ECOLOGICAL ASPECTS OF FRUIT BATS (MEGACHIROPTERA) IN PENANG ISLAND, MALAYSIA

NUR JULIANI BINTI SHAFIE

UNIVERSITI SAINS MALAYSIA

2016

ECOLOGICAL ASPECTS OF FRUIT BATS (MEGACHIROPTERA) IN PENANG ISLAND, MALAYSIA

by

NUR JULIANI BINTI SHAFIE

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

FEBRUARY 2016

ACKNOWLEDGEMENT

Praises to ALLAH S.W.T. I am thankful to HIM that I am able to complete my PhD thesis. Here, I would like to write down these individuals who were directly or indirectly involved in this project.

First of all, I would like to deliver my utmost gratitude towards my main supervisor, Dr. Nik Fadzly Nik Rosely for his advises and guidance. Thank you for your helpful comments which really did a lot to facilitate me in writing this thesis.

I would also like to express my appreciation and gratitude to my co-supervisors, Prof. Dr. Shahrul Anuar Mohd Sah. He has given me a lot of motivation to complete my thesis and also to Dr. Wan Mohd Muhiyuddin Wan Ibrahim for his guidance and helpful comments in GIS part. Thanks to MyBrain (KPT) for the scholarship and Research University Grant, Universiti Sains Malaysia for funding my research.

My utmost thanks to all lab assistants from the School of Biological Sciences, Mohd Yusof Omar, Mohd Hafizul Hasmadi bin Mohd Noor, Mohd Shukri Saad, and Nordin Ahmad that never give up to help me during my sampling. To all my comrades, Munira, Muin, Aini, Amira, Fuzah, Adibah, Bidarul, Aisyah, Mira, Maryam, Evan and Fatim thank you for your help and support. I really appreciate it and love you all.

To my beloved mum, Hajah Puziah Hamzah and my siblings thanks for all your patience, support and valuable love to me and thanks for your patience in allowing me to pursue my dreams. I convey this thesis to my late father, Haji Shafie bin Mohd Ramli. I miss and love you so much, dad. Last but not least, to my beloved husband, Mohd ‘Ulul ‘Ilmie bin Ahmad Nazri and my adorable baby boy, Muhammad Uwais, thanks for your support and I love you both.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT	II
TABLE OF CONTENTS	III
LIST OF TABLES	VII
LIST OF FIGURES	VIII
LIST OF ABBREVIATIONS	X
LIST OF PUBLICATIONS AND PRESENTATIONS	XI
ABSTRAK	XII
ABSTRACT	XIV
CHAPTER ONE: GENERAL INTRODUCTION	1
1.1 Taxonomy, distribution and behaviour of Megachiroptera (Pteropodidae)	1
1.2 Bats conservation status in Southeast Asia and Malaysia	3
1.3 Thesis structure	6
CHAPTER TWO: LITERATURE REVIEW	10
2.1 The sensitivity of bats to urbanisation	10
2.2 The application of the Geographical Information System (GIS) in bat studies	13
2.3 The feeding behaviour in relation to the visual and fruit odours of fruit bats	17
2.4 The conservation efforts of bats in Malaysia	20
CHAPTER THREE: GENERAL MATERIALS AND METHODS	23
3.1 Study sites	23
3.2 Mist-netting methods	26

3.3 Bat capture and identification 28

CHAPTER FOUR: EFFECT OF URBANISATION ON SPECIES RICHNESS, ABUNDANCE AND BODY SIZE OF FRUIT BAT (PTEROPODIDAE) ASSEMBLAGES 29

4.1 Introduction 29

4.2 Materials and Methods 31

4.2.1 Study area and land-use data 31

4.2.2 Bat and mist-netting method 35

4.2.3 Statistical analysis 36

4.3 Results 37

4.4 Discussion 50

CHAPTER FIVE: HABITAT SUITABILITY ANALYSIS USING GEOGRAPHICAL INFORMATION SYSTEM (GIS) AND ANALYTICAL HIERARCHY PROCESS (AHP) OF FRUIT BATS IN PENANG ISLAND 54

5.1 Introduction 55

5.2 Materials and Methods 58

5.2.1 Study area 58

5.2.2 Bat capture and identification 60

5.2.3 Developing the area map of habitat suitability 60

5.2.4 Database compilation 61

5.2.5 Identification of weights of factors 62

5.3 Results 67

5.4 Discussion 73

CHAPTER SIX: THE ROLE OF OLFACTION AND VISUAL IN 77

THE FEEDING BEHAVIOUR OF *Cynopterus brachyotis* AND C. *sphinx*

6.1 Introduction 77

6.2 Materials and Methods 80

6.2.1 Study site and bat collection 80

6.2.2 Experimental set up 83

6.2.3 Statistical analysis 84

6.3 Results 84

6.3.1 General observations 84

6.3.2 Comparison of bat responses for different experiments 85

6.3.3 Comparison of bat responses between *C. brachyotis* and *C. sphinx* 88

6.3.4 Nightly activity patterns of bats 88

6.4 Discussion 92

CHAPTER SEVEN: DIFFERENCES IN KNOWLEDGE AND AWARENESS LEVEL AMONG LOCAL COMMUNITIES: A STUDY OF BAT CONSERVATION EFFORT 96

7.1 Introduction 96

7.2 Materials and Methods 99

7.2.1 Study area 99

7.2.2 Survey design and questionnaire 101

7.2.3 Statistical analysis 102

7.3 Results 103

7.3.1 Demographics 103

7.3.2 Knowledge of bats 103

7.3.3 The relationship of demographics structure with the conservation knowledge of bats 106

7.3.4 Participation in conservation actions 110

7.4 Discussion 112

7.4.1 The relationship of demographics structure with the conservation knowledge of bats 112

7.4.2 Recommendation 115

7.4.2.1 Legal protection 115

7.4.2.2 Educating the public 116

7.4.2.3 Long-term monitoring programs 118

CHAPTER EIGHT: SUMMARY AND CONCLUSION 119

REFERENCES 123

APPENDICES 142

LIST OF TABLES

		Page
Table 4.1	Details of the sampling points	34
Table 4.2	Bats collected across urban-rural gradients in Penang Island. Body size in mm (Mean ± SD). Specialisation categories: S – habitat specialists, G – habitat generalists. U1 – urban site 1, S1 – suburban site 1, R – rural site 1, etc.	39
Table 5.1	Scale of pair-wise comparison (measurement scale according to Saaty, 1977; Malczewski, 1999).	63
Table 5.2	Random Index (RI) for Consistency Ratio (CR).	66
Table 5.3	Number of individual per species of bats captured in all sampling sites.	68
Table 5.4	Pair-wise comparison matrix and calculation of final weightage for each factor.	69
Table 5.5	Total area under different classes of habitat suitability for bats in Penang Island.	72
Table 6.1	Behavioural responses of *Cynopterus sphinx* and *Cynopterus brachyotis* towards fresh fruit, blended fruit and artificial fruit in captive condition. Data are given in mean ± S.D. (*n* = 5).	87

LIST OF FIGURES

		Page
Figure 3.1	Map showing the land use in Penang Island, Malaysia.	25
Figure 3.2	Mist net that was used during sampling.	27
Figure 3.3	The measurements for bats (T = tail, HB = head-body, HF = hind-foot, FA = forearm, E = ear) (modified from Francis, 2008).	28
Figure 4.1	Map of the study area showing the location of the sampling points in Penang Island, Malaysia.	33
Figure 4.2	Photos of bats species captured in Penang Island, Malaysia; (a) *Cynopterus brachyotis*, (b) *Cynopterus sphinx*, (c) *Cynopterus horsfieldi*, (d) *Eonycteris spelaea*, (e) *Macroglossus minimus*, (f) *Macroglossus sobrinus* (g) *Dyacopterus spadiceus* and (h) *Penthetor lucasi*.	43
Figure 4.3	Species abundance (a) and species richness (b) differences across the Penang Island urban-rural gradient.	45
Figure 4.4	Graphical representation of the non-metric multidimensional scaling (NMDS) ordination based on chord distance matrix of bat composition and abundance across urban, suburban and rural gradient. Note that the result for NMDS stress value was equal to 0.01.	47
Figure 4.5	The average forearm length (mm) correlated with percentage of urbanisation: (a) average forearm length of *C. sphinx* and percentage of urbanisation; and (b) average forearm length of *C. brachyotis* and percentage of urbanisation.	49
Figure 5.1	Map of the sampling points in Penang Island, Malaysia.	59
Figure 5.2	Habitat suitability map of bats in Penang Island.	71
Figure 6.1	The (a) external and (b) internal view of the captive room located at the School of Biological Sciences, Universiti Sains Malaysia.	82
Figure 6.2	Nightly variation in the duration of activity of *C. sphinx* and *C. brachyotis* when (a) fresh fruit, (b) blended fruit and (c) artificial fruit were given.	90

Figure 6.3	Feeding behaviour of *C. sphinx* when (a) fresh fruit and (b) blended fruit were given.	91
Figure 7.1	Map of the study sites where surveys were carried out in Penang Island, Malaysia.	100
Figure 7.2	Respondents knowledge of (a) bat occurrence in their residential area, (b) importance of bats to our ecosystem and (c) level of threat to bat populations.	105
Figure 7.3	Mean marks of the respondents based on age groups.	106
Figure 7.4	Mean marks of the respondents based on education.	107
Figure 7.5	Mean marks of the respondents based on monthly income.	108
Figure 7.6	Respondents willingness (a) to participate in conservation actions and (b) to participate in possible conservation actions to mitigate threats.	109

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
DOAP	Department of Agriculture Penang
EE	Environmental Education
ENFA	Ecological Niche Factor Analysis
GIS	Geographical Information System
GLM	Generalised Linear Models
GPS	Geographical Position System
HSI	Habitat Suitability Index
IUCN	International Union for Conservation of Nature
MBCRU	Malaysia Bat Conservation Research Unit
PEGIS	Penang Geographical Information System
RI	Random Index
SEABCRU	Southeast Asian Bat Conservation Research Unit
SPSS	Statistical Package for Social Science
UNESCO	United Nations Educational, Scientific and Cultural Organization

LIST OF PUBLICATIONS AND PRESENTATIONS

Shafie, N.J., Abdul Rahman, N.A., Mohd Sah, S.A, and Nik Rosely, N.F. (2013). The roles of olfaction and vision in the foraging behaviour of *Cynopterus brachyotis* (Pteropodidae). 2nd *Seminar on Sustainable Agriculture and Natural Resources, Strategies for Food Security through Innovative Development 9 April 2013.* Universiti Sains Malaysia. (Oral presentation)

Shafie, N.J., Nik Rosely, N.F., Mohd Sah, S.A., Wan Ibrahim, W.M**.** (2013). The proposal on distribution, ecology and feeding behaviour of fruit bats in Penang Island, Malaysia. *9th Colloquium PPSKH/IPS Postgraduate 6 November 2013*. School of Biological Sciences, Malaysia. (Oral Presentation)

Shafie, N.J., Mohd Sah, S.A, Mohamed, N.Z., Md Akil, M.A.M., Omar, M.Y., Harun, M.S., Azman, N.M., Quah, E. (2013). Survey of chiroptera species at Lata Belatan, Gunung Tebu Forest Reserve, Terengganu, Peninsular Malaysia. *Pembentangan Kertas Kerja Seminar Ekspedisi Saintifik Kepelbagaian Biologi Hutan Gunung Tebu, Terengganu 11-12 September 2013*. Hotel Permai, Kuala Terengganu. (Oral presentation).

Shafie, N.J., Abdul Rahman, N.A., Mohd Sah, S.A, and Nik Rosely, N.F., Maryam, S. (2014). Feeding behaviour of *Cynopterus sphinx* (Pteropodidae) under captive conditions. *Tropical Life Sciences Research*, 25(2), 53–59.

Shafie, N.J., Mohd Sah, S.A, Abd Mutalib, A. H. and Nik Rosely (2014). Saving the dark knights: The role of locals in conserving bats. *Tropical Life Sciences Research*. (in review).

Shafie, N.J., Mohd Sah, S.A, Wan Mohd Muhiyuddin, W. I., Ilmie, M.U. and Nik Rosely. (2014). Habitat suitability modelling of fruit bats in Penang Island. *Mammalia*. (in review).

Shafie, N.J., Mohd Sah, S.A, Amirrudin, A., and Nik Rosely (2014). Does urbanisation affect species richness, abundance and body size of fruit bat (Pteropodidae) assemblages? *Population Ecology*. (in review).

Azmy, S. N., Akmal, M. N., Shahrul Anuar, M. S., **Shafie, N.J**., Azman, A., Zulkepli, M., Muhammad Nor Akmal, and Mohd Shahir, S. 2012. Counting in the dark: Non-intrusive laser scanning for population counting and identifying roosting bats. *Nature Journal Scientific Reports*, 2: 524.

ASPEK EKOLOGI KELAWAR BUAH (MEGACHIROPTERA) DI PULAU PINANG, MALAYSIA

ABSTRAK

Kajian ini memfokuskan kepada taburan, ekologi, tabiat pemakanan dan pengetahuan dan kesedaran komuniti tempatan terhadap isu berkaitan konservasi kelawar buah di Pulau Pinang. Pengumpulan data telah dijalankan dari 2012 sehingga 2014. Objektif yang pertama adalah untuk menentukan sama ada urbanisasi memberikan kesan yang signifikan terhadap kekayaan spesies, kelimpahan spesies dan saiz badan kelawar buah. Sejumlah 521 individu yang terdiri daripada lapan spesies telah disampel. Terdapat perbezaan yang signifikan terhadap kelimpahan spesies kelawar apabila merentasi kawasan urban-pedalaman (ANOVA satu hala, $F_{(2, 18)} = 5.4947$, $p < 0.0162$). Kelimpahan kelawar buah adalah paling tinggi di kawasan suburban dan paling rendah di kawasan urban. Data menunjukkan urbanisasi memberi kesan positif terhadap saiz badan bagi *Cynopterus sphinx*. Walaubagaimanapun, korelasinya adalah korelasi yang lemah ($r^2 = 0.333$, $n = 18$, $p < 0.05$). Kajian ini mencadangkan taman di kawasan bandar penting untuk mengkonservasi tempat persinggahan dan habitat untuk mencari makanan bagi kelawar buah di kawasan bandar. Objektif kedua adalah menentukan taburan dan kesesuaian habitat bagi kelawar buah dengan menggunakan Sistem Maklumat Geografi. Jarak daripada kawasan kajian ke hutan, jalanraya, sungai, kawasan agrikultur, kawasan pembangunan, kawasan industri, kawasan rekreasi dan kawasan perumahan telah dianalisis. Nilai pemberat yang tertinggi adalah kawasan hutan dengan 0.36 dan dua skor terendah adalah jalanraya dan kawasan industri dengan masing-masing 0.03. Kawasan hutan didapati adalah faktor utama bagi kesesuaian

habitat kelawar buah. Di dalam objektif yang ketiga, tabiat pemakanan *C. brachyotis* dan *C. sphinx* di dalam kurungan dibandingkan dengan memberikan beberapa pilihan makanan iaitu pisang masak, pisang yang dikisar dan juga pisang tiruan. Kebolehan deria bau dan visual kedua-dua spesies ini terhadap diskriminasi bau dan bentuk pisang telah ditentukan. Tindakbalas *C. sphinx* dan *C. brachyotis* terhadap pisang yang dikisar dan pisang masak menunjukkan kedua-dua spesies ini menggunakan deria bau sebagai isyarat utama untuk mencari sumber makanan. Objektif yang terakhir menilai tahap kesedaran tentang kelawar di kalangan penduduk berdasarkan kumpulan umur, jantina, tahap pendidikan, tempoh bermastautin dan pendapatan bulanan. Kumpulan umur ($F_{(2, 150)} = 9.272$, $p = 0.0002$), tahap pendidikan ($F_{(3, 150)} = 5.727$, $p = 0.0010$) dan pendapatan bulanan ($F_{(3,150)} = 6.087$, $p = 0.0006$) berbeza secara signifikan di kalangan responden. Keputusan pengetahuan responden terhadap kelawar menunjukkan majoriti responden mempunyai tahap pengetahuan yang rendah terhadap kepentingan kelawar kepada ekosistem. Saranan yang dapat digarap daripada kajian ini termasuklah meningkatkan undang-undang perlindungan, memberi pendidikan kepada orang awam dan mewujudkan program pemantauan jangka masa panjang.

ECOLOGICAL ASPECTS OF FRUIT BATS (MEGACHIROPTERA) IN PENANG ISLAND, MALAYSIA

ABSTRACT

This study focuses on the distribution, ecology, feeding behaviour and knowledge and awareness of local community on conservation related issues of fruit bats in Penang Island. Data collection was conducted from 2012 until 2014. The first objective was to determine the effect of urbanisation on the species richness, species abundance and body size of fruit bats. A total of 521 individuals consisting of eight species were captured. There was a significant difference of abundance across the urban-rural gradient (one-way ANOVA, $F_{(2, 18)} = 5.4947$, $p < 0.0162$). The abundance of fruit bats was highest in suburban and lowest in urban sites. Urbanisation has a positive effect on body size of *Cynopterus sphinx*. However, the correlation was weak ($r^2 = 0.333$, n =18, $p < 0.05$). Urban parks appeared to be important for conserving roosting sites and foraging habitat for fruit bats in urban areas. The second objective was to determine the habitat suitability of fruit bats using the Geographical Information System. Proximity of the sampling points to forest, road, river, agriculture, development, industrial, recreational and settlement areas were analysed. The highest weight value was the forest area with 0.36 and the two lowest score were road and industrial area with 0.03 respectively. This result shows that the forest factor was the main important factor for habitat suitability of fruit bats. In the third objective, the feeding behaviour of *C. brachyotis* and *C. sphinx* in captive condition were compared by offering a selection of ripe bananas, blended bananas and artificial bananas. The responses of *C. sphinx* and *C. brachyotis* towards blended fruit and ripe banana fruit indicate that both these species use odour as the main cue to locate food source. The final objective revealed the knowledge and level of awareness regarding the conservation efforts of bat among locals based on age group, gender, level of education, years at present residence and their monthly income. The age groups ($F_{(2,\ 150)} = 9.272$, $p = 0.0002$), level of education ($F_{(3,\ 150)} = 5.727$, $p = 0.0010$) and monthly income ($F_{(3,150)} = 6.087$, $p = 0.0006$) were significantly different among the respondents. Results on respondents' knowledge of bats showed that the majority of the respondents had a low level of knowledge on the importance of bats to our ecosystem. Recommendations developed from this study include improving legal protection, educating the public and also developing long-term monitoring programs.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Taxonomy, distribution and behaviour of Megachiroptera (Pteropodidae)

All bats are grouped in the kingdom Animalia, Phylum Chordata and Class Mammalia. Bats are very special as they are the only mammal group that can truly fly (Medway, 1983). Mammals are distinguishable from other animals through several features. All bats have one pair of mammae on the chest. Most Malaysian species normally give birth to one young at a time. The fur of juveniles is characteristically several shades darker and grayer in color than that of adults or aged animals, which often becomes progressively tinged with red until renewed by moulting. Besides that, they also have a well-developed set of teeth (incisors, canines, premolars and molars) and their teeth are adaptable to their feeding behaviour.

Bats are classified under Order Chiroptera with two Suborders, Megachiroptera (frugivorous bats) and Microchiroptera (insectivorous bats). Family Pteropodidae is the only family under Megachiroptera, while there are another seven families under Microchiroptera; Nycteridae, Molossidae, Emballonuridae, Vespertilionidae, Megadermatidae, Rhinolophidae and Hipposideridae (Kingston *et al*., 2006). Members of family Pteropodidae are distinguished from all other Malaysian bats by the possession of a claw on the second digit of the wing (except for Cave fruit bat). In addition, they have moderately elongated muzzles, large eyes, simple and relatively small ears and either no tail or a very short tail.

Frugivorous bats are widespread and locally common in variety of habitat types from highland to lowland forest, orchards, and plantations (Francis *et al*., 2007). They usually inhabit and roosts in small groups in trees, under the fronds of palms, occasionally in houses or caves. Fruit bats orientate in darkness by sight and not by means of echolocation like insectivorous bats.

Frugivorous bats mainly feed fruits and nectar and they play important roles in the dispersal of seeds of many plant species, particularly in the tropics (Fleming, 1993). They usually depend on many factors to disperse plant, such as the factor of colour, shape, size, display, nutritional value and also the phenology of the plants (Mack, 1993). The feeding behaviour of frugivorous bats also depends on their ability to find fruit and there are three important cues that they mainly use to find food; vision, echolocation and olfaction (Von Helversen *et al*., 2000). While olfaction and echolocation are important in darkness, vision may support the search for plants in moonlight or crepuscular times (Von Helversen & Von Helversen, 2003).

1.2 Bats conservation status in Southeast Asia and Malaysia

The Southeast Asian region is one of the world's biodiversity hotspots (Myers *et al*., 2000) and constitutes approximately 30% of the region's mammal species. Chiroptera or bat is the second most diverse groups after rodents with 1116 species worldwide (Acharya, 2001). Wilson and Reeder (2005) listed 320 species of bats in Southeast Asia with another ten records were described including, *Kerivoula kachinensis* (Bates *et al*., 2004), *K. krauensis* (Francis *et al*., 2007), *K. titania* (Bates *et al*., 2007a), *Murina harrisoni* (Csorba & Bates, 2005), *M. tiensa* (Csorba *et al*., 2007), *Rhinolophus chiewkweeae* (Yoshiyuki & Lim, 2005), *Hipposideros khaokhaouayensis* (Guillén-Servent & Francis, 2006), *H. boeadii* (Bates *et al*., 2007b), *Dyacopterus rickarti* (Helgen *et al*., 2007), and *Styloctenium mindorensis* (Esselstyn, 2007). Overall, a total of ten families, 67 genera and 330 species of bats have been recorded in Southeast Asia with 197 species endemic to the region. As a consequence, this region is pivotal for international bat conservation.

The conservation status of bat populations in Southeast Asia is a major concern in this region. Only 53% of bat species are currently classified as Least Concern, while another 47% are classified into one of four categories of conservation concern either they are Near Threatened, Vulnerable, Endangered, or Critically Endangered. Nearly 20% of species are Data Deficient with fewest data available for the Rhinolophidae, Hipposideridae, Vespertilionidae, and Molossidae. The conservation status for Pteropodidae is better known, with only nine species considered Data Deficient, but 37 of the 96 species are threatened or nearly threatened (Kingston, 2010).Among Southeast Asian countries, Malaysia is known as one of 17 megadiverse countries that has a very unique biodiversity. Malaysia is a critical country for international bat conservation (Kingston *et al.*, 2006) with 109 species of bats from Peninsular Malaysia, 94 species from Sabah and 76 species from Sarawak (Simmons, 2005). Additional new geographic records for species of bats from Peninsular Malaysia; *Rhinolophus chiewkweeae* (Yoshiyuki & Lim, 2005), *Kerivoula krauensis* (Francis *et al*., 2007) and also an addition to bat list from Sarawak (Jayaraj *et al*., 2006; Khan, 2008; Sazali *et al*., 2011), making the total with 133 species from Peninsular Malaysia and 84 species from Sarawak. This represents over 10% of the world's bat fauna and about 40% of Malaysian mammal species. However, this is an underestimate of true species richness as many other species have yet to be described (Wiantoro *et al*., 2012).

In Peninsular Malaysia, the Krau Wildlife Reserve, Pahang is a crucial home for diverse species of insectivorous bats. This is officially a world record holder, within a 3 km^2 area surrounding Kuala Lompat Research Station, 53 species of bats have been recorded (Kingston, 2013). Moreover, the total includes 12 species that are listed by the International Union for the Conservation of Nature (IUCN, 2012) as being at some risk of extinction. These findings are the result of 8 years of bat research at Kuala Lompat and incorporate data from another 10 bat surveys at Krau Wildlife Reserve including from Lord Medway and David Wells in the early 70s.

Although only 18% of Malaysian bat species are considered threatened or near threatened (IUCN, 2012), populations are still decreasing at 26% of species and only 15% still stable. The population trends of 77 species (58%) are still unknown

(IUCN, 2012). In Southeast Asian countries, the primary threats to bat populations are due to habitat loss, degradation through logging activities and also hunting (Kingston *et al.,* 2006).

Declines in local species richness and abundance of bat species are likely to have profound effects on critical ecosystem services that bats provide as insect predators, pollinators and seed dispersers and which underpin forest regeneration (Hodgkison & Balding, 2004), the sustainability of commercial fruit crops and also control of insect crop pests (Leelapaibul *et al*., 2005). At least 31 Malaysian plant species rely on Old World fruit bats (Megachiroptera) to pollinate them, including favourites such as *Durio zibenthinus* (durian), *Parkia speciosa* (petai), *Mangifera indica* (mango), *Musa acuminata* (banana), *Psidium guajava* (guava), *Artocarpus heterophyllus* (jackfruit) and *Carica papaya* (papaya) (Kingston *et al.,* 2006). According to Carter (1984), the pollen grains of durians have been found to form a large part of the diet of only one species of bat, *Eonycteris spelaea*, a long-tongued fruit bat. Fortunately, *Eonycteris spelaea* comes in a wide range in Southeast Asia. Malaysian exports of durians in 2011 were valued at nearly US$9 million (Kingston *et al*., 2006). The insect-eating bats (Microchiroptera) are just as important. Every night, an insectivorous bat needs to eat an amount of at least half its body weight in insects. This is equivalent to 600 mosquito-sized insects in just an hour, and large colonies can consume over 2,000 tonnes of insects per year (Kingston *et al.,* 2006) and this is important for insect control.

1.3 Thesis structure

Conservation of fruit bats is crucial in sustaining the population and maintaining their role in our ecosystem. At this moment, 37 out of 96 species of Pteropodidae or fruit bats are listed as threatened or nearly threatened by the Red List of International Union for Conservation of Nature (IUCN). A proper set of effective and efficient strategies in conservation efforts need to be implemented to ensure the sustainability of this species.

This study provides initial information and evaluation of fruit bats conservation in Penang Island. Being the second most important urban centre in Malaysia, the urbanisation in Penang Island is expected to affect the biodiversity of wildlife, including the population of bats in this area. This thesis explores the biological, geographical, behavioural and social aspects on the conservation of fruit bats in urbanized area of Penang Island. In biological aspect, the effect of urbanisation on species richness, abundance and body size of fruit bats are emphasized. In addition, the geographical aspects determine the important environmental factor for fruit bats using the application of Geographical Information System (GIS). Furthermore, the role of olfaction and vision in the feeding behaviour of fruit bats are determined in behavioural aspects. The community-based conservation effort of bats in social aspects described the level of knowledge and awareness among local residents in Penang Island. In general, each chapter has their own objectives and hypothesis. The general objectives of this study are as follows:

(i) To determine the effects of urbanisation on species richness, abundance and body size of fruit bat assemblages.

(ii) To develop the habitat suitability model of fruit bats (Pteropodidae) using Geographical Information System (GIS) application.

(iii) To investigate the role of olfaction and vision in the feeding behaviours of *Cynopterus brachyotis* and *C. sphinx* under captive conditions.

(iv) To study the level of knowledge and awareness regarding the conservation efforts of bats among locals based on age group, gender, level of education, years at present residence and monthly income.

Chapter 1 provides the introduction, objectives and hypothesis of the study. A general look on fruit bats (Megachiroptera) is also presented in this chapter to give some insights, basically on its taxonomy, distribution, behaviour, and also the conservation status.

Chapter 2 provides the literature review that consists of several subchapters that cover all four main objectives in this study. The first subchapter discusses the sensitivity of bats on the effect of urbanisation. The second subchapter reviews the application of the Geographical Information System (GIS) on bat studies. The third subchapter determines the feeding behaviour in relation to the visual and fruit odours of fruit bats and the last subchapter discusses the conservation efforts of bats in Malaysia generally.

Chapter 3 provides the general materials and methods involved in this study such as the general information of the study area, mist-netting methods for bats capture and also the process involved in the identification of bats.

Chapter 4 focuses on the ecology of fruit bats in Penang Island. Sections for this chapter includes: the species richness and abundance across the urban-rural gradient, the correlation between the percentage of urbanisation and the average forearm length of *Cynopterus brachyotis* and *C. sphinx*. The hypothesis was that the species richness, species abundance and body size of fruit bats across urban-suburban-rural areas are different, and it is predicted that the species richness and abundance of fruit bats are higher in rural areas than urban areas.

Chapter 5 developed the habitat suitability model of fruit bats (Pteropodidae) in Penang Island using Geographical Information System (GIS) and Analytical Hierarchy Process (AHP). Eight independent variables including the proximity of the sampling points to forest, river, road, development, agriculture, industrial, recreational, and settlement areas were used in the process of the spatial modeling. The hypothesis was that independent variables do affect the spatial distribution of fruit bats in Penang Island.

Chapter 6 compared the feeding behaviours of *Cynopterus brachyotis* and *C. sphinx* under captive condition. The feeding behaviours between these two species toward ripe banana fruit, which included measuring the frequency of visits to banana fruits, the duration of feeding and resting periods, and the manner of fruit manipulation were compared. The relative role of olfactory and visual cues in the feeding behaviour of these two species and whether bats primarily use olfactory cues in detecting fruits were also determined. The hypothesis was that the feeding behaviours of *C. brachyotis* and *C. sphinx* are different, they use olfactory cues more than visual cues on detecting fruits.

Chapter 7 presented the level of knowledge and awareness among locals in Penang Island regarding the conservation efforts of bats in this area. This chapter revealed the level of awareness based on their age group, gender, level of education, years at present residence and also their monthly income. The conservation actions that residents are willing to take to mitigate local threats were also determined. The hypothesis was that the knowledge and level of awareness among locals are different between age groups, gender, level of education, length of residency and monthly income.

Chapter 8 concludes the thesis by summarizing the whole findings of the study and present several recommendations for future research to be undertaken. Each chapter in this thesis is written as a stand-alone manuscript. However, for clarity there may be repetitions of information in certain chapters.

CHAPTER TWO

LITERATURE REVIEW

2.1 The sensitivity of bats to urbanisation

The effects of urbanization on biodiversity of wildlife are generally considered to be negative. However, studies from around the world suggest that the impacts of urbanization on wildlife are not always negative, it can be differ between geographic regions and taxa. There are valid reasons to study the urban ecology of bats, besides the fact that they are a highly diverse group of mammals that occur worldwide (Voigt & Kingston, 2016). Bats are also good bioindicators of habitat quality and are responsive to urbanisation (Fenton, 2003).

Habitat loss or more specifically urbanisation is associated with the primary threats to the Southeast Asian and Malaysian bat species (Kingston *et al*., 2012). However, the sensitivity of bat on urbanisation varies due to several factors. In some cases, urbanisation may favour some species to succeed in human-altered conditions. For example, urbanisation benefits the Prairie bats in Alberta, Canada by creating structurally complex island that increased access to the vertical landscape elements such as buildings and trees in which they roost (Coleman & Barclay, 2012). The urbanisation increased the abundance of Prairie bats, but not the diversity of this species. Instead, the urban bat assemblage was less diverse and exhibited decreased species richness compared to non-urban assemblages. In Brazil, the presence of bright light from street lighting, attracting large groups of insects, significantly increased bat foraging activity around lights in this area (Gazarini & Pedro, 2013).

Similarly, *Mormopterus* spp. was the only species able to exploit the resources provided by urbanisation and foraged in areas with higher numbers of white streetlights. However, the remaining species of bats in the city of Townsville, North Queensland, Australia preferred to forage within close proximity to natural vegetation and with low numbers of streetlights (Hourigan *et al*., 2006).

The type of land cover and urban matrix also influence the sensitivity of bats on the effect of urbanisation. The relationship between land cover (agricultural, forest, suburban and urban mosaic) and activities of six species of insectivorous bats in USA were determined by Dixon (2012). The results showed that the responses of species vary depending on different scales (100, 500 and 1000 m of the sampling location) due to differences in their foraging and roosting behaviours. The tree cover and proximity to water were positively correlated to bat activity, but encroachment of impervious surfaces associated to urbanisation such as buildings and parking lots decreased the abundance of bats. Certain species of insectivorous bats in this study appear to do well in urban environments provided that there is sufficient tree cover. Another study that investigated the use of urban matrix and surrounding bushland on insectivorous bats found that tree density were the most common predictors of individual species presence, particularly rare species (Basham *et al*., 2011). On the other hand, the area of bushland, hollow abundance and average tree diameter were positively correlated with species richness.

Besides the land cover and urban matrix, many studies determined the role of urban parks on the activity, richness and abundance of bats in this area. A study by Johnson *et al*., (2008), determined the relationship between bat activity and composition in and adjacent to 11 national parks in the U.S. Both overall and species-specific activities were affected more by forest fragmentation within urban parks than by urbanisation adjacent to parks. Urban park was considered as intermediate degrees of urbanisation (Voight & Kingston, 2016). The species richness, relative abundance and diversity of bats were higher in urban parks compared to wooded and non-wooded streets in southeastern Brazil (Oprea *et al*., 2009). Urban parks do provide an abundance of potential bat roosting sites, natural and anthropogenic, but it is difficult to establish if they provide more roosting sites than rural areas (Johnson *et al*., 2008). Another study that was conducted in 10 urban parks in southeastern U.S found that the species richness was not related to development or any other landscape characteristics including the size of the urban park. In contrast, species evenness declined with increasing development, due to the dominance of big brown bats (*Eptesicus fuscus*) in these parks (Loeb *et al*., 2009).

Body size, wing form, echolocation call structure, feeding and roosting ecology all determine how bats fly and use the habitat landscape. Thus, it is not surprising that the effects of urbanisation on bats are to a significant extent species-specific (Voigt & Kingston, 2016). Because flight efficiency increases with body size, the energetic costs of flying farther to suitable foraging is greater for smaller species. Thus, in the eastern U.S., smaller species such as pipistrelles, evening bats, and red bats may be more heavily impacted by the effects of urbanisation than big brown bats which can better afford to fly to distant foraging sites if necessary (Loeb *et al*., 2009). This species also tend to be food and habitat generalists, exploiting the wide range of foods present in urban areas and travelling easily through matrix habitats (Baker & Harris, 2007).

Most of the researches on urban ecology have been limited to temperate insectivorous bats (Coleman & Barclay, 2012), and much attentions were given to urban birds (Garden *et al*., 2006). How tropical frugivorous bats and other vertebrate classes respond to urbanisation is less well understood. Furthermore, the effect of urbanisation towards the body size of frugivorous bats is still yet to be discovered. In order to address these research gaps, this study determined if there is significant effect of urbanisation on the species richness and species abundance of frugivorous bats, and to determine if there is a significant effect of urbanisation on the body size (forearm length) of frugivorous bats based on their species.

2.2 The application of the Geographical Information System (GIS) in bat studies

The Geographical Information System (GIS) are increasingly being applied into many fields including in wildlife ecology. Biologist and ecologist indicate that this trend will continue for the foreseeable future. Research in biology that used the application of GIS has followed many different methods. Overall, the applications of the GIS in wildlife studies are used as a conservation effort of many animal species. Since landscape modification is often considered the principal cause of population decline in many animal species, animal conservation rely heavily on knowledge about species-landscape relationships. The habitat suitability model or HSM predicts the spatial distribution of a wildlife species and has been widely used in wildlife ecology, biogeography, species management, and nature conservation (Huber *et al*., 2008; Elith & Leathwick, 2009; Huck *et al*., 2010.)

In bat studies, Jaberg and Guisan (2001) implemented the statistical models using bat abundance data to produce maps of landscape gradient affecting bat species assemblages and potential habitat distribution of individual bat species in Jura mountains, Switzerland. This study presented quantitative models using canonical correspondence analysis (CCA), generalized linear model (GLM) combined with GIS to draw up maps. Out of eight descriptors for landscape structure; elevation, forest or woodland cover, lakes and suburbs were found to be the most important predictors that affect the distribution of bat species in this area.

Another study conducted in Switzerland recorded the echolocation calls of two cryptic bat species, *Pipistrellus pipistrellus* and *P. pygmaeus* to study their distribution and abundance (Sattler *et al*., 2007). The echolocation and genetic data combined with GIS, Ecological Niche Factor Analysis (ENFA) and discriminant analysis were used to characterize species-specific habitat requirements, built habitat suitability maps and to determine interspecific differences in niche parameters. The distribution of *P. pygmaeus* was associated with landscape matrices comprising large rivers and lakes, human settlements and open woodland, whereas *P. pipistrellus* utilized similar habitat matrices but was far more tolerant to deviations from its optimal habitat.

Echolocation calls of bat also have been used by Hughes *et al*. (2010) to identify the species of insectivorous bats in Thailand. Presence-only modelling using maximum entropy (MaxEnt) was used to predict the distributions of species with similar echolocation calls and to determine whether such species used different calls in sympatry and allopatry. The eco-geographic variables (EGVs) used in the modelling included climatic variables, elevation, land cover, soil type, geology, caves, urban areas, waterways, roads and karsts. In another study by Hughes *et al*. (2012), they projected the effects of several climate change scenarios on bat diversity, and predicted changes in range for 171 bat species throughout Southeast Asia. Eco-geographical variables (EGVs) included in models were placed into three broad classes; unchanging physical variables (e.g. altitude, rivers and soil pH), changing vegetation predictions and changing environmental (i.e. climatic) variables.

The HSM inputs are environmental variables to predict the presence or absence locations of the studied species. The selection of environmental variables depends on existing knowledge of ecological systems and data availability (Koreň *et al*., 2011). Other than CCA, GLM, ENFA and MaxEnt, there is also another method for habitat suitability which is Analytical Hierarchy Process (AHP). Some models such as MaxEnt and ENFA work only with presence data, but AHP runs on a given presence and absence data or generates its own by an internal procedure.

Saaty (1980) proposed that Analytical Hierarchy Process (AHP) is a method for ranking decision alternatives and selecting the best option when the decision maker has multiple criteria. With AHP, the decision maker selects the best decision criteria and develops a numerical score to rank each alternative decision. The AHP enables the decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria (Saaty, 1977).

In AHP, preferences between alternatives are determined by making pairwise comparisons. In a pairwise comparison, the decision maker examines two alternatives by considering one criterion and indicates a preference. These comparisons are made using a preference scale, which assigns numerical values to 10 different levels of preference. The standard preferred scale used for the AHP is 1-9 scale which lies between "equal importance" to "extreme importance" (Saaty 1977, 1980). In the pairwise comparison matrix, the value 9 indicates that one factor is extremely more important than the other, and the value 1/9 indicates that one factor is extremely less important than the other, and the value 1 indicates equal importance. Therefore, if the importance of one factor with respect to the second factor is given, then the importance of the second factor with respect to the first is the reciprocal. The ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements (Saaty, 1980).

The method of AHP has been applied in many previous studies. Huhta and Jokimäki (1996) used the eigenvalue technique as applied in the AHP to determine the habitat suitability of two bird species; the Redstart (*Phoenicurus phoenicurus*) and the Pied Flycatcher (*Skeletocutis odora*). In addition, Store and Jokimäki (2003) improved the method used in GIS, integrated with habitat suitability index and AHP method to produce georeferenced ecological information about the habitat requirements for these two bird species. In 2001, Store and Kangas produced the habitat suitability maps of the Pied Flycatcher (*S. odora*) using GIS data processing and spatial analysis, together with modern decision analysis techniques to improve habitat suitability evaluation of this species over large areas. Similarly, Nikolakaki

(2004) used the same method which focuses on deciduous woodland with the Redstart, *Phoenicurous phoenicurous*.

To date, no study has been conducted using the AHP method on bat species. The AHP approach is generic, applicable to any species, and it can be a useful aid in conservation planning (Nikolakaki, 2004). Thus, in this study, the statistical models using presence-absence data combined with Analytical Hierarchy Process (AHP) in IDRISI and GIS software was implemented to determine the habitat suitability of the family Pteropodidae (fruit bats). Eight factors for landscape structure including; distance of forest cover, rivers, roads, development, agriculture, industrial, recreational, and settlement areas were chosen to determine the most important factors that may affect the distribution and habitat suitability of this family in the whole Penang Island.

2.3 The feeding behaviour in relation to the visual and fruit odours of fruit bats

Fruit consumption and seed dispersal by the family of fruit-eating bats (Pteropodidae) are important for conservation of forest area, especially for plant reproductive success, forest diversity maintenance and forest recovery after mild or severe disturbances (Medellin & Gaona, 1999). Most of fruit-eating bats use vision and olfaction not only for searching food, but also for spatial orientation and obstacle avoidance (Thies *et al*., 1998). The importance of vision and olfaction in feeding behaviour of fruit bats have been determined by many previous studies based on histological and anatomical studies (Bhatnagar & Kallen, 1975), laboratory experiments (Laska, 1990a), and field observations (Thies *et al*., 1998).

In semi-natural conditions, Thies *et al*. (1998) evaluated the attraction of *Piper* fruits on *Carollia* spp. They tested the response of *C. perspicillata* and *C. castanea* to variations in texture, form, position, and odour of *Piper marginatum* fruits. Both species exhibited positive responses to mimetic fruits of *P. marginatum* containing odour of smashed real ripe fruits, but both ignored real unripe and odourless mimetic fruits. They concluded that odour is more important than form and texture for food location and choice by *Carollia* spp. Mikich *et al*. (2003) performed field tests using mimetic *Piper* fruits with and without essential oil extracted through hydro distillation from *P. gaudichaudianum* ripe fruits in order to evaluate the role of odour in *Carollia perspicillata* attraction and capture in mist-nets. They concluded that odour is more important over visual cues in food location by *C. perspicillata* in a field situation. In addition, preference tests conducted in the laboratory by Laska (1990a) and in the field by Fleming *et al*. (1977) showed that this species was able to distinguish different stages of ripeness of a fruit.

Another study conducted under captive condition also found that both *Pteropus pumilus* and *Ptenochirus jagori* were not only able to locate fruits by their odour, but can also discriminate between ripe and unripe fruits of the same species by olfaction (Luft *et al*., 2003). Besides that, both of these species were given different type of fruits (e.g. banana, mango, and fig fruits) that are known to be consumed in the wild by *P. jagori*. Six fruit species were given to *P. pumilus* and five fruit species to *P. jagori*. Both could discriminate accurately between an empty dish and a dish containing fruits of one of several fruit species by odour alone.

In Malaysia, the role of visual and olfactory cues on the foraging behaviour of the short-nosed fruit bat (*Cynopterus brachyotis*) was conducted under captive condition at Kuala Lompat, Krau Wildlife Reserve, Pahang (Hodgkison *et al*., 2007). This study investigated the effect of both natural and synthetic fig fruit odours on the foraging behaviour of *C. brachyotis*, an important disperser of figs within the study area. Results showed that this species responded to both visual and olfactory cues when foraging for figs. However, the strongest foraging reaction that resulted in feeding attempt was associated with the presence of a ripe fruit odour, either in combination with visual cues or when presented alone. In addition, reaction rates to natural fruit odours were higher than those to synthetic blends.

The feeding behaviour of *Cynopterus sphinx* (Greater Short-Nosed Fruit Bat), one of the common species in Malaysia has also been conducted under captive condition in India (Elangovan *et al*., 2006). Seven undiluted odourants i.e. isoamyl acetate, ethyl acetate, hexanol, benzaldehyde, limonene, pinene, and dimethyl disulfide were assessed for odour discrimination. Results showed that this species were highly attracted to ethyl acetate, a chemical compound that is present in banana fruit, *Musa* spp. In early experiments, *Rousettus egyptiacus* was shown to discriminate between a box filled with 100 mg of banana and an empty box (Möhres & Kulzer, 1956), and between banana concentrate and natural banana fruit (Kulzer, 1958, 1961) by their smell. Rieger and Jakob (1988) manipulated the odour and shape of banana fruit during mist-net tests and concluded that odour was the main factor responsible for fruit-eating bat attraction and capture.

Cynopterus sphinx and *C. brachyotis* are common bat species in Malaysia, which occur sympatrically over a wide range from the Indian subcontinent to the Indo-Malayan region (Bates & Harrison, 1998). The present study aimed to compare the role of visual and olfaction in the feeding behaviour of these two species by providing fresh banana fruit (control), artificial banana fruit and cotton saturated with ripe banana fruit.

2.4 The conservation efforts of bats in Malaysia

Southeast Asia is one of the most biologically rich regions in the world. Within Southeast Asia, Malaysia is a pivotal country for bat conservation with over 10% of the world's bat fauna (Kingston *et al*., 2012). Although only 18% of bat species are considered threatened or near threatened (IUCN, 2012), populations are still decreasing at 26% of species and only 15% still stable. The primary threats to bat populations are due to habitat loss, degradation through logging activities and also hunting (Kingston *et al*., 2006a). Conservation research is urgently needed to reduce the impact of these threats on the Malaysian bat species.

With respect to Southeast Asia, the Southeast Asian Bat Conservation Research Unit (SEABCRU) was established and launched in May 2007 at the 1st International South East Asian Bat Conference in Thailand (Kingston, 2010). The Malaysian Bat Conservation Research Unit (MBCRU) was established in 2001 to promote research and conservation education on Malaysian bat species (Kingston *et al.*, 2012). It is a collaboration between scientists from the US (Texas Tech University, Boston University), Malaysia (Universiti Kebangsaan Malaysia and the Department of Wildlife and National Parks) and has also been supported by the National Science Foundation (US) and the National Geographical Society (US). The mission of the unit includes long-term research on bat diversity and conservation, the development and acquisition of skills and resources in Malaysia, and implementation of a local and web-based education program to highlight the diversity and biology of bats, as well as the international importance of Malaysia to bat conservation. Research focuses on establishing patterns of species abundance and distribution in undisturbed forest, and on identifying the ecological processes that influence these patterns (Kingston *et al.*, 2012).

MBCRU research is conducted in and around Krau Wildlife Reserve (KWR), Pahang, the oldest and second-largest protected area in Peninsular Malaysia. KWR is a home to at least 70 species of bats (about 60% of the Peninsula's bat fauna) and efforts have focused on over 30 species of insectivorous bats of the rainforest interior, as predicted to be particularly vulnerable to forest degradation (Kingston *et al.*, 2003).

In the early establishment of MBCRU, three local masters students and one PhD student were fully sponsored by MBCRU at UKM. The development and implementation of a five day capacity building workshop "Bat Identification and Survey Techniques" was conducted between 2002 and 2004, with over 50 participants from Department of Wildlife National Park (DWNP) officers, NGO staff and students (Kingston *et al.*, 2012). In 2006, MBCRU published a field guide for

Malaysian bats species, “The Bats of Krau Wildlife Reserve” which provides a photographically illustrated key to external features for all bat (known at that time) of Peninsular Malaysia and full species accounts (description and ecology) for over 70 species of KWR. In addition, MBCRU produced a manual that described bat handling techniques, species identification using dichotomous keys, survey methods, data collection protocols and also specimen preparation (Kingston *et al*., 2012).

MBCRU also conducts MBCRU Environmental Education (EE) in Malaysia to emphasize three key elements; the diversity of bats in Malaysia, their ecological and economic role, and their vulnerability to habitat loss and hunting (Kingston *et al*., 2006c). Materials designed in this EE program include; an introductory brochure on the bats of Malaysia which was distributed to 8000 secondary school student members of MNS’s Nature Club, posters illustrating the diversity of bats in Malaysia, a guide for a children’s bat workshop for 7-12 years old, environmental maths problems for older children, and role play and bat projects for adults and amateur naturalists. The focus of MBCRU effort is to train outreach workers and educators to use the materials in their own programs through workshops.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Study sites

Penang is one of the 13 states of the Federal territory of Malaysia and is located on the northwest coast of the Peninsular Malaysia. It is bordered in the north and east by the state of Kedah, to the south by the state of Perak and to the west by the Straits of Malacca and Sumatra (Indonesia). Penang is known as 'Pearl of the Orient' and is the second most important urban centre in Malaysia (Teo, 2003). Penang consists of the island of Penang and a coastal strip on the mainland, previously known as Province Wellesley (Seberang Perai). The island covers an area of 285 km^2 and consists of coastal plains, hills and mountain (Pradhan *et al*., 2012). The population of Penang is approximately 1.6 million of which 41.5% are ethnic Chinese, 40.9% Malays, 9.9% Indians, 7.0% Non-Malaysian citizens, 0.4% others Bumiputera and 0.3% others (Department of Statistics, 2013).

According to the Malaysian Meteorological Department data, the temperature of Penang ranges between 29 ºC and 32 ºC, mean relative humidity between 65% and 70% and rainfall averages between 2,670 and 6,240 mm (Lee & Pradhan, 2006). This present study was conducted between September 2012 and February 2014 within Penang Island, Malaysia.

All of the working chapters in the study are generally carried out in different sampling points within Penang Island. To investigate the role of olfaction and vision of fruit bats (Chapter 6), each sampled bat was immediately brought back and housed in a captive room at the School of Biological Sciences (SBS), Universiti Sains Malaysia, Pulau Pinang for the behavioural experiments. Figure 3.1 shows the land use map in Penang Island, Malaysia.