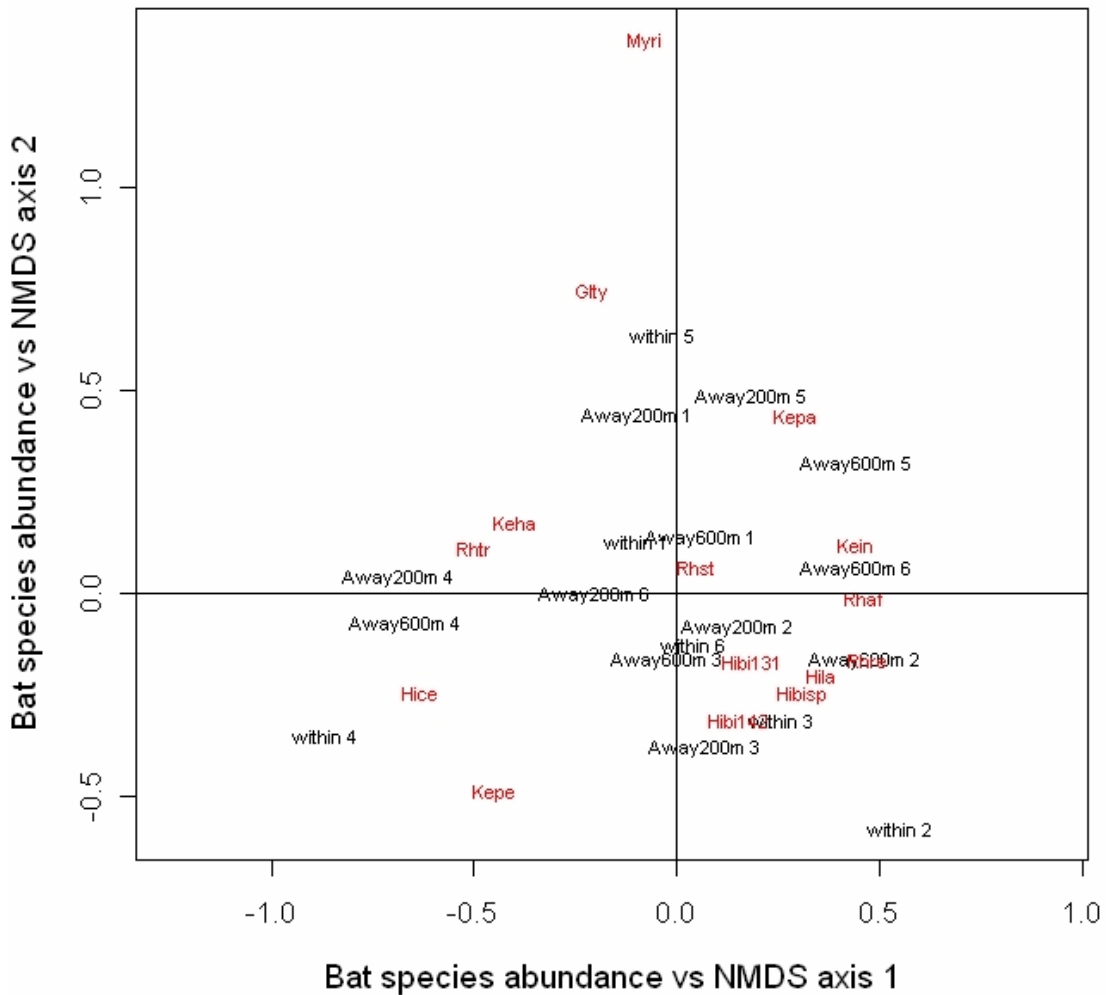
Figure 3.9 Non-metric multidimensional scaling (NMDS) of bat species abundance (of species ≥ 5 % of the population) and sites categorized as 'within' for within Virgin Jungle Reserve (VJR), 'Away200m' and 'Away > 600m' for traps at 200m and > 600m away from VJR, respectively. The numbers (1–6) indicate the size class (1 - Class I; 2 - Class II; 3 - Class III; 4 - Class IV; 5 - Class V; 6 - Class VI). Distances between sampling sites on the ordination reflect dissimilarity in bat species composition using Bray-Curtis coefficients. See Table 2.2 for species codes.
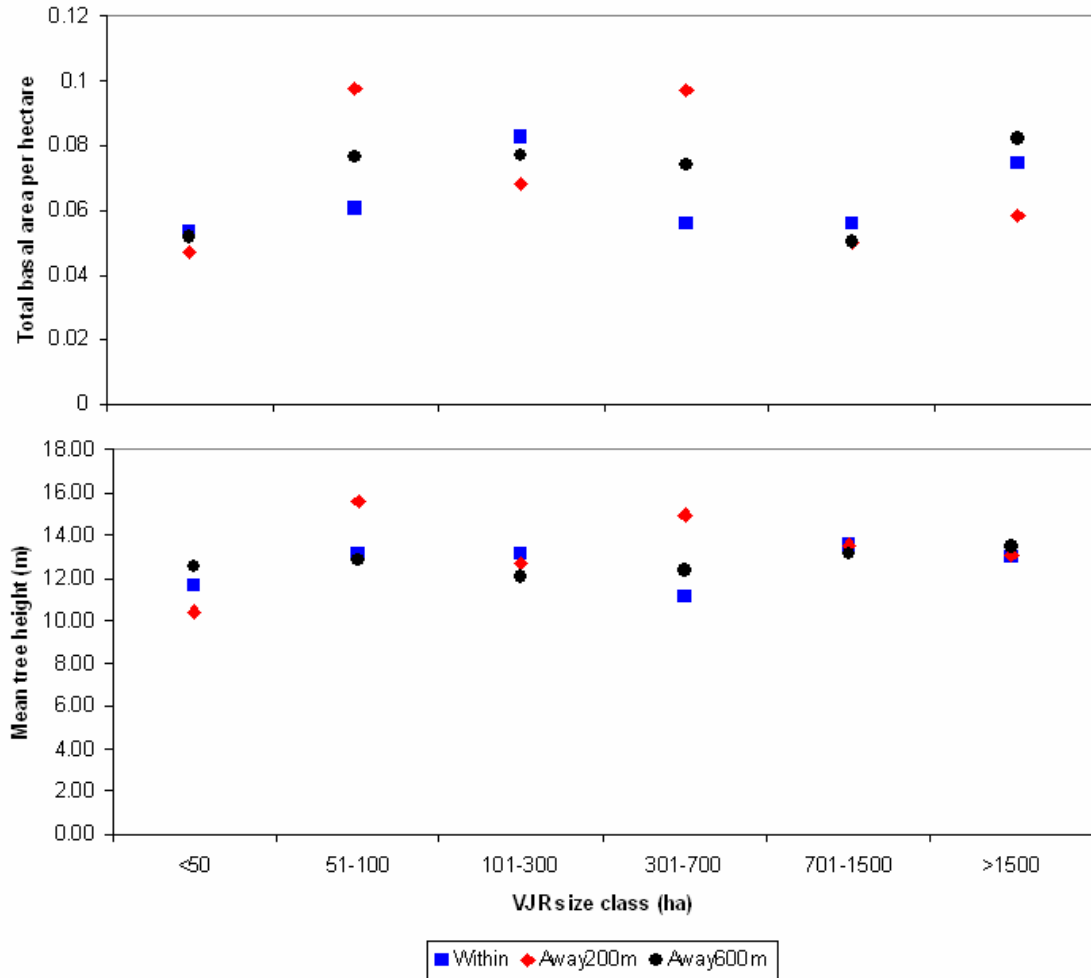
Figure 3.10 (a) Total basal area per hectare, (b) mean tree height (m) within the Virgin Jungle Reserve (VJR), 200 m and > 600 m away from the VJR at six sites (< 50 - Class I; 51–100 - Class II; 101–300 - Class III; 301–700 - Class IV; 701–1500 - Class V; >1500 - Class VI).

**3.4 DISCUSSION**

3.4.1 Bat assemblage between size classes

The results indicate that bat abundance did not increase as VJR size class increased. However there are two distinctive increasing trends of bat abundance with increasing size classes. The Class II (51–100 ha) and Class III (101–300 ha) size classes that had relatively high number of bat captures have similar elevational range of 200–500 m asl, but are located on either side of the main range (Titiwangsa Range). It is postulated that there may be other confounding factors besides VJR size class that are affecting this increasing trend. Besides size, habitat quality is also an important factor in a VJR (Laidlaw 1994). Further to this, Struebig *et al*. (2008) concluded that a fragment area explains the majority of variation in total bat abundance. Low abundance may result from avoidance of fragmented habitats that are of low-quality (surrounded by urban development) as opposed to high quality (continuous forest) (Henry *et al*., 2007). The VJR in Class I is located at the centre of the forest reserve. According to Laidlaw (1994), disturbed VJRs are more likely to be found at the edge of the forest reserve as opposed to the undisturbed VJRs that are usually found at the centre of the forest reserve. Semangkok FR (Class I) located 60 km to the North of Kuala Lumpur (Kominami *et al*., 2000) is adjacent to a two lane Kuala Kubu Bharu-Fraser Hill trunk road. According to Kanuch and Kristin (2005), higher diversity was found on the more isolated habitat. Besides the road, Semangkok FR is isolated with no signs of disturbance or encroachment. Kerth & Melber (2009) showed that motorways can restrict habitat

accessibility for bats which very much depends on the species' foraging ecology and wing morphology. However, there is not much information on species home range to test the significance of roads on the species found in Semangkok FR.

On the other hand, while Gunung Angsi FR in Category 1 and Berembun FR in Category 2 had similar surroundings of human settlement, Gunung Angsi FR had much more disturbance from encroachment, farming and rubber plantations surrounding it but it had the highest bat capture. These disturbances surrounding the Gunung Angsi FR may have opened opportunities for bats to feed because spatial and temporal activities of foraging bats often likely correspond with the distribution and abundance of insects (Lee & McCracken, 2004). Fruiting trees in the surrounding villages may have attracted herbivorous insects which then attract insectivorous bats (Fletcher *et al*., 2004). Swystun *et al*. (2001) suggested that increased insect densities would attract foraging bats to residual tree patches. Although bats were captured within the forest, the high abundance of bats indicate availability of roosting ground within the forest as well as food resources inside and at the forest edge, to which they can commute to in a short distance. However this study did not attempt to examine the relationship between bat and insect abundance.

Chao estimates showed that the largest size class, Berembun FR was sampled adequately with equal effort as compared to other classes. Therefore it is surprising to find that smaller size classes like Gunung Angsi FR and Ulu Gombak FR were under sampled (< 90 % of richness estimator) based on the same estimates. In fact Chao estimated a relatively high number of species for these two sites. This could mean that these areas are

highly diverse with rare species that may not be detected as often as other species. This could be due to the lack of trapping effort (Mohd. Azlan *et al*., 2005; Anwarali *et al*., 2008) or the type of sampling technique administered (Kingston *et al.,* 2000). This can only be confirmed by further increasing the sampling effort.

A large portion of the bats captured in Class II and Class III consisted of *Hipposideros bicolor* sp*.* This most probably occurred because the traps were coincidentally placed on their flight paths. The study showed a decrease in Simpson's diversity index between Category 1 (0–300 ha) size classes. There seems to be an important effect on mammal communities in this size range. A study by Laidlaw (1994) showed a sharp increase of mammal diversity (not including bats) from 70 ha to 164 ha.

Factors that might influence the abundance and diversity of bats in the study sites have been presented, among which are VJR size, its location and the disturbance that surrounds it. But within the bat community, the most important aspect to focus on is the species themselves. All forests are important habitats for bats, but the composition of the bat community within a forest conveys a lot about the value and importance of the forest for the conservation of bats. As mentioned in previous paragraphs, high abundance can sometimes be contributed by a single species as a result of traps being coincidentally placed in the foraging or commuting pathways of bats that occur and forage in large groups. But high abundance of certain species groups such as tree/foliage roosting species indicates that a site is undisturbed (Struebig *et al*., 2009). Therefore, looking at

the species composition within each site will help shed more light on the importance of the VJR size class to the bat community.

The Hipposideridae family was well represented in terms of abundance with *Hipposideros bicolor 131* and *H. bicolor* sp. representing $\geq 5$ % of the total population in all six sites. This is most probably due to their gregarious roosting habits. These species are highly versatile, meaning they can either roost in large numbers under boulders or rock crevices within the forest or in caves (Thabah *et al.*, 2006). And because they are so adaptable, they are found in most forests (Struebig *et al.*, 2009). Their roosting requirements would seem to be directly correlated to topography rather than vegetation, making them less vulnerable to anthropogenically-induced habitat change (Sheema, 2006). Stuebig *et al*. (2008) indicated in his study that *H. larvatus,* a primarily cave-dwelling species, was in greater abundance in larger fragments ($\mu = 5410$ ha) compared to in smaller ($\mu = 70$ ha) and more isolated sites. In this study however, *H. larvatus,* was present in high abundance ($> 5\%$) in the smaller VJR size classes (Category 1) regardless of distances from the VJR and was completely absent in the larger size classes (Category 2). It is surprising that there were no captures of *H. larvatus* in larger fragments such as Class VI. Only Class III had high captures ($> 5\%$) of Hipposiderid bats suggesting that the area may have included a system of caves or rock boulders suitable for roosts.

On the other hand, it is interesting to observe *Rhinolophus trifoliatus,* a forest specialist, although present in many sites, were even more abundant ($> 5$ %) in the larger size classes, similar to the study by Streubig *et al*. (2008). This species have small home ranges of $< 100$ ha and do not extend beyond forest boundaries (Fletcher, 2006). They are

often found roosting alone or in pairs under leaves (Kingston *et al.*, 2006). Their roosting behavior and dependence on foliage could render them vulnerable to human activities resulting in habitat loss (Sheema, 2006). However in this study, *R. trifoliatus* was found evenly distributed regardless of distances from the VJRs. This may be a good indication that forest specialists such as this species have been able to re-colonize the surrounding logged-over forests and thus may be of lesser extinction risks due to logging (Fletcher, 2006).

This study also recorded captures of two rare species that are incidentally the only two species from the family Vespertilioninae that were caught. Although *Glischropus tylopus* or commonly known as the bamboo bat was caught in only one site (Class I), it was captured in high abundance (>5%). This species is often associated with bamboo in forested areas (Kingston *et al*. 2006). *Myotis ridleyi* however, was caught only in Class V. Not much is known about its habitat ecology besides a record by Medway (1983) indicating the presence of *M. ridleyi* in primary forest and in caves far from the forest. Kingston *et al*. (2006) did indicate that it is an uncommon species and one of the few from its family that has adapted to foraging in the forest interior. The significant contribution of these two species (*G. tylopus* and *M. ridleyi*) to the population in those sites may indicate that there are certain criteria that these species thrive on. *Myotis ridleyi* is listed as Near Threatened (NT) under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List (IUCN, 2009). Unfortunately not much is known at present about their habitat ecology to make any precise recommendations for conservation.

Many species that are listed as Near Threatened (NT) and Vulnerable (VU) are tree/foliage roosting species. Species that are of greatest concern are NT species like *Phoniscus atrox*, *R. sedulus*, *Nycteris tragata* and VU species such as *Murina rozendaali* which were not only present in low abundance but were found primarily in only one of the six study sites. However there were tree/foliage roosting species such as *K. pellucida* and *K. intermedia* which are listed as least concerned (LC) were present in most of the study sites but not in high abundance. These tree/foliage roosting species are very vegetation-dependant as opposed to topography-dependant species like cave-roosting bats, whereby restricting their occurrence around viable roosts (Struebig *et al.*, 2009). According to Fletcher (2006), hollows in trees with a dbh of 55 cm and above, which also falls within the cutting limit of the Selective Management System (SMS) felling, is the preferred roosting site by *Rhinolophus sedulus*. Roosting ecology and roosting behaviour such as these are important factors in determining both local abundances and commonness which may also influence their vulnerability to human activities (Sheema, 2006).

In terms of habitat variables, Class I and Class V had similar dbh and total basal area in the three plot distances. Although these variables were not significantly correlated with bat abundance and diversity, there is one particular species that was very common ($\geq 10$ %) in those two size classes. *Kerivoula papillosa* is a forest specialist that typically prefers to roost in the hollows of small trees (Kingston *et al*., 2006). These specialized roosting requirements might be an important factor influencing the abundance of this species. Therefore any disturbance such as logging may be a potential threat to this

species that has adapted well to the structure of a primary forest. Other studies have also made similar observations of species-specific roosting requirements. According to Lee and McCracken (2004), the restricted occurrence of bats in Central Indiana may be due to the lower availability of suitable roosting sites in the northern quarter of the states. Some bats, like the southern yellow bat, only use dead palm fronds of the Texas sabal palms for roosting (Mirowsky, 1997). This kind of specificity shown by bats can also be taken into consideration when administering forest management practices by conserving areas known to harbour suitable roosting sites.

3.4.2 Bat distribution between distances

According to Ewers and Didham (2006), the portion of a fragment that is altered by external conditions is termed edge habitat, while unaffected portions are called core habitat. The distribution of species abundance contains the maximum amount of information about a community's diversity (Magurran, 2004). Therefore, investigating the distribution of bats within each site would help shed some light on how bats are distributed within a VJR (core) and the secondary forest that surrounds it (edge). Again, when looking at abundance, there seems to be two distinctive classes at distances of > 600 m away from the VJR. As the VJR size class increases, the number of bats captured at traps placed furthest from the VJR (> 600 m) decreased as opposed to the total bat abundance of Category 1 (0–300 ha class) and Category 2's (301–1500 ha class) increasing trend mentioned in the results. This indicates that the size of the VJR has no direct effect in increasing the population of bats > 600 m away from the VJR boundary.

There were many other species such as *Glischropus tylopus* and *Myotis ridleyi* which were not only restricted to certain sites but were only found within the VJR. This is evident in the state of Washington in the United States of America where all seven *Myotis* species are three to six times more abundant in old-growth than they were in disturbed forests. Similar observations were recorded in Oregon (Thomas, 1992). A noteworthy difference between the inside and outside of the VJRs would be the vegetation. The Selective Management System (SMS) was introduced in 1978, and has since been the main forest management system used (Awang Noor, 1997). This system uses a 30-year cycle, meaning that the forest is expected to have been regenerated after 30 years with 30 to 40 m$^3$ of Dipterocarp trees per hectare (Jabatan Perhutanan Semenanjung Malaysia, 1997). In a study conducted in Sabah, Phillips (1986) revealed that the reduction of basal area due to selective logging is approximately 20%, but this is unlikely to have a prolonged effect on the growth of the residuals stands. Sites like Semangkok FR did not show much difference in the total basal area within the VJR and the adjacent logged-over forests. Forests which have regenerated after heavy logging are likely to have big trees with relatively shorter trunks (Whitmore, 1984), but the trees in the trapping area 200 m away from the VJR in Class II and Class IV, were recorded to be taller than those within the VJR. The total basal area within the VJR in these two sites, were also lower compared to that in the trapping area away from the VJR. This either means that the logging was done in a sustainable manner and the forest has therefore regenerated very well or that the gaps created by logging had provided opportunities for pioneer species to succeed creating a floristic shift (Whitmore, 1990). The sampling method that was used in this study focused on understorey bats. Therefore other bats that

might be more affected by tree height and canopy structure such as those that utilize the canopy levels, was not sampled adequately. This suggests that vegetation might not be the sole factor that is restricting the distribution of these bat species in the adjacent logged-over forests. There might be other contributing factors such as insect availability; topography (Lloyd *et al.*, 2006) and roost availability (Fenton, 1982; Crampton & Barclay, 1996; Mirowsky, 1997; Lee & McCracken, 2004; Fletcher, 2006), which may provide a more convincing explanation for species distribution.

Despite the specific roosting requirements and sensitivity toward logging, *K. papillosa* was found in both the primary forest (VJR) as well as the surrounding logged-over forest. The forest conditions outside the VJR were not correlated with species abundance, which indicates that the logged-over forest did not have an adverse effect on the bat population. The NMDS ordination also reveals that the communities in each site are more similar between distances rather than between size classes. This again indicates that the location of the forest fragment influences assemblage-level abundance, species richness and composition (Struebig *et al.*, 2009). According to Whitmore (1984), most species survive logging by persisting in un-logged pockets from which they re-establish, so long as such pockets occur within their dispersal range or rather in this case, their home range.

This study concludes that bat abundance and diversity does not increase with increasing VJR size class. There were uneven distributions of species abundance among sites, similar to the results obtained by Kingston *et al.* (2003a). However it has been shown that each forest site exhibits distinctive bat assemblage, regardless of its VJR size. Based on

the results of this study, it is postulated that there may be other confounding factors such as forest surroundings, topography and anthropogenic disturbances that may influence the type of bat assemblage in a forest. Different species have different requirements that may enable them to increase their population successfully. Multiple traits correlated with roosting ecology such as vagility, population size and foraging behavior (Altringham, 1999) might help in identifying the reason behind the presence or absence of bat species in a particular area. This is because roosting requirements of bats are determined by physiological demands, predation pressure, sociological considerations or morphology (Findley 1993). Bats spend half of their lifetime in their roost environment (Kunz, 1982), therefore limited roost opportunities may affect the diversity of bats (Fenton, 1982) and are likely to have a major impact on reproductive success and reduced fitness. Further research on patterns of habitat use for each bat species will help provide a more in-depth analysis for particular species rather than general information on multiple species (Miller *et al.*, 2003; Patriquin & Barclay, 2003). Increased understanding of population density and habitat requirements will be of great value and significance when administering forest management practices (Francis, 1990), because forest managers will be able to make better and more informed decisions for the conservation of vulnerable and threatened species.

There were species that are listed as threatened and vulnerable in the IUCN Red List that were only found within the VJRs regardless of their size, but not much is known about the habitat ecology and factors that limit the distribution of these species (Kingston *et al.*, 2003a). VJRs may be the last remaining natural remnant holding our biodiversity.

Identifying their internal and external threats as well as the endangered species within them (Borhan & Cheah, 1986) is extremely important for the survival of their inhabitants. The principle of sustainable forest management is to harvest the natural forest resources without compromising the social and ecological value of the forests (Sist *et al*., 1998 cited in Seng *et al*., 2004). Therefore in order to ensure the maintenance of forest dynamic processes, a greater conservation effort should be directed towards the protection of old-growth remnant patches, regardless of fragment size (Faria *et al*., 2009).

# CHAPTER 4

## EFFECTS OF SPATIAL DIVERSITY ON SPECIES COMPOSITION OF INSECTIVOROUS BATS

### 4.1 INTRODUCTION

Biodiversity varies across space and time (Campos & Isaza, 2009; Vences *et al.*, 2009), and is not random (Rahbek, 1997). The complexity within a tropical forest ecosystem creates various aspects that contribute to changes in species composition (Sundarapandian & Swamy, 2000). This often presents the difficult task of determining the driving force behind the changes. He *et al.* (1996) suggested that studying spatial organization would help understand the mechanisms that generate diversity within the tropical rainforest.

### 4.1.1 Forest topography

Spatial diversity is defined here as variations in topography (diversity) within a certain elevation (space). Forest topography and elevation has an influence on the distribution of trees (Clark *et al.*, 1999; Abdul Rahman *et al.*, 2002). They regulate seed, water and materials redistribution, which in turn creates variety in tree density and canopy cover within a forest (Parker, 1982). This directly or indirectly affects organisms associated with trees (Moning *et al.*, 2009) because trees are seen as proxy for overall biodiversity

(Ashton, 2008). Most plant species do not extent throughout the whole geographic range of their habitat (Whitmore, 1984), because within a rainforest formation it is common for some species to be associated with different topographic situations, especially with valleys or ridge crest (Whitmore, 1990). The ecotone between the lowland and hill forest is clearly visible through the replacement of many lowland species by the hill species such as the hill-ridge species, *Shorea curtisii*. This species flourish well in the ridges where soils are infertile and have low water holding capacity (Whitmore, 1984). Like *S. curtisii* many species are drawn to certain topographic features of a forest.

Among the many factors influencing tree distribution and tree growth in the tropics are soil and temperature regimes (Russo *et al.*, 2005; Xu *et al.*, 2008; Griffiths *et al.*, 2009; Silk *et al.*, 2009; Wan Juliana *et al.*, 2009; Wang *et al.*, 2009). Variations in plant distribution associated with topographic characteristics such as elevation and slope aspect (de Castilho *et al.*, 2006) are closely associated with local climate e.g. precipitation and evaporation (Costa *et al.*, 2005; Griffiths *et al.*, 2009). These hierarchical factors determine the microclimate experienced by any organism within a forest (Jennings *et al.*, 1999) thus creating variability within the forest, and different variables affect individual organism differently.

4.1.2    Bats and the forest

The tropical region supports the highest diversity of bat fauna known (Kunz, 1982), and are among the most species rich and ecologically diverse of all mammals (Kingston,

2009). This makes it difficult to address the community as a whole. The various food guilds, foraging pattern, echolocation call and wing morphology creates diversity within the bat taxon. So instead of addressing the entire bat community, this study focuses specifically on forest-interior insectivorous bat species. They are good study subjects because many forest interior bats are sedentary (Fleming *et al*., 1977). They have small home ranges and thus are usually caught close from their roost site.

The forest plays a crucial role for forest-dwelling bats not only for food but also for shelter (Findley, 1993; Patriquin & Barclay, 2003; Henderson *et al.*, 2008). The complexity of their echolocation call and their wing morphology (Crome & Richards, 1988; Vaughan *et al*., 2000; Kingston *et al*., 2003b) for navigation very much depends on the forest structure. This is due to various reasons that are based on their diverse habitat that varies according to species, and an ever changing forest landscape (Bontadina *et al*., 2002; Patriquin & Barclay, 2003; Estrada *et al*., 2006; Lloyd *et al*., 2006; Henderson *et al*., 2008; Meyer *et al*., 2008). Wing morphology and echolocation data reflect strategies of resource use (Arita & Fenton, 1997; Schmieder, 2009). These features are more apparent for Old World bat communities, because there are more morphological overlaps within the Neotropical bat community compared to the Paleotropics (Heller & Volleth, 1995).

4.1.3   Spatial effects

It is evident that there are differences in foraging activity within a 1,000 m elevation change (Grindal & Brigham, 1999). However, smaller spatial scales have become more important in determining spatial distributions (Tylianakis *et al.*, 2006) and extinction rate for terrestrial species (Gaston & Fuller, 2009). To put this in a clearer perspective, it is as if we know the difference from the top of a hill to the foothills but very little of what happens in between. There has been many bat studies conducted in the lowland forest of Peninsular Malaysia (Kingston *et al.*, 1999; Kingston *et al.*, 2000; Kingston *et al.* 2003a, b; Fletcher, 2006: Thabah *et al.*, 2006), but not many in the hill forest (Fletcher *et al.*, 2004). The effects of habitat and distance on bat distribution in Malaysia can be explored further. These effects may be more apparent in hill forests due to factors such as elevation, topography and soil regimes that influences species stockings (Cedergren *et al.*, 2002), structure, growth rates (Appanah & Weinland, 1990) and distribution of trees (Whitmore, 1984).

There are many spatial and temporal activities of foraging bats that often correspond with various factors such as the distribution and abundance of insects (Lee & McCracken, 2004), combination of vegetation characteristics like forest strata, height, and cover of trees (Estrada *et al.*, 2006) and topography (Lloyd *et al.*, 2006). Smaller and more maneuverable species are less affected by tree density than the larger, less maneuverable species (Patriquin & Barclay, 2003). Habitat selection also differs depending on species due to resource partitioning (Arlettaz, 1999) for reduced competition and prey selections

(Roverud *et al*., 1991; Sierro & Arlettaz, 1997; Dodd *et al*., 2008). According to Francis (1990), patterns of habitat use will help establish population densities and habitat requirement for bats. There is however limited data upon which to base habitat management for forest-roosting bats (Miller *et al*., 2003; Kingston *et al*., 2003a). With vast niche diversity among the species, bats are forced to create niche partitioning. Micro habitat selection such as topography may help explain these diversity patterns of bat communities within the forest.

It is hypothesized that topography affects the distribution of forest interior bats. This study was carried out to determine the species composition of forest interior bats and the effects of ridge, slope and valley on their foraging preference. The possible drivers of variation in the ridge, slope and valley is examined by assessing the habitat structure of these three topographic classes located between 300–500 m apart within a hill forest. The assumption is based on the understanding that species tend to be most abundant in their environmental optimum (Fletcher *et al*., 2004; Fukami & Wardel, 2005).

**4.3 METHODS**

4.3.1 Study sites

The study was conducted between September 2007 and June 2009 at six different sites selected throughout Peninsular Malaysia. Certain criteria were adopted during the site selection process, they were: 1) the forest type was restricted to hill dipterocarp forest, 2) at elevations between 100–700 m asl (Table 2.1), and 3) with granite geological structure. It was impossible to get the plots distributed in the various sites to fall on a ridge, slope and valley topography perfectly; therefore some valley sites had to be taken below the elevations of a hill forest (< 300 m) (Table 4.1). Nevertheless, there is no sharp boundary between these forest types but rather a gradation of one into the other.

Table 4.1 Details of selected forest sites in Peninsular Malaysia (see Appendix C).

| Forest Reserve (FR) | State | Elevation of transects (meters above sea level) |
|---|---|---|
| Semangkok | Selangor | 400–600 |
| Gunung Tebu | Terengganu | 60–450 |
| Gunung Angsi | Negeri Sembilan | 200–600 |
| Ulu Gombak | Selangor | 450–670 |
| Kledang Saiong | Perak | 200–550 |
| Berembun | Negeri Sembilan | 245–610 |

4.3.2 Sampling design

In each site, nine 300 m transect lines were set up. Transects were distributed based on topographic maps of the sites. One sampling unit consist of transects on a ridge, slope and valley. Each study site has three units, meaning each site has three replicates. Each sampling unit is parallel to one another and is orientated perpendicular to the slope. They are positioned to capture the maximum variation in topography. A ridge is defined in this study as upper slope with an almost flat surface. A slope is defined as the area 100–300 m between the ridge and valley. A valley is the lower portion of the hill where the topography is almost flat, and often has streams flowing through. Transects in each study site were established 200–500 m apart.

Sampling was restricted to insectivorous bat species that are readily captured in the forest under-storey. Three four-bank harp traps (Francis, 1989) (ca. 2 m width and 3 m height) were set up along each transect for three consecutive nights, with each trap at least 50–75 m apart. They were set up approximately 1 m above ground level on clear pathways with trees and undergrowth on either side as well as above the harp trap. Each night nine traps were set up on three transects which are on the ridge, slope and valley respectively. They were moved to the next three transect lines on the fourth day (Francis, 1989). A data-logger, HOBO$^{®}$, was also placed on each transect to measure temperature and humidity every 30 minutes throughout the trapping period.

4.3.3 Field Sampling

Captured bats were held in catch bags before biometric data such as forearm length and weight were obtained. The forearm length measured to 0.1 mm with a caliper (Bontadina *et al*., 2002). Wing bands were placed on the right forearm for females and left forearms for males to account for recaptures. Species were identified using Payne and Francis (1997) and Kingston *et al*. (2006). All bats were released after required information was gathered.

4.3.4 Habitat survey

To examine the possible drivers of observed variation in bat species diversity between transects, a habitat survey was conducted. A 20 x 80 m plot was established parallel to each transect (Figure 4.1). The baseline of the plot (80 m) was laid out parallel to the slope along a constant compass bearing. Each 20 x 80 m plot was subdivided into 20 x 20 m subplot and further subdivided into 10 x 10 m quadrates. All perpendicular lines were positioned up slope of the baseline. Within each plot, the diameter at breast height (dbh) (diameter at 1.3 m or diameter above buttresses) of trees $\geq 5$ cm were measured with a diameter tape. All trees $\geq 5$ cm dbh were measured for height using a laser tree height measurer and measuring pole. Height here is to give a picture of the tree strata or foliage height in the plot (Whitmore, 1984).
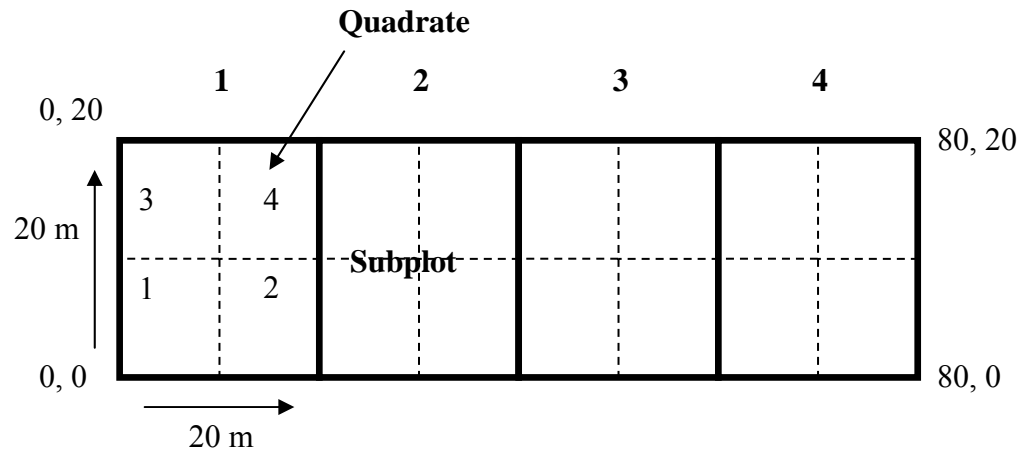
Figure 4.1 Sampling plot for habitat survey established at each sampling site.

4.3.5 Statistical analysis

The total number of bats caught and species identified were compared across ridge, slope and valley. A species rank abundance curve was displayed to observe the species composition at each topographic class. Alpha diversity derived from Simpson's diversity index (Simpson, 1949) and Pielou's evenness (Pielou, 1966) was compared for all sites.

To estimate the number of species at each site and to compare them to those captured, an extrapolated species richness using Chao estimator was derived. Sampled species richness was then divided by each estimator for each topographic class to calculate the percentage of total richness estimated by Chao (Tylianakis *et al*., 2006).

A block Multiple Response Permutation Procedure (MRPP) was used to show the differences in the bat community between different topographic classes of each site (Biondini *et al*., 1985; Mielke, 1984). It is a nonparametric multivariate test of differences between groups based on distance matrix (McCune & Grace, 2002). To analyze the differences of species composition between the topographic classes, a distance matrix was calculated using Sorenson distance for species presence/absence.

Non-metric multidimensional scaling (NMDS) is the most generally effective ordination method for ecological community data (McCune & Grace, 2002). It is used here on each sample species space in relation to topographic class (Struebig *et al.*, 2009). This method will display the association of each species to the topographic classes.

Basal area within each site was calculated from the dbh of each tree to estimate the density between and within sites. Basal area provides a good description of the forest because it is more closely proportional to leaf area and foliage mass (McCune & Grace, 2002) and it may be a better indicator for monitoring the extent of relative disturbance levels in the site (Seng *et al.*, 2004). A distance matric was calculated using Steinhaus index for tree height and basal area at each topography class of each site; this was done to observe the dissimilarities between the habitat structures. To test for the effect of vegetation on each topographic class, a Generalized Linear Model (GLM) with a Poisson distribution was done to see the influence of habitat variables (tree height and basal area) on each topographic class. A Poisson distribution was chosen based on the assumption that habitat variables were randomly distributed. Pearson's correlation test was done to look at the relationship between the habitat variables and local climate (temperature and humidity).

To analyze the differences in species composition between topographic classes, a distance matrix was calculated using Steinhaus distance for proportion of species that contributed > 5 % to the total bat abundance. In order to verify the relationship between species composition (ecological distance) and habitat variables (environmental distance), a Mantel test was done using Steinhaus distance (Kindt & Coe, 2005).

The software use for these analyses is R Statistical computing (R Development Core Team, 2009).

**4.4 RESULTS**

4.4.1 Bat species composition in relation to topography

A total of 958 individuals of 27 insectivorous bat species (Table 4.2) were captured over 486 trap nights. The highest abundance of bats were caught in the valley (53.86 %) (Figure 4.2). With 26 species, the valley was also the highest in species richness. The ridge and slope however had almost similar number of species with 20 and 19 species respectively.

More than 90 % of the species estimated by Chao richness estimator were captured in all the three topographic class. The steepness in the species rank abundance curve for each topographic class was contributed by one particular species, *Hipposideros bicolor* sp. However, the shallower slopes (straight line) at the tail of the curve indicate high evenness among the remaining species (Magurran, 2004) (Figure 4.3). This is further depicted in the Simpson's (1-D) diversity index and Pielou's evenness (Table 4.3). The low Simpson index in the valley indicate that although the valley was rich in species they were not highly proportionate in abundance and are thought to be less diverse. Figure 4.4 displays the proportion of each species caught in the ridge, slope and valley. Although there were species found only in the valley (100 %), the table below the graph indicates that they were low in counts ($\leq 5$ individuals).

Table 4.2 List of bat families and species present at the ridge, slope and valley across six sites in Peninsular Malaysia.

| Family | Species | Codes | Topography | | | Ensemble |
|---|---|---|---|---|---|---|
| | | | Ridge | Slope | Valley | |
| Hipposideridae | *Hipposideros bicolor 131* Temmninck | Hibi131 | ● | ● | ● | C/B |
| | *Hipposideros bicolor 142* Temmninck | Hibi142 | ● | ● | ● | C/B |
| | *Hipposideros bicolor sp* Temmninck | Hibisp | ● | ● | ● | C/B |
| | *Hipposideros cervinus* Gould | Hice | ● | ● | ● | C/B |
| | *Hipposideros larvatus* Horsfield | Hila | ● | ● | ● | C/B |
| | *Hipposideros sabanus* Peters | Hisa | ● | ● | ● | T |
| | *Hipposideros galeritus* Cantor | Higa | | | ● | C/B |
| Rhinolophidae | *Rhinolophus stheno* Andersen | Rhst | ● | ● | ● | C/B/T |
| | *Rhinolophus lepidus* Andersen | Rhre | ● | ● | ● | C/B |
| | *Rhinolophus sedulus* Andersen | Rhse | ● | | | C/T |
| | *Rhinolophus trifoliatus* Temminck | Rhtr | ● | ● | ● | T |
| | *Rhinolophus affinis* Horsfield | Rhaf | ● | ● | ● | C/B |
| | *Rhinolophus luctus* Temminck | Rhlu | ● | ● | ● | C/B/T |
| | *Rhinolophus pusillus* Temminck | Rhpu | | | ● | C/B |
| Murininae | *Murina suilla* Temminck | Musu | ● | ● | ● | T |
| | *Murina cyclotis* Dobson | Mucy | ● | ● | ● | T |
| | *Murina rozendaali* Hill and Francis | Muro | ● | | ● | T |
| Kerivoulinae | *Kerivoula papillosa* Temminck | Kepa | ● | ● | ● | T |
| | *Kerivoula hardwickii* Horsfield | Keha | ● | ● | ● | T |
| | *Kerivoula pellucida* Waterhouse | Kepe | ● | ● | ● | T |
| | *Kerivoula intermedia* Hill and Francis | Kein | ● | ● | ● | T |
| | *Phoniscus atrox* Miller | Phat | | | ● | T |
| Vespertilioninae | *Glischropus tylopus* Dobson | Glty | | ● | ● | T |
| | *Tylonycteris robustula* Temminck | Tyro | | ● | ● | T |
| | *Myotis ridleyi* Thomas | Myri | | | ● | C |
| Megadermatidae | *Megaderma spasma* Linnaeus | Mesp | | | ● | T |
| Nycteridae | *Nycteris tragata* Andersen | Nytr | ● | | ● | T |

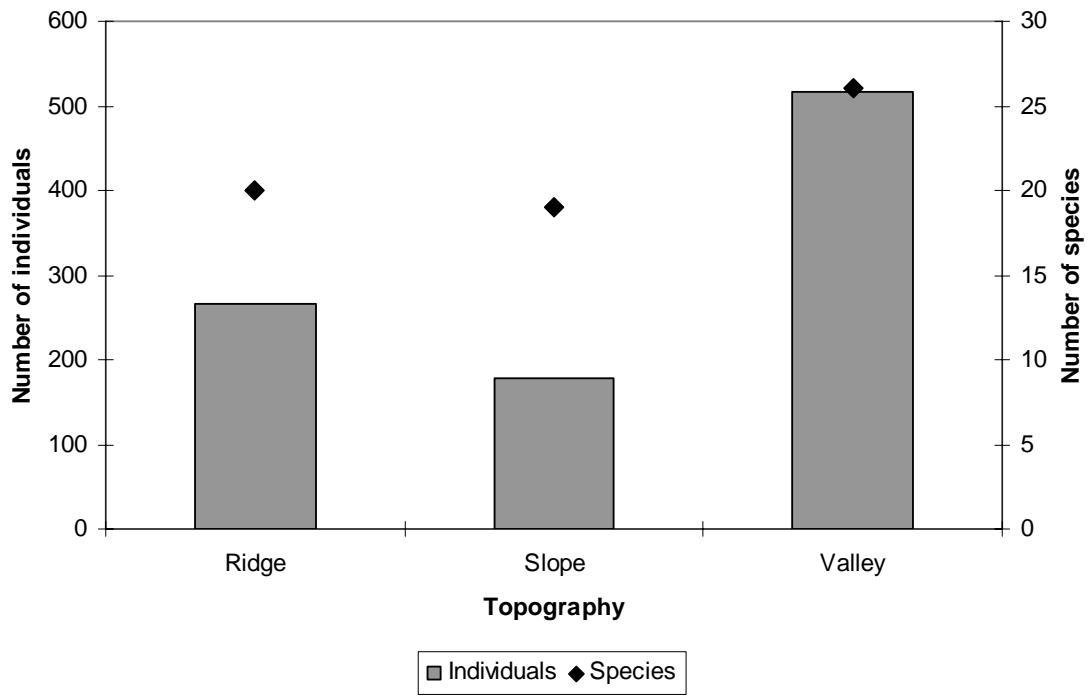*C - Cave; B – Boulders; T – Tree/ foliage*

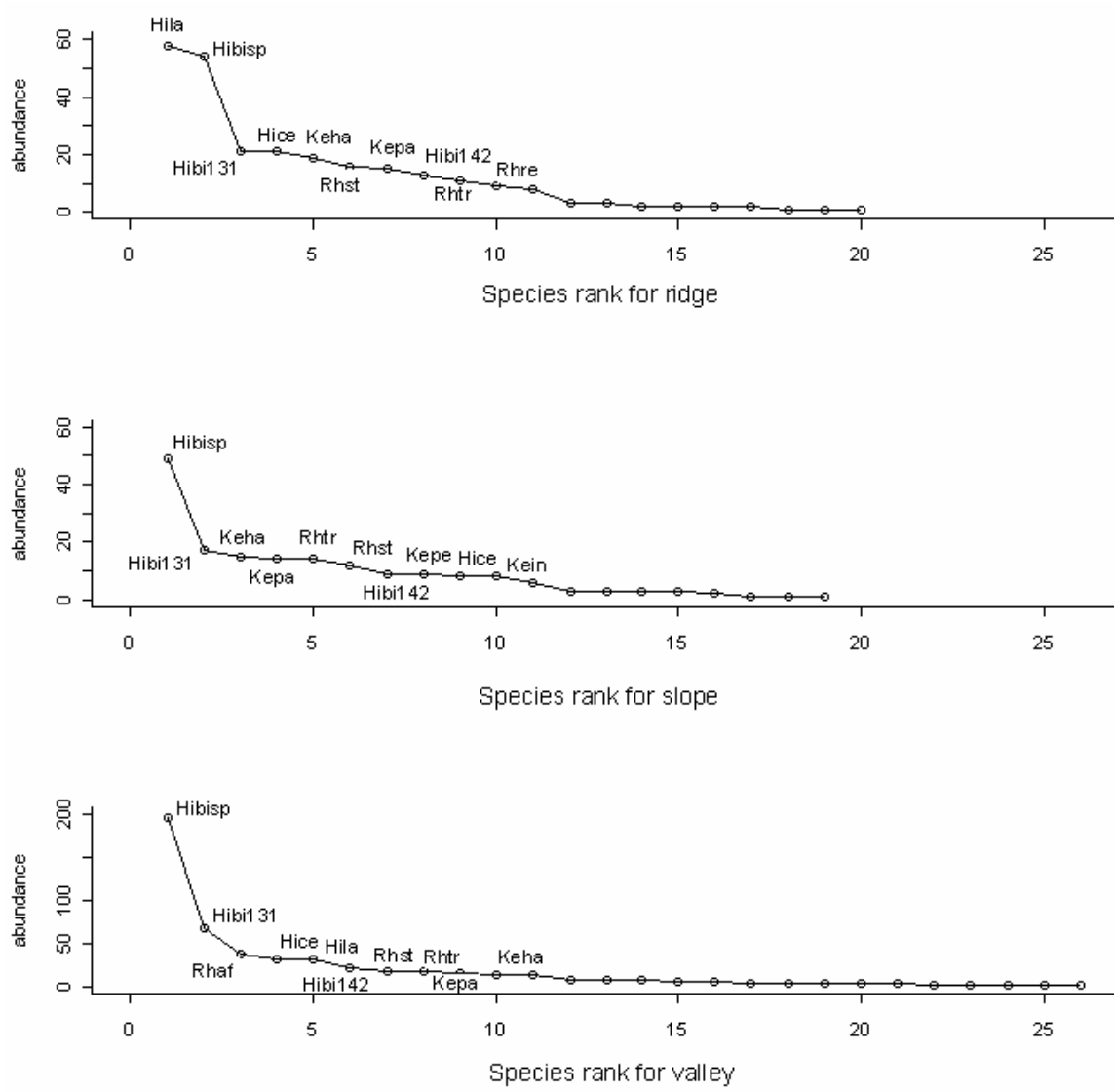Figure 4.2 Total number of bats and species caught at the ridge, slope and valley across six sites.

Figure 4.3 Species rank abundance at the ridge, slope, and valley across six sites. Codes indicate the ten most abundant species caught at each topographic site. See Table 4.2 for species codes.

Table 4.3 Extrapolated species richness with Chao estimates for the ridge, slope and valley (SE - standard error)

| Topography | Species | Simpson's Diversity Index (1-D) | Pielou's Evenness | Chao | Chao.SE | % of total richness estimated |
|---|---|---|---|---|---|---|
| Ridge | 20 | 0.8714 | 0.8004 | 21 | 2.645751 | 90.48 |
| Slope | 19 | 0.8778 | 0.8370 | 18 | 0 | 100.00 |
| Valley | 26 | 0.8160 | 0.7098 | 26.125 | 1.768871 | 95.69 |



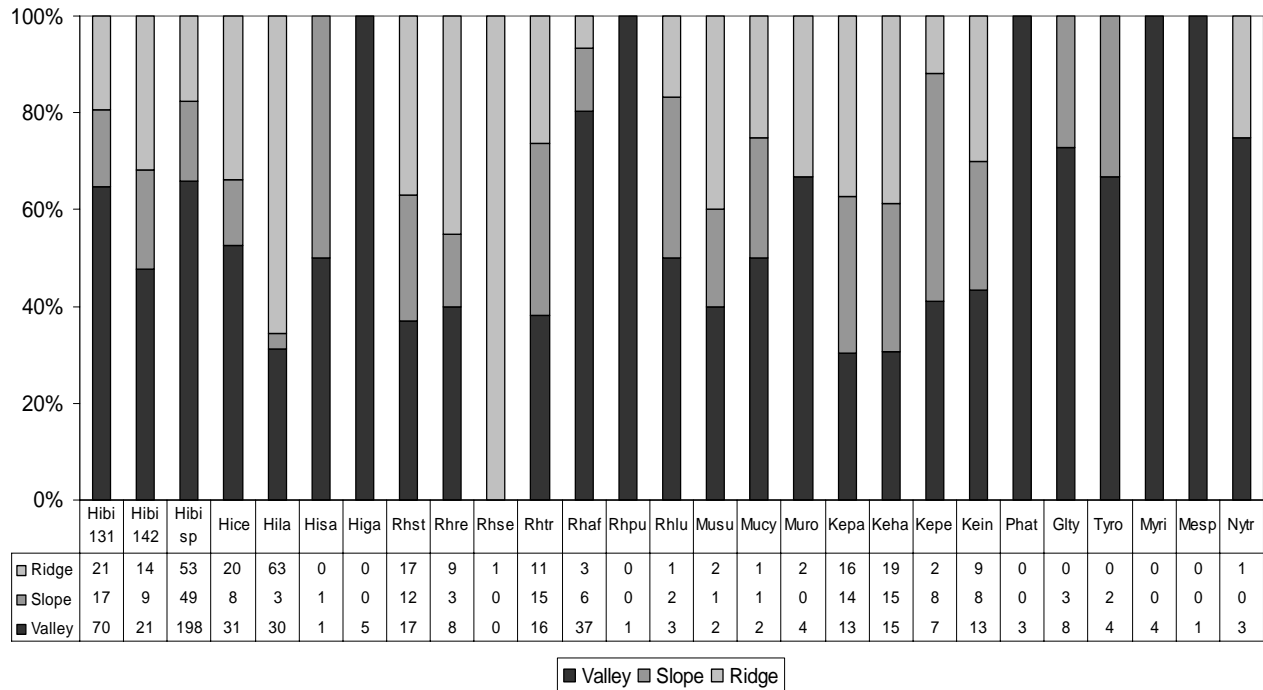| | Hibi 131 | Hibi 142 | Hibi sp | Hice | Hila | Hisa | Higa | Rhst | Rhre | Rhse | Rhtr | Rhaf | Rhpu | Rhlu | Musu | Mucy | Muro | Kepa | Keha | Kepe | Kein | Phat | Glty | Tyro | Myri | Mesp | Nytr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ridge | 21 | 14 | 53 | 20 | 63 | 0 | 0 | 17 | 9 | 1 | 11 | 3 | 0 | 1 | 2 | 1 | 2 | 16 | 19 | 2 | 9 | 0 | 0 | 0 | 0 | 0 | 1 |
| Slope | 17 | 9 | 49 | 8 | 3 | 1 | 0 | 12 | 3 | 0 | 15 | 6 | 0 | 2 | 1 | 1 | 0 | 14 | 15 | 8 | 8 | 0 | 3 | 2 | 0 | 0 | 0 |
| Valley | 70 | 21 | 198 | 31 | 30 | 1 | 5 | 17 | 8 | 0 | 16 | 37 | 1 | 3 | 2 | 2 | 4 | 13 | 15 | 7 | 13 | 3 | 8 | 4 | 4 | 1 | 3 |

Figure 4.4 Proportion in percentage of all the species caught at the ridge, slope, and valley across six sites. Table below displays the number of individuals caught. See Table 4.2 for species codes.

The difference in community of bats between the topographic classes at each site is depicted by the block MRPP (Table 4.4). It showed that slopes and valley are significantly dissimilar ($p < 0.05$). A cluster dendogram (Figure 4.5) derived from a Sorenson's distance from the species presence/absence data show that most similar sites and not topography that are clustered together. This indicates that species presence/absence is more similar to individual sites rather than topography. However, when a Steinhaus distance was derived for the proportion of species contributing $> 5\%$ of the total capture (*Hipposideros bicolor 131, H. bicolor* sp.*, H. cervinus, H. larvatus, Kerivoula hardwickii*), many slope and valley sites were clustered together (Figure 4.6).

Table 4.4 Block Multiple Response Permutation Procedure (MRPP) results Chance-corrected within-group agreement (A) describes within-group homogeneity. If all observed items are identical within groups, A=1, which is the highest possible value. If there is less agreement within groups than expected by chance, A < 0. The higher the *A* value the more identical the sites are in terms of bat communities. If the p value is p< 0.05, it indicates that the pair is significantly dissimilar.

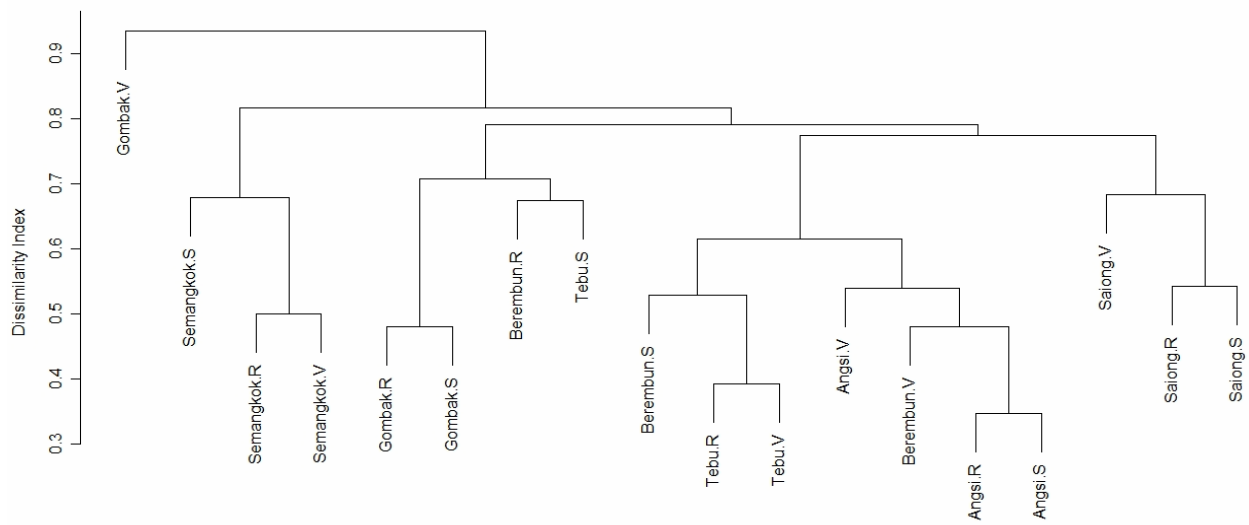| Topography class compared | A | *p* |
|---|---|---|
| Ridge  vs. Slope | 0.0098 | 0.1572 |
| Ridge  vs. Valley | 0.0077 | 0.1492 |
| Slope  vs. Valley | 0.0212 | 0.0331 |

Figure 4.5 Cluster dendogram using Sorenson dissimilarity index of species presence-absence at the ridge (R), slope (S), valley (V) at six sites.
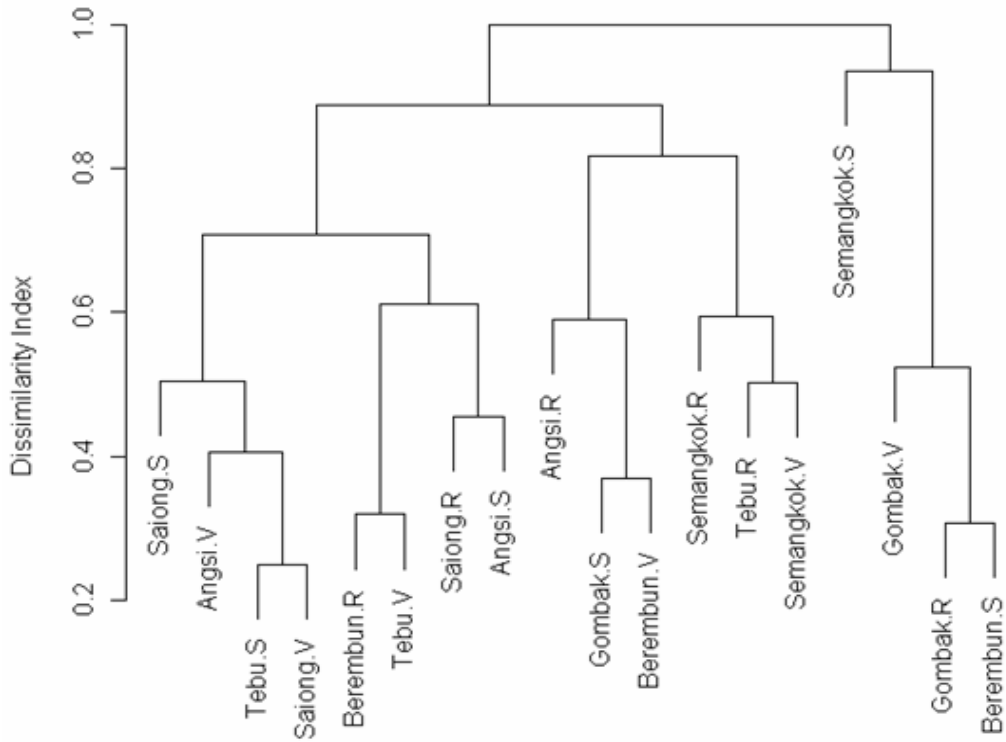
Figure 4.6 Cluster dendogram using Steinhaus dissimilarity index for proportion of species contributing > 5% of the total capture (*Hipposideros bicolor 131, H. bicolor* sp., *H. cervinus, H. larvatus, Kerivoula hardwickii* ) at ridge (R), slope (S), valley (V) for six sites.

The NMDS ordination graph reflects distances of each topographic class in relation to each species in terms of degree of similarity between them (Figure 4.7). Species closest to a site are expected to have a higher abundance (Kindt & Coe, 2005). The graph portrays that each topographic class is well spaced with many species centered in the middle, indicating no strong preference neither to ridge, slope nor valley. However there were some species that showed tendencies towards certain topography, such as *Hipposideros larvatus* that *w*as highly dominant in the ridges. Although *Rhinolophus sedulus* was plotted in the ridge portion of the graph, but it was very far apart from the ridge because *R. sedulus* had only two individuals and both were caught in the ridges. The overlapping species in the top far right indicate species with low counts caught only at the valley (*H. galeritus, R. pusillus, Phoniscus atrox, Myotis ridleyi, Megaderma spasma)*. Species that are centered towards the middle indicate that they were almost equally present at all topographic classes.

Figure 4.7 Non-metric multidimensional scaling (NMDS) of bat species abundance and sites categorized as ridge, slope and valley. Distances between sampling sites on the ordination reflect dissimilarity in bat species composition using Bray-Curtis coefficients. See Table 4.2 for species codes.

4.4.2 Habitat structure in relation to topography and local climate

To account for habitat variables, basal area per tree and tree height was taken to account to provide the habitat structure at the ridge, slope and valley (Table 4.5). The cluster dendogram using Steinhaus distance between the topographic classes at the six sites show that the dissimilarity index between tree height and basal area found in the ridge, slope and valley was not high (Figure 4.8). For tree height, there were sites clustered together regardless of topographic class, such as the slopes and valleys of Semangkok, the ridges and slopes of Kledang Saiong and the slopes and valleys of Gunung Tebu (Figure 4.8). As for basal area, there were similar topographic class clustered together regardless of site, such as the slopes in Ulu Gombak and Gunung Tebu and the ridges of Gunung Angsi and Semangkok (Figure 4.9). Although clustering exists according to sites and topographic classes, the dissimilarity indexes between them are small. The GLM showed no strong evidence ($r^2 > 0.01$, $p > 0.5$) that there were differences in habitat structure explained by topographic classes.

Table 4.5 Mean tree height and basal area per tree at the ridge, slope and valley for the six sites.

| Site | Topopgraphy | Mean Tree Height (m) | | Mean Basal Area per tree (m$^3$) | |
|---|---|---|---|---|---|
| | | Min. | Max. | Min. | Max. |
| Gunung Tebu FR | Ridge | 12.22 | 15.16 | 0.0169 | 0.0334 |
| | Slope | 11.81 | 16.06 | 0.0210 | 0.0381 |
| | Valley | 13.58 | 15.58 | 0.0225 | 0.0276 |
| Kledang Saiong FR | Ridge | 12.95 | 13.78 | 0.0127 | 0.0174 |
| | Slope | 13.08 | 14.03 | 0.0171 | 0.0186 |
| | Valley | 12.62 | 14.14 | 0.0187 | 0.0213 |
| Semangkok FR | Ridge | 12.27 | 16.27 | 0.0222 | 0.0315 |
| | Slope | 7.96 | 12.81 | 0.0086 | 0.0153 |
| | Valley | 9.92 | 10.88 | 0.0105 | 0.0142 |
| Ulu Gombak FR | Ridge | 12.59 | 14.01 | 0.0233 | 0.0338 |
| | Slope | 11.74 | 14.53 | 0.0222 | 0.0312 |
| | Valley | 8.75 | 16.23 | 0.0103 | 0.0351 |
| Berembun FR | Ridge | 12.71 | 13.25 | 0.0215 | 0.0258 |
| | Slope | 12.52 | 14.20 | 0.0219 | 0.0265 |
| | Valley | 12.41 | 14.64 | 0.0150 | 0.0298 |
| Gunung Angsi FR | Ridge | 11.91 | 12.86 | 0.0203 | 0.0267 |
| | Slope | 10.47 | 13.27 | 0.0175 | 0.0259 |
| | Valley | 13.34 | 15.12 | 0.0303 | 0.0321 |
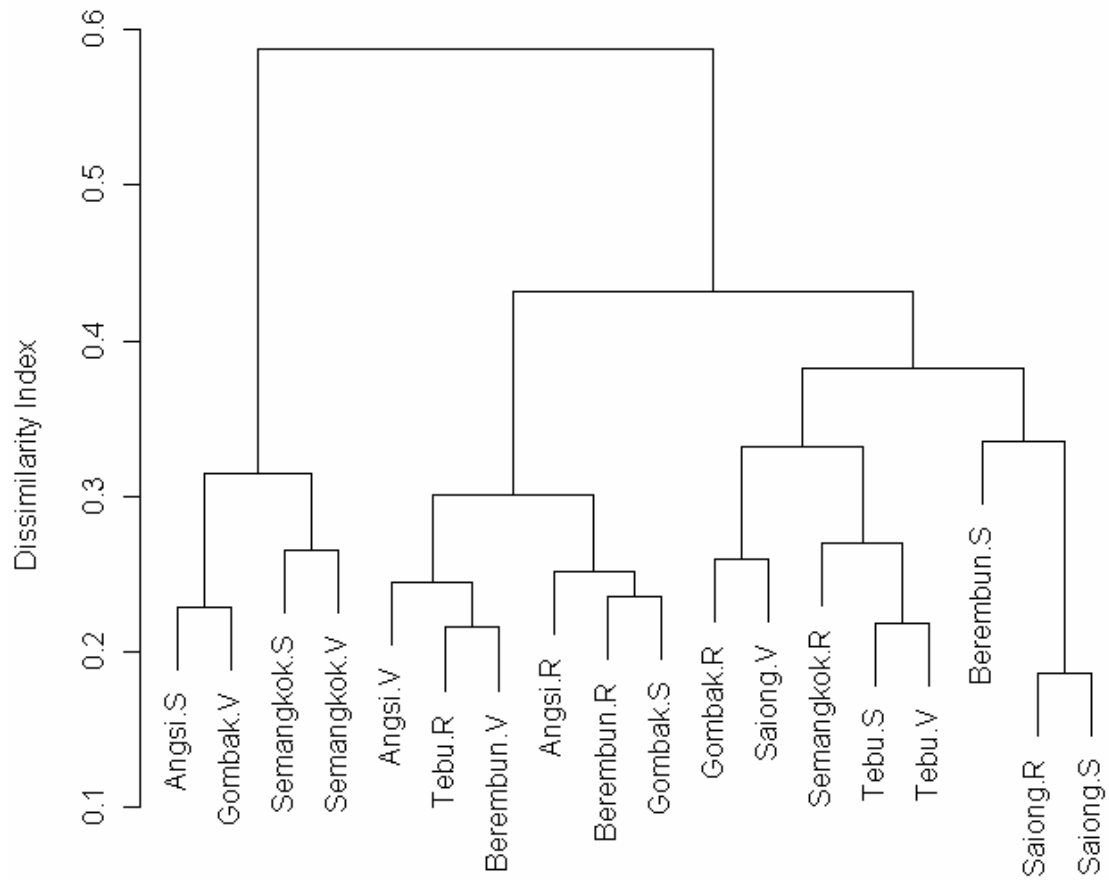
Figure 4.8 Cluster dendogram using Steinhaus dissimilarity index for proportion of trees at different height classes according to ridge (R), slope (S), valley (V) for six sites.
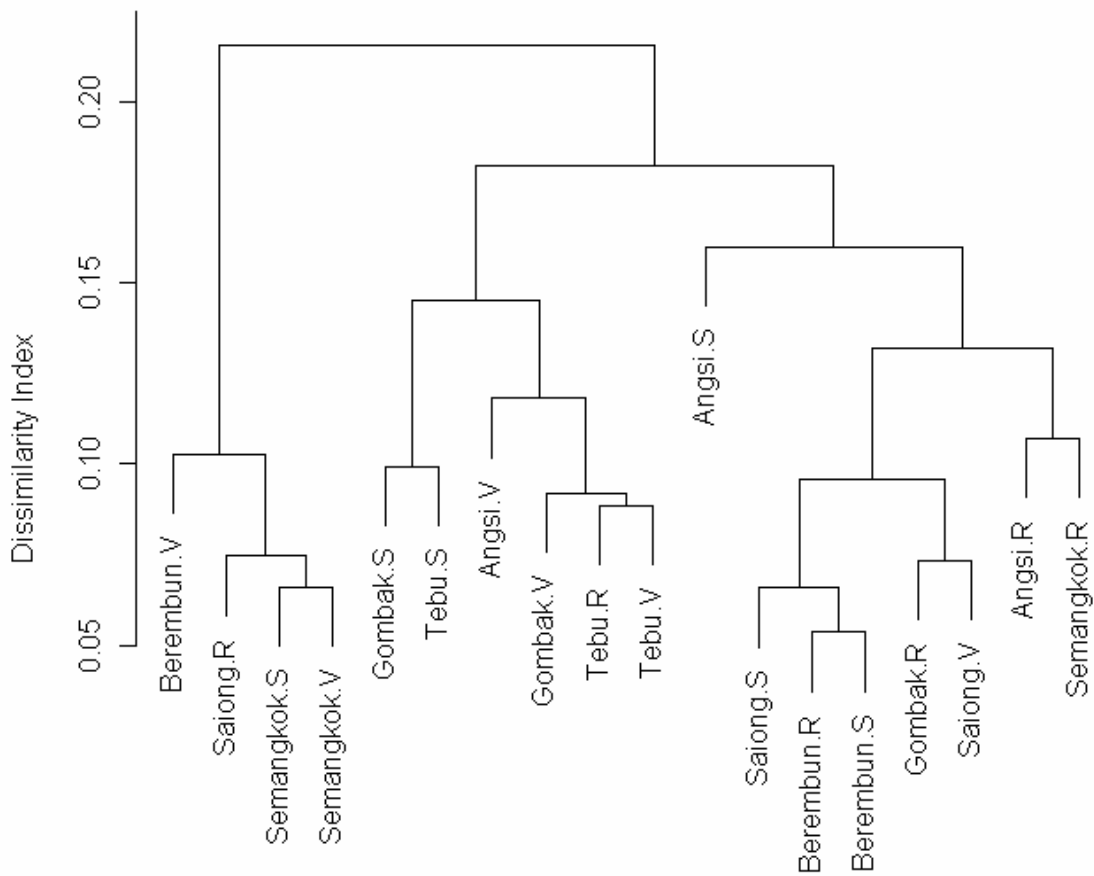
.

Figure 4.9 Cluster dendogram using Steinhaus dissimilarity index for proportion of trees at various basal area classes according to ridge (R), slope (S), valley (V) for six sites.

The data loggers placed on each transect showed that the valley had a higher mean temperature (°C) in most sites (Figure 4.10a), and the highest mean relative humidity (%) in all study sites (Figure 4.10b). Ulu Gombak however had similar temperature and humidity throughout the topography.

4.4.3 Habitat structure and species composition

The Mantel test revealed that species composition and both tree height ($r = 0.1194$, $p = 0.123$) and basal area per tree ($r = 0.111$, $p = 0.123$) were not significantly correlated. Species contributing > 5% of the total bat capture (dominant species) showed that they had non-significant negative correlation with tree height ($r = -0.03384$, $p = 0.62$) and basal area ($r = -0.1188$, $p = 0.873$).
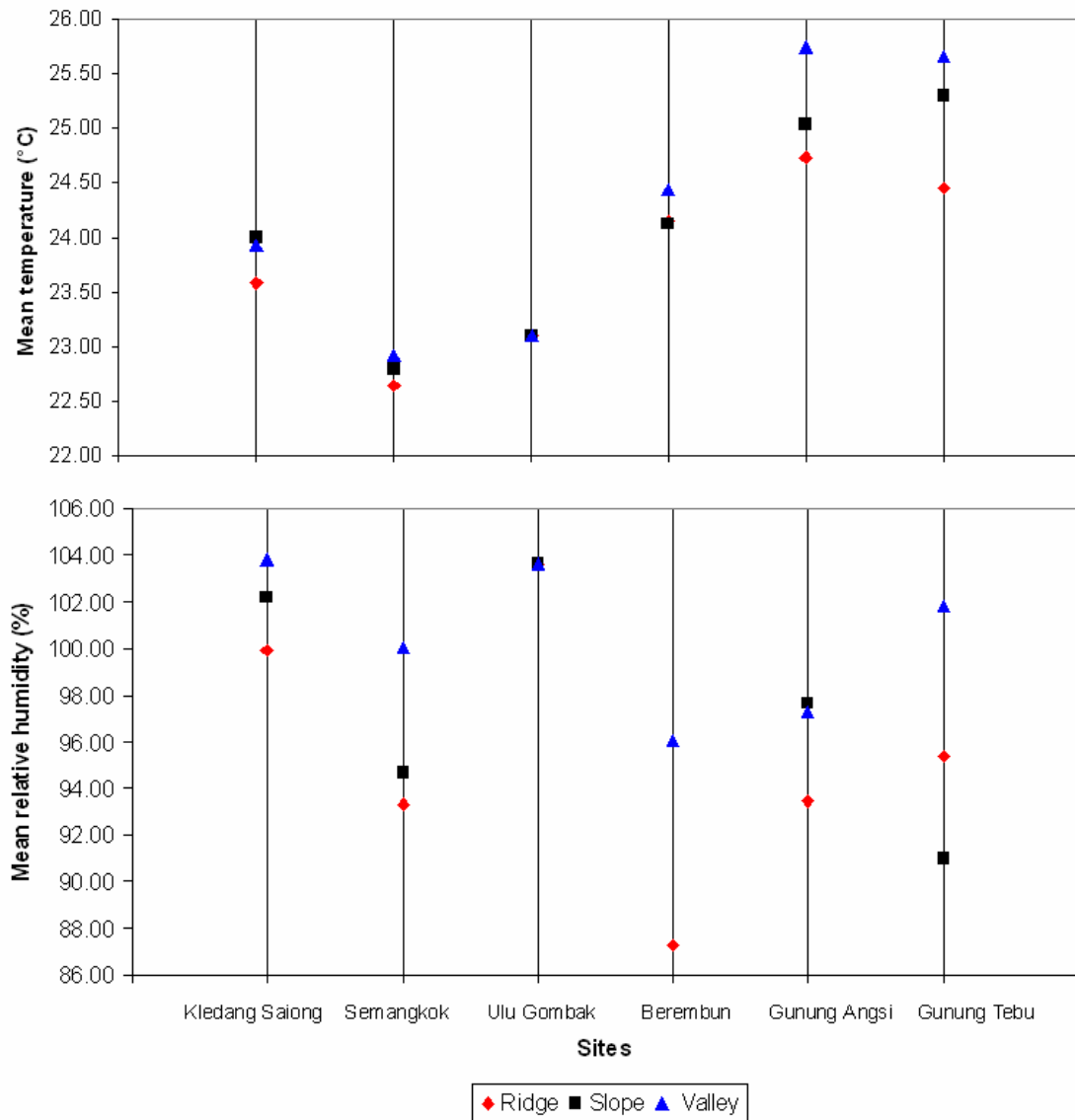
Figure 4.10 Mean (a) temperature (°C) and (b) relative humidity (%) obtained from the data logger HOBO® placed on each transect at each study site. The graph shows a missing value for the mean relative humidity for the slope in Berembun FR due to a faulty data logger.

**4.5 DISCUSSION**

In the introduction, the study clearly established the importance of forest structure on bat ecology. Therefore, habitat variables that are often associated with bats such as basal area per tree that accounts for potential roost sites as well as forest density, and tree height for vertical forest structure were measured. Before discussing further the relevance and association of ridge, slope and valley to bats, it would be pertinent to first discuss the differences in habitat structure within these three topographic classes as revealed in this study.

4.5.1 Habitat structure in relation to topography and local climate

The results of the dissimilarity dendogram suggest that tree height is more closely associated with factors related to each site rather than similar topography class of different sites. However basal area per tree showed that size of each tree is more closely associated among similar topographic class regardless of sites. Despite these similarities, basal area and tree height showed no strong evidence that there were differences in habitat structure explained by topographic class because the correlation with topographic class and these two habitat variables were non-significant. However from personal observation, the ridges seemed less cluttered than the slopes and valleys, trees at the ridges seemed to be more transparent.

Dipterocarps are the primary tree species found in the lowlands up to the low mountains of Peninsular Malaysia (Tange *et al.*, 1998) which means there are no major transitions of tree family composition between the lowland and hill forest gradients. Because all sites were controlled for geological structure, the possibilities of variation due to geological features were eliminated. However, soil variations may have caused the dissimilarities observed between topographic classes in the cluster dendogram. Many studies have established variations in plant diversity due to soil regimes because different species have different nutrient requirement (Costa *et al.*, 2005; Pitman *et al.*, 2008; de Castilho *et al.*, 2009; Griffiths *et al.*, 2009; Wan Juliana *et al.*, 2009). However a study conducted in Pasoh, Malaysia concluded that only a small portion of the variation in plant diversity is explained by topographic and spatial variables (He *et al.*, 1996) and that soil and degree of slope play a secondary role (Sanchez-Gonzalez & Lopez-Mata, 2005). Habitat structure such as tree height in fact corresponds to different light environments in the upper and lower slopes (Osada *et al.*, 2004). This study only took into account height and dbh for habitat variables and did not identify tree species, soil type or measure light intensity, since the focus of the study was to relate tree structure at different topography to bats and not so much on the environmental variables affecting tree distribution.

Gunung Tebu FR in the east coast of Peninsular Malaysia had the highest annual mean rainfall and temperature because it experiences heavy rainfall during the monsoon season. Although the valley indicated higher microclimate for mean temperature and humidity for all sites, environmental variables showed no correlation with either the habitat variable or bat abundance. Although temperature and humidity is known to affect the

selection of roost, it may however not be apparent in this study due to subtle differences in temperature (SD = ± 0.99) and humidity (SD = ± 4.98) between the topographic classes. Furthermore, this study did not consider the temperature and humidity inside the roost cavity. These effects are more evident in temperate countries (Sedgeley & O'Donnell, 1999; Sedgeley, 2001).

It is a great challenge to clarify complicated relationships between vegetation, soil and topography (Xu *et al*., 2008). Studies have shown that topography has a significant correlation with vegetation, but the scope of these studies were either at a greater spatial scale or elevational range (Costa *et al.* 2005; Pitman *et al.* 2008), and experience changes in local climate (Sanchez-Gonzales & Lopez-Mata, 2005). However, smaller spatial scales have become more important in determining spatial distributions (Tylianakis *et al.* 2006). This study only focused on topographic changes in the hill forest which falls between 320 – 760 m asl (Wyatt-Smith, 1961; Whitmore, 1990; Cedergren *et al*., 2002) and between plot distance that does not go beyond 500 m. This only means that tree height and basal area per tree does not have significant difference with topography within the specified range because the study failed to detect any strong difference in physical characteristics found between the three topographic classes.

4.5.2 Bat species composition in relation to topography

Grindal and Brigham (1999) did establish that spatial complexity may be the limiting factor for foraging bats. This often presents the difficult task of determining these spatial

complexities. Since the study has established that there were no significant differences in the forest structure between topography sites, it is postulated that there may be other contributing factors influencing the high abundance and species richness in the valley.

Species or communities have high turnover rates related either to geographical barriers, such as rivers or high levels of habitat specificity. From personal observations, the valley often had small streams flowing through, with gaps and crevices created by large rocks and boulders that are ideal as roost for cave bats. Bats are more active along streams because they use the streams for drinking (Lloyd *et al.* 2006), which might also increase their chances of getting caught in the harp traps (Fletcher, 2004). Grindal and Brigham (1999) also observed that bat activity was the greatest at low elevations with higher occurrence of reproductive active population. Valleys often have greater prey richness and quality because of insect larvae found in streams (Wolda, 1987; Grindal & Brigham 1999; Armstrong, 2004; Meyer *et al*., 2004; Akasaka *et al*., 2009), and prey availability has the strongest influence on bats when it comes to selecting foraging sites (Fenton, 1990; Whitaker *et al*., 2000; Meyer *et al*., 2004).

The lower elevations or valley sites are usually closer to the forest edge, therefore bats commuting to the forest are more likely to forage in these areas (Kanuch & Kristin, 2005), creating a higher diversity. Although many species tend to forage in the valley, the effects of strong representation of prominent species like *H. bicolor* sp. and the low counts of the other species is depicted in the low Simpson's diversity index for the valley. The study also tends to agree with Fletcher *et al.* (2004) that species caught at higher

altitudes can be found at lower altitudes but not necessarily vice versa. Unlike valleys, the ridges more often than not have a very open environment and do not have any narrow flyways suitable for placing harp traps. Although the openness and less cluttered environment may facilitate the foraging activities of some bats (Patriquin & Barclay, 2003), it also presents the difficult task of capturing them. There are limited suitable points to place the traps because there are no existing pathways thus trapping in these areas may have been less successful resulting in a false representation of the actual bat community.

The Hipposideridae family was well represented in terms of abundance and was present in all three topographic classes. This could readily be attributed to the gregarious roosting habits of these species. They are highly versatile, meaning they can either roost in large numbers under boulders or rock crevices within the forest or like most hipposiderids in caves (Thabah *et al.*, 2006). Because they are highly versatile, they are usually found in most forest (Struebig *et al.*, 2009). Its roosting requirements would seem to be directly correlated to geology rather than vegetation, making it less vulnerable to anthropogenically induced habitat change (Sheema, 2006).

It is interesting that *H. larvatus* was very dominat in the ridges. This species is a common inhabitant of limestone caves as well as in the crevices of large rock boulders (Struebig *et al.*, 2009). Cave-roosting bats in nature have larger home ranges because they commute from their roosting caves to the forest to forage for food. With a forearm length of > 55 mm, *H. larvatus* is considered as one of the larger species compared to the other

hipposiderids caught (e.g. *H. bicolor*, *H. cervinus*.) (Kingston *et al.,* 2006). According to Patriquin and Barclay (2003), large, less maneuverable species were more confined to more open habitat with less clutter. Therefore *H. larvatus* may prefer foraging in the ridges because as mentioned earlier, the ridges were less cluttered (pers. obs.), allowing them to maneuver easily (Lloyd *et al.,* 2006). This concept of body size affecting partitioning of species diversity was also applied by Summerville *et al.* (2006) on forest moths.

Although the ridges had less species compared to the valley but the high Simpson's diversity index showed that it was well represented in terms of abundance by the species that was present there and hardly any singletons as compared to the valley. The MRPP permutation for species composition in topographic class indicated that species composition in the slopes and valleys were more significantly dissimilar compared to the ridges. There were no species that highly dominated the slopes; all species present in the slope were shared by either the ridge or slope or both. It is predicted that species with larger home ranges (e.g. *H. bicolor 131, H. bicolor* sp., *R. stheno*) were caught in the slopes while commuting between the ridge and the valley (Fenton, 1982). Species with smaller home ranges such as *Kerivoula papillosa, K. hardwickii, K. pellucida* and *R. trifoliatus* may have also been actually roosting and foraging in the slopes.

There were a few species that were only present in either the valley or ridge in low abundance (*Megaderma spasma, Myotis ridleyi, Phoniscus atrox, R. pusillus, R. sedulus* and *H. galeritus*). Their low numbers suggests that they might not have been captured

due to the lack of trapping effort or the possibility that they may be rare species (Kingston *et al*., 2003a; Mohd. Azlan *et al*., 2005; Anwarali *et al*., 2008). Many of the rare species (< 0.1 %) like *Rhinolophus sedulus*, *Nycteris tragata*, *Phoniscus atrox* and *Myotis ridleyi* are classified as Near Threatened (NT) by the International Union for Conservation of Nature and Natural Resources (IUCN, 2009). The rarity or abundance of these species could be influenced by the spatial distribution of specific roosting or habitat requirements (Kingston *et al*., 2003b; Fletcher, 2006). Species such as *R. sedulus* and *N. tragata* were categorized as patchily distributed by Kingston (2000; 2001) because of its specific roosting preference (Fletcher, 2006).

In general, many forest interior species caught in this study (*R. stheno, R. trifoliatus, K. papillosa, K. hardwickii, K. intermedia)* did not have the tendency towards a particular topographic class. They were present in high abundance at all topographic classes. These species are randomly distributed and more of a habitat generalist (Kingston, 2001; Fletcher, 2006). According to observations made by Patriquin and Barclay (2003) small, maneuverable species were able to exploit the entire habitat available to them regardless of the vegetation structure, such as the rhinolophids (Neuweiler, 1989). However, different sites are preferred for various reasons such as for foraging, roosting or commuting (Fenton, 1982; Crampton & Barclay, 1996). Bats have a higher tendency to be caught if they are foraging, thus contributing higher abundance at certain sites. According to Saunders and Barclay (1992), there are some degrees of resource partitioning between two species on a spatial basis. Redistributing throughout a given area may be a way of reducing competition for food and space (Arlettaz, 1999; Whitaker,

2004), especially in areas like the valley which seemed to be the more favored foraging ground.

Most ecological efforts has been concentrated in the temperate regions where vegetation is of much simple structure and comprise of far fewer species than in the tropics (Whitmore 1984). It is often easy to detect changes in species distribution rather than evaluating the factors behind the changes, because there are many confounding factors affecting these changes (Abdul Rahman *et al*., 2002; Kessler, 2009). This study shows that there is no significant difference in the habitat structure and microclimate of a ridge, slope and valley that is within 500 m distance of each other. It may be due to the weak effects caused by limited sampling plots or plot size (Cedergren *et al*., 2002) or stronger effects by other environmental variables such as soil and light intensity which were not measured in this study. However through personal observations, there were differences in forest structure between the ridge and both the slope and valley. Each topographic site had different characteristics which can be an advantage or disadvantage to a bat species because of their vast niche diversity. Valleys do have its own attractions; it has streams, higher abundance of insects and are usually closer to the forest edge. This may attract bat species either from within the forest or from the surrounding areas. Since all species found in the ridge and the valley were also captured in the slopes, it is predicted that the slopes are used by species with large home ranges for commuting and species with smaller home ranges as their primary site for roosting and foraging. Ridges are particularly crucial for larger bats that prefer a less cluttered environment.

Results from this study infer that the forest is used by bats regardless of their topographic class. According to Costa *et al.* (2005), homogeneity in plant distribution would mean that any portion of the forest will have the same value for conservation. This concept can also be applied for the bat community. Forest structure is important for the optimal survival of forest interior bat species. Forest interior bats are an extremely diverse group in Peninsular Malaysia (Kingston *et al.*, 2003a); therefore any destruction or disturbance to the forest is likely to have a major impact on the reproductive success and survival of the bat community, especially the rare and threatened species. Understanding and predicting how they will respond to habitat disruption remains a major challenge. However, further research on patterns of habitat use for each bat species will help provide more in-depth analysis for particular species rather than just general information for all species (Miller *et al.*, 2003; Patriquin & Barclay, 2003). This will hopefully increase our understanding on population density and habitat requirements for sound conservation management practices (Francis, 1990) and could present opportunities for possible conservation tools such as predictive modeling of species composition for various forest conditions (Kanuch *et al.*, 2008).

**CHAPTER 5**


**GENERAL CONCLUSION**


This study has examined the distribution of insectivorous bats in relation to spatial aspects such as geography (chapter 2), size and distance (chapter 3) as well as topography (chapter 4). The analysis was derived from the 958 individuals and 27 insectivorous bat species captured and identified. This study, which was conducted over a span of 18 months, consisted of six study sites across Peninsular Malaysia with 486 trap nights.

Results of this study indicated that the insectivorous bat assemblage of Peninsular Malaysia comprises mainly of the Hipposideridae and Rhinolophidae family. There was no indication that any species were geographically distributed between the study sites that ranged within the peninsular. Elevational range and forest surroundings are among the factors observed to have influenced the similarities or dissimilarities identified among bat species composition within the peninsular.


IUCN regards any species that has experienced a reduction in population of more than 50% over the last three generations as endangered, and those with a 20% reduction as vulnerable (Ashton, 2008). The IUCN Red List has recently amended the status of five species identified in this study; *Nycteris tragata, Rhinolophus sedulus, Kerivoula pellucida* and *Phoniscus atrox* from Low Risk (LR)/least concern (lc) in 2007 to Near Threatened (NT) and *Murina rozendali* to Vulnerable (VU) in 2008 (IUCN, 2009). This study showed that NT species such as *P. atrox*, *R. sedulus*, *N. tragata* and VU species *M. rozendaali* were not

only present in low abundance but were found mostly in only one of the six study sites. *Kerivoula pellucida* and *K. intermedia* that are listed as least concerned (LC) were present in most of the study sites but were low in abundance.

As for the effect of primary habitat size, this study showed that VJR size did not show any correlation with insectivorous bat assemblages. This indicates that the removal and addition of ecosystem components (caused here by logging) that produce changes in spatial configuration of landscape elements has no significant effect on the disturbance response of bats in an ecosystem over a range of >15 years. However there were two distinct increasing trends of bat abundance with increasing size class, Category 1 (0–300 ha) and Category 2 (301–1500). Variations observed in the different study sites such as forest surroundings, topography and anthropogenic disturbances may have been contributing factors in influencing the assemblage-level abundance, species richness and composition of bats in the forest. As for the distance aspect, the population of bats 200 m away from the VJR tends to increase with increasing VJR size, but the proportion of bats furthest away from the VJR (> 600 m) decreased. The MRPP showed that species composition at different distances were not significantly dissimilar. However there were threatened and vulnerable species such as *Glischropus tylopus* and *Myotis ridleyi* which were only found within the VJR regardless of their size, indicating the need for pristine primary forest for certain species.

This study also showed no significant difference in the habitat structure and microclimate between the ridge, slope and valley within a 500 m distance, but bat abundance and species richness was the highest in the valley. Therefore it is postulated there may be

other confounding factors for this high abundance. Valleys are often closer to the forest edge, with streams flowing through and have rich insect (prey) diversity. However many forest interior species caught in this study were habitat generalists (*R. stheno, R. trifoliatus, K. papillosa, K. hardwickii, K. intermedia)* because they had no tendency towards a particular topographic class except for *H. larvatus*, which was very dominant in the ridges. Its large forearm often translated as body size may be reason for its preference towards the ridges because the ridges were less cluttered (pers. obs.), allowing for easier maneuverability. Forest is important for bats regardless of their topographic class. However, different topography is preferred for various reasons, such as for foraging, roosting or commuting (Fenton, 1982; Crampton & Barclay, 1996).

Most ecological studies concentrated in the temperate regions where vegetation is of much simpler structure and comprise of far fewer species than in the tropics (Whitmore 1984). Southeast Asia has the highest relative rate of deforestation of any major tropical region, and could lose three quarters of its original forests by 2100 and up to 42% of its biodiversity (Sodhi *et al*., 2004). In a time where landscapes are rapidly changing, conservation should focus in bridging the gap between knowledge (research) and action (implementation) because as new species are being discovered, so is the impending destruction of their habitat. Despite the threats to tropical forests, conservation capacity is limited and resources must be allocated effectively if conservation is to be successful (Sheil, 2002). Habitats that are often rich in endemism, once identified, should carry maximum conservation priority; and adequate habitat representation is set aside before it is too late (Ashton, 2008).

Forest structure is important for the optimal survival of forest interior bat species. Forest interior bats are an extremely diverse group in Peninsular Malaysia (Kingston *et al*., 2003a); therefore any destruction or disturbance to the forest is likely to have a major impact on the reproductive success and survival of the bat community, especially the rare and threatened species. This study has indicated that despite the various aspects of a forest (topography, distance, etc.), there is no definite reason behind bat species distribution. This is because different species tend to be most abundant around their environmental optimum (Fukami & Wardel, 2005), and the importance here is determining this balance for the survival of the community. Understanding and predicting how they will respond to habitat disruption remains a major challenge. However, further research on patterns of habitat use for each bat species will help provide more in-depth analysis for particular species rather than general information on multiple species (Miller *et al*., 2003; Patriquin & Barclay, 2003). This will hopefully increase our understanding on population density and habitat requirements for sound conservation management practices (Francis, 1990).