SPECIES RICHNESS, COMMUNITY COMPOSITIONS AND MICROHABITAT CHARACTERISTICS OF NON-VOLANT TERRESTRIAL SMALL MAMMALS IN DISTURBED HABITATS IN SABAH, MALAYSIA

LEONA WAI

THIS DISSERTATION IS SUBMITTED TO OBTAIN A BACHELOR'S DEGREE QUALIFIES

CONSERVATION BIOLOGY PROGRAMME

FACULTY OF SCIENCE AND NATURAL RESOURCES

UNIVERSITI MALAYSIA SABAH

262922

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: SPECIES RICHNESS, COMMUNITY COMPOSITIONS AND MICROHABITAT CHARACTERISTICS OF NON-VOLANT TERRESTRIAL SMALL MAMMALS IN DISTURBED HABITATS IN SABAH, MALAYSIA

IJAZAH: SARJANA MUDA SAINS DENGAN KEPUJIAN

SAYA: LEONA WAI (HURUF BESAR) SESI PENGAJIAN: 2012-2015

Mengaku membenarkan tesis *(LPSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/)

[ ] SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di AKTA RAHSIA RASMI 1972)

[ ] TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana Penyelidikan dijalankan)

[ ] TIDAK TERHAD

PERPUSTAKAAN UNIVERSITI MALAYSIA SABAH

Disahkan oleh: NURULAIN BINTI ISMAIL
LIBRARIAN
UNIVERSITI MALAYSIA SABAH

(TANDATANGAN PENULIS) (TANDATANGAN PUSTAKAWAN)

Alamat tetap: NO 67, LORONG 3A, TAMAN MALAKUN, KAMPUNG KUAI, JALAN RAMAYAH UTAMAN, 89507 PENAMPANG, SABAH

PROF. MADYA DR. HENRY BERNARD
NAMA PENYELIA

Tarikh: 19/6/15 Tarikh:

Catatan :- * Potong yang tidak berkenaan.
*Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.
*Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana Secara penyelidikan atau disertai bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM)

DECLARATION

The materials of this thesis are original except for quotation, excerpts, summaries and references, which have been dully acknowledged.

LEONA WAI

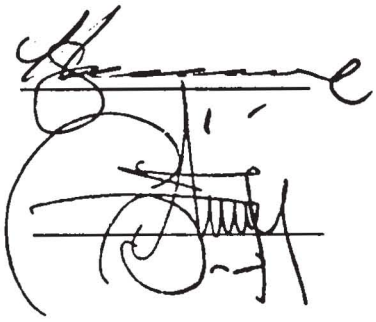
BS12110288

MAY 2015

APPROVED BY

Signature

1. **SUPERVISOR**
   (ASSOC. PROF. DR. HENRY BERNARD)



2. **DEAN**
   (PROF. DR. BABA MUSTA)

ACKNOWLEDGEMENT

Firstly, I would like to give my deepest gratitude to God for His everlasting blessing and protection throughout my research period. I give my sincere thanks to my most wonderful supervisor, Dr. Henry Bernard for his comments, discussions, ideas, support and patience to bear with my attitude. Without him, I would wander aimlessly and this project would be impossible. I also thanked Sabah Forestry Department (SFD) for giving me permissions to do my research. Without a letter of permission from SFD, it would be impossible for me to collect data and do my sampling. I would like to express my appreciation to my friends Tan Kok Kiat, Foo She Fui, Hah Huai En, Eddie, Mohd. Imran, Nursuhadila, Ika, Audrey, Jaspher and Lonnie for helping me to carry those heavy traps up the hill, accompanied me to check traps and those bedtime stories that we shared. To all the research assistants that have helped me during this project; Alex, Ling, James, Zinin, Sabri, Wan, Sulaiman, Max and Albinus. Without them, I would not be able to reach my study sites and I will be lost in the forest. Thank you for teaching me the basic survival in the forest and for giving me useful advices. To all lecturers, friends and staff that have helped in directly and indirectly, thank you for everything. Especially to my mother for her constant support and accompanied me in her prayers.

Leona Wai

FSSA, UMS

ABSTRACT

A study on the small mammals communities was carried out in disturbed habitats around Sabah, namely Universiti Malaysia Sabah (UMS), Klias Peat Swamp Forest Reserve (Klias), Kawang Forest Reserve (Kawang), Kalabakan Forest Reserve (within the SAFE project area) and Maliau Basin Conservation Area (Maliau). The aim of this study was to investigate how the habitat disturbance affects the species richness, community compositions and microhabitat-use patterns of the small mammals. The specific objectives were (1) to determine the species richness and composition of non-volant small mammal communities in disturbed habitats; (2) to characterize the microhabitat-use patterns of the non-volant small mammal communities in disturbed habitats; and (3) to determine the microhabitat preferences of the non-volant small mammal communities in disturbed habitats. Small mammal trapping was conducted using wire mesh live cage traps located along line-transects at all the sampling sites. The study was carried out from October 2014 to March 2015 and has resulted in a total sampling effort of 540 trap-nights. Overall, 71 individuals representing 14 species were successfully caught during the study. Taking sampling effort into account, the observed species richness appeared to follow a humped shape with sampling sites having intermediate disturbance appeared to show higher species number (SAFE, Klias and Kawang). Whereas, sites that are least disturbed (Maliau) and highly disturbed (UMS) recorded the least species number. Analysis of habitat variables showed that all study sites were generally divided into three distinctive groups which can be explained based on habitat disturbance levels and differences in terms of forest types. Canonical Discriminant Function Analysis was used to analyze the microhabitat preferences and microhabitat use-pattern of the small mammals. Results of this analysis showed that small mammals preferred areas with high shrub cover (*Rattus rattus* and *Callosciurus notatus*), litter cover (*Callosciurus prevostii* and *Echinorex gymnurus*) and herbs limber (*Tupaia gracilis*) which could be related to predator avoidance.

Keywords: Small mammals, habitat disturbance, microhabitat preferences, microhabitat use-pattern, species richness

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
ha	hectare
mm	millimeter
cm	centimeter
m	meter
am	morning
pm	evening
g	gram
et al	and others
i.e.	that is

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
ha	hectare
mm	millimeter
cm	centimeter
m	meter
am	morning
pm	evening
g	gram
et al	and others
i.e.	that is

LIST OF SYMBOLS

SYMBOLS	DESCRIPTION
%	percentage
=	equal
>	more than
&	and

CHAPTER 1

INTRODUCTION

1.1 Study Background

Mammals are among the most successful group of animals. There are 5,488 species of extant mammals in the world, divided generally into 29 orders and 154 families (Wilson & Reeder, 2005). In Borneo, there are 221 species of mammals (Payne & Francis, 2007), of which 164 species are known to be found in the state of Sabah in northern Borneo. In Sabah, 66 species of mammals are regarded as "small mammals" (Payne & Francis, 2007). The small mammals are generally defined as all mammals whose adult live weight in the wild is less than 1 kg, and this includes all rodents, bats and shrews (Barnett & Dutton, 1995). In terms of lifestyle, the small mammals are divided into four groups; terrestrial, fossorial, scansorial and arboreal (Begon *et al.*, 1996). As with other mammals in general, the small mammals are abundant and occupy various habitats ranging from the lowlands to the highlands.

Small mammals play important roles in the tropical rainforest ecosystems including potentially influencing forest regeneration and recovery, as well as maintaining the population dynamics of other animals. For example, many small mammal species are seed dispersers, pollination agents (Paine & Beck 2007; Wells *et al.* 2009) and important food sources to a variety of predators (Grassmann *et al.*, 2005). Therefore, it is essential to elucidate how the small mammal communities are affected by habitat disturbance and how this in turn affects their distribution and abundance, and other ecological aspects, such as habitat-use patterns. This information is useful to assist in the development of conservation and management plan of protected areas. Moreover, studying the small mammals are important because many species feed on food crops in agricultural area and caused significant loss to humans properties (Stenseth *et al.*, 2003; Singleton *et al.*,

2009), while other species have been implicated in the transmissions of various diseases to humans (Wells *et al.,* 2014).

Habitat conversion and degradation usually result in the loss of biodiversity and ecosystem services, though its effects on different groups of animals may not be similar (Well *et al.,* 2014). The species composition and richness of small mammal community will change, as a result of changes in vegetation structure following habitat disturbance and conversion (Eccard *et al.,* 2000; Blaum *et al.,* 2007; O' Farrell *et al.,* 2008). Specialist species will usually be lost or decrease in abundance due to the loss of specific microhabitats, while other species that are highly adaptable, will be more resilient to habitat change and may in fact increase in abundance (Wells *et al.,* 2007; Umetsu & Pardini, 2007; Puttker *et al.,* 2008; Bernard *et al.,* 2009).

1.2 Research Justification

The rapid and extensive conversion of primary forest areas to disturbed and converted habitats, such as regenerating secondary forests and agricultural plantations, would imply that in the future biodiversity conservation will have to take place in human modified habitats with some primary forest sites. Studies to investigate the habitat-use patterns or preferences of the non-volant small mammals can provide useful information for the conservation management of these mammals and their microhabitats, especially in disturbed habitats (Bernard, 2004). It is important to have the knowledge on habitat preferences of the small mammals, so that mammal species conservation can be made in areas where suitable habitats are still present. The present study aims to investigate the relationship between habitat disturbance and microhabitat-use patterns and the species richness and composition of the non-volant small mammal communities at various sites subjected to varying levels of disturbance in the state of Sabah.

1.3 Research Objectives

The specific objectives for this research are:

1. To determine the species richness and composition of the non-volant small mammal communities in disturbed habitats;
2. To characterize the microhabitat-use patterns of the non-volant small mammal communities in disturbed habitats; and
3. To determine the microhabitat preferences of the non-volant small mammal communities in disturbed habitats.

1.4 Research Hypothesis

The hypothesis of this research is that habitat disturbance affect the species richness and composition of the small mammal communities and the microhabitat-use patterns of the small mammals are not the same across the different habitat disturbance levels.

CHAPTER 2

LITERATURE REVIEW

2.1 NON-VOLANT SMALL MAMMALS

Non-volant or non-flying small mammal refers to ground dwelling and sometimes arboreal small mammals, but excluding all flying small mammals i.e., the bats. They are generally divided into four groups based on their lifestyle i.e., terrestrial, fossorial, scansorial and arboreal (Begon *et al.*, 1996). Terrestrial small mammals are active on the forest floor, while fossorial small mammals are adapted to digging holes and live underground. The scansorial small mammals, though they may spend most of their active time on the forest floor, are adapted to climbing. Arboreal small mammals are the true canopy specialist and active mostly in the canopy (Begon *et al.,* 1996).

2.1.1 Small Mammals Diversity and Distribution in Sabah

The term "small mammal" does not exist as a taxonomic or zoological group. According to Barnett & Dutton (1995), small mammals are defined as all mammals whose adult live weight in the wild is less than 1 kg. Small mammals include rodents, bats and shrews. A total of 221 species of terrestrial mammals are known to exist in Borneo (Payne & Francis, 2007), but only 164 species of extant mammals have been recorded in Sabah, north Borneo. Out Of this number, 66 species are considered as small mammals. The small mammals in Sabah are generally grouped under three orders, namely Insectivora, Scandentia and Rodentia (Payne & Francis, 2007).

Order Insectivore consists of only two families; Erinaceidae and Soricidae. Erinaceidae consist of only two species; *Echinosorex gymnurus* and *Hylomys suillus*. *E. gymnurus* or commonly known as the moonrat, is adapted only to living in lowland dipterocarp forest and is distributed in Burma, Peninsular Thailand and Malaysia, Sumatra and Borneo (Payne & Francis, 2007). Meanwhile, *H. Suillus* or known as the

lesser gymnure, can only be found in high altitude or montane forest (Payne & Francis, 2007). In Sabah, this species has been recorded only from Mount Kinabalu and Trus Madi (Yasuma *et al.*, 2003). Soricidae belongs to the shrew's family and almost every species in this family are rarely found and are not widely distributed. Soricidae is active on the forest floor and sometimes live inside burrows (Payne & Francis, 2007).

Scandentia consist of 10 species that are very similar looking to species from family Sciuridae. Morphological character that distinguished these two species is the long muzzle with a total of 38 pointed teeth (Payne & Francis, 2007). Scandentia is widely distributed, ranging from lowland to montane forest. All species in this family are diurnal except for one species, *Ptilocercus lowii*. *Tupaia montana* is commonly found in montane forest while *T. minor* is adapted living near human settlements (Emmons, 2000).

The order Rodentia has the highest number of species compared to the other orders. The rodents are represented by three families; Sciuridae (34 species), Muridae (25 species) and Hystricidae (3 species). Rodents are widely distributed, ranging from beach area to montane forest and they have high tolerance towards habitat disturbance and conversion. Four species are known as commensal species, where it is adapted to living near human settlements; *Rattus rattus, R. exulans, R. norvegicus* and *M. castaneus* (Zubaid, 1999). The existences of these four species are normally associated with damage to crops and other humans' properties.

2.1.2 Roles of Small Mammals in Natural Ecosystem

Small mammals play important roles in restoring the ecology of the forest (Converse *et al.*, 2006; Cusack, 2011). According to Wells & Bagchi (2005), small mammals are important seed dispersers of many tree species, including large lowland dipterocarps that are valuable commercially. They revealed that the Murid has the habits of removing seed before consumption at the feeding stations and this aids in seed dispersal. Moreover, small mammals are important food sources for various predators such as leopard cats (Grassmann *et al.*, 2005), and Malaysian Barn owls (Puan *et al.*, 2011).

2.2 Microhabitat Preferences and Microhabitat Use Pattern of Small Mammal Communities

In a hierarchal scale, habitat preferences can be arranged accordingly from geographic range of species, to individual home range within landscape and finally to selection of habitat for specific requirement within home range (Dotter and James, 1998; Wells *et al.*, 2006; Loveridge, 2012). In general, small mammals are able to use different microhabitat in different types of habitat (Bernard, 2004). Habitat use pattern and distribution of small mammals in the tropics can be affected by many ecological factors (Bernard, 2004). Factors such as different types of forest ecosystem, food availability, effects of predators and vertical and altitudinal stratification of vegetation, will affect the habitat preferences of small mammals (Whitten *et al.*, 1997).

Stapp (1997) concluded that patterns of habitat selection by small mammals reflect variation in the availability of resources in space and time. Small mammals will select their habitat based on the food abundance and minimum risk of predation (Loveridge, 2012). Habitat preferences of small mammals are affected by food abundance and suitability for reproduction (Bernard, 2004). For example, frugivores species such as spiny rat prefer a habitat where fig and palm fruit are abundant (Alder, 2000). Another example, in Brazil Cerrado, there is a high habitat variation, ranging from open grasslands to forested areas (Vieira *et al.*, 2005), where the species richness of small mammal is high in areas that have very dense vegetation (Marinho-Filho *et al.* 2002).

Food availability is also one of the main factors that affect the diversity and distribution of small mammals (Hoch & Adler, 1997; Miura, 1997; Bernard, 2004). Habitat selection are influenced by food availability, hence causes the increase in species composition in the selected habitat (Miura, 1997). Muda (2000) found out that *Tupaia glis* has the most diverse diet compared to other small mammals where they eat insects, fruits and vegetative matter. Small mammals such as rodents and insectivores, includes snail and slug in their diet (Vriends & Heming Vriends, 2000). *Ratufa affinis, Tupaia minor* and *Sundasciurus tenuis* have diet consisting of fruits, tree barks and plants (Payne & Francis, 2007).

Species richness is usually high in moderately disturbed forest; however species that are specialist will decline (Bernard, 2004). In disturbed habitats, the ground vegetation is dense due to low number of large trees (Loveridge, 2012). Dense vegetation is preferred by small mammals because it allows cover from predators. Dense vegetation minimizes the risk of predation and increase food abundance (Loveridge, 2012). According to Bernard (2004), in general, small mammals are able to adapt to environment changes although the species composition in disturbed habitat is different from primary forest.

In terms of temporal activities, the small mammals are generally divided into three groups; nocturnal, diurnal and crepuscular (Vaughan *et al.*, 2000). Nocturnal small mammals are active during night time. In Sabah, all Muridae and Erinaceidae species are nocturnal (Payne & Francis, 2007). Diurnal small mammals are active during the day; examples are Sciuridae (except all species of flying squirrels) and Tupaidae, except for *Ptilocercus lowii* (Payne & Francis, 2007). According to Banks *et al.* (2013), crepuscular small mammals are active during either or both dawn and dusk, for example rats and common mouse.

Whitten *et al.* (1996) stated that small mammals can be found in three layers of vertical strata; canopy level, scansorial and forest floor. During daytime, all strata are occupied by squirrels and treeshrews, however they will be replaced by rodents during night time (Yasuma *et al.*, 2003). For example, Black Giant Squirrel (*Ratufa bicolor*) can be found only 25 m above canopy level whereas Common Giant Squirrel (*Ratufa affinis*) can be found both on canopy level and middle storey of 5m (Payne & Francis, 2007). Vertical stratification reduces the predation risk by providing a better cover (Maisonneuve & Rioux, 2001). Example of small mammals that dwell on the forest floor is the Erinaceidae species (Payne & Francis, 2007). Long-tailed mouse (*Oryzomys longicauda*) is one of the examples for scansorial species, which adapted to both climbing trees and dwelling on forest floor (Martinez, 1997).

Small mammals are also segregated along the altitudinal gradient and their abundance changes accordingly as the elevation increases (Patterson *et al.*, 1990). Species diversity in lowland forest is high due to higher forest productivity, which means increase in the availability of the resources (Begon *et al.*, 1996). According to Payne and Francis (2007), example of lowland forest species are Pentail Treeshrew (*Ptilocerus*

lowii) and Common Treeshrew (*Tupaia glis*) whereas Himalayan Water Shrew (*Chimarrogale himalayica*) and Mountain Treeshrew (*Tupaia Montana*) are examples for montane forest species.

2.3 Tropical Rainforest in Sabah

Tropical rainforest in Sabah covers 44, 487.5 km^2, which is about 60.3% of the total area of Sabah itself, which is 73, 371 km^2 (Marsh & Greer, 1992). The tropical rainforest consists of six types of forest; lowland dipterocarp forest, montane forest, beach forest, palm forest, peat swamp forest and kerangas forest (Yasuma & Andau, 1999). Variety kind of flora and fauna in one complex ecosystem can be found in tropical rainforest due to different types of forest (Palik & Engstrom, 1999).

Whitten *et al.* (1997) explained that forest structure in Sabah changes according to the altitude change, which is from lowland dipterocarp forest to montane forest. Lowland dipterocarp forest is a forest that begins from beach area to 1200 m a.s.l. (Morley, 2000). This type of forest is dominated by giant trees from Dipterocarpaceae family, which has the diameter over 180cm and has a high commercial value (Campbell, 1994). Forest canopy of lowland dipterocarp forest can reached up to 70 m and considered as the tallest forest compared to other tropical rainforest in the world (Corrlet & Primack, 2011).

Tilling *et al.*, 1997 remarked that starting from 1,200 m, dipterocarp tree such as Shorea, Dipterocarpus and Parashorea spp. are slowly being replaced by low oak tree, which can be found at the range height of 5 m-33 m. This type of forest is known as montane forest. At 3,000 m a.s.l., montane forest shows more extreme feature, where the forest is covered with mosses and trees are covered with cotton-like coat to protect trees from high temperature, ultraviolet radiation and freezing (Whitmore, 1990). Strong wind and cold environment causes growth of trees to be stunted and the physical appearance of the trees are often twisted (Tilling *et al.*, 1997).

2.4 Habitat Disturbance

Sala *et al.* (2000) remarked that one of the major threats to biodiversity is the transformation or destruction of habitats due to unsustainable land use. Forest fragmentation will cause changes in habitat (Saunders *et al.*, 1991) such as tree species

richness or the size of the tree (Laurance *et al.*, 2002). Futhermore, slash-and-burn agriculture also affects forest in tropical regions (Nakagawa *et al.*, 2006). Secondary forest are allowed to regenerated after the abandonment of slash-and burn agriculture (Nakagawa *et al.*, 2006) however, this will cause a complete alteration of soil nutrients vegetation cover and biological production (Giardina *et al.*, 2000; Lawrence and Foster, 2002; Annan-Afful *et al.*, 2005).

According to Nakagawa *et al.* (2006), forest is used to satisfy human purposes and this will cause the increase of anthropogenic deforestation. Habitats alteration will affect the biodiversity of wild animals, raising the conservation concern and in need for a proper forest management. Whitmore (1997), Sodhi *et al.* (2004) and Nakagwa *et al.* (2006) stated that the increase in habitat loss is due to human activities such as logging and conversion of forest to agricultural area. Forest structure is essential for home to many wildlife species, however it is extremely altered by edge effects, selective logging, fire and the regeneration process (Cochrane, 2001; Dewalt *et al.*, 2003; Tews *et al.*, 2004).

In Sabah, approximately 60% of its 7.3 million ha area is still forested, of which 48% are gazetted as Forest Reserve or State or National Parks, respectively (Marsh *et al.*, 1996). Large proportion of Sabah is still considered under natural forest cover; however, many of these remaining forests have been modified and disturbed (Aiken & Leigh, 1992). Rapid transformation and conversion of natural forest in Sabah will likely continue in the future and this change will affects the wildlife communities that live in the forest (Bernard *et al.*, 2009).

Therefore, it is important to know the relationship between wildlife and the environment in order to improve conservation management (Bernard *et al.*, 2009). Wells *et al.* (2007) remarked that study on a wide spectrum of organism from different trophic levels is important because the impacts of habitat conversion differ among different groups of organism.

2.4.1 Small Mammals in Disturbed Habitats

Overexploitation of natural resources, habitat loss and conversion, introduction of invasive species and other anthropogenic pressure threaten mammals around the world and at least 82 mammal species have gone extinct to date (IUCN, 2014). Although small

mammal communities have low level of threat compared to other larger mammals, almost half of all extinct species are rodents (IUCN, 2014). This shows that not only large mammals are affected by global changes, the small mammals are also equally affected by it.

According to Eccard *et al.* (2000), Blaum *et al.* (2007) and O'Farrell *et al.* (2008), the species composition and richness of the small mammal communities will change, as a result of changes in vegetation structure due to the effects of conversion of habitats. According to Kelt (2000), changes in habitat structure due to fragmentation, affects the population of wildlife, such as small mammals. Species that are specialist in primary forest may be lost or decrease in abundance due to the loss of specific microhabitats that they favour (Wells *et al.*, 2007).

Hansen *et al.* (2001) explained that habitat disturbance is caused by logging and intensive agricultural lands, with uncertain effect towards ecological communities that are affected. One of the main conservation goals is to understand the relationship between wildlife communities and habitat disturbance (Hansen *et al.*, 2001). Previous studies have highlighted the harmful effects of logging activities towards small mammals, especially specialist species (Wells *et al.*, 2007; Umetsu & Pardini, 2007; Puttker *et al.*, 2008). Some species are able to withstand and become adapted to disturbed habitat whereas species that are easily affected by habitat disturbance were closely associated with old growth forest characteristics (Puttker *et al.*, 2008).

Lambert *et al.* (2006) concluded there is a positive relationship between small mammals and to both resource availability and habitat feature such as presence of vines in disturbed habitat. Wells *et al.* (2007) remarked that unlogged forest have higher species richness and diversity compared to logged forest. However, Bernard *et al.* (2009) and Nakagawa *et al.* (2006) stated that there is no noticeable difference of small mammal communities in logged and unlogged forest sites. According to Converse *et al.* (2006), habitat changes should have effect on small mammal communities; however it is still unclear how the habitat changes affect small mammal communities. However, Pardini *et al.* (2005) concluded that small mammals are good indicator for effects of disturbed habitats as they clearly respond to habitat and landscape alteration.

REFERENCES

Adler, G.H., Kielpinski, K.A., 2000. Reproductive phenology of a tropical canopy tree, Spondias mombin. *Biotropica*, **32**: 686–692.

Aiken, S.R. and Leigh, C.H. 1992: *Vanishing rain forests: the ecological transition in Malaysia.* Oxford: Oxford University Press.

Annan-Afful, E., Masunaga, T., Wakatsuki, T., 2005. Soil properties along the toposequence of an Inland valley watershed under different land use in the Ashanti region of Ghana. *Journal of Plant Nutrition.* **28**: 141–150.

Banks, R. E., Sharp, J. M., Doss, S. D. & Vanderford D. A. 2010. *Exotic Small Mammal Care and Husbandry.* John Wiley & Sons, USA.

Barnett, A. & Dutton, J. 1995. *Expedition Field Techniques: Small Mammals (excluding bats).* Expedition Advisory Centre, London, England

Begon, M., Harper, J. L. and Townsend, C. R. 1996. *Ecology: Individuals, Populations and Communities. 3rd edition.* Blackwell Science, UK.

Bernard, H. 2004. Effects of selective logging on the microhabitat-use patterns of non-volant small mammals in a Bornean tropical lowland mixed-dipterocarp forest. *Nature and Human Activities*, **8**: 1-11

Bernard, H. Fjeldså J. & Maryati M. 2009. A case study on the effects of disturbance and conversion of tropical lowland rain forest on the non-volant small mammals in north Borneo: Management implications. *Mammal Study*, **34**: 85-96

Blaum, N., Rossmanith, E., Jeltsch, F. 2007. Land use affects rodent communities in Kalahari savannah rangelands. *Afr. J. Ecol.* **45**: 189-195.

Campbell, E. J. F. 1994. *A Walk Through the Lowland Rain Forest.* Natural History Publications (Borneo) Sdn. Bhd., Sabah.

Coakes, S. J. & Steed, L. G. 2001. *SPSS: Analysis without anguish: version 10.0 for Windows.* Wiley

Cochrane, M.A.. 2001. Synergetic interactions between habitat fragmentation and fire in evergreen tropical forests. *Conservation Biology* **15**: 1515–1521.

Converse, S. J., Block, W. M. and White, G. C. 2006. Small mammal population and habitat responses to forest thinning and prescribed fire. *Forest Ecology and Management* **228**: 263-273

Cusack, J. 2011. Characterising small mammals responses to tropical forest loss and degradation in northern Borneo using Capture-Mark-Recapture methods. (*Unpublished)* Imperial College London.

Danielsen, F., and Heegaard, M. 1995. *Impact of logging and plantation development on species diversity: A case from Sumatra. In: Sanbukt (eds) Management of tropical rainforest: Towards an integrated perspective.* Centre for Development and the Environment, University of Oslo. Pp 73-92

DeWalt, S.J., Maliakal, S.K., Denslow, J.S. 2003. Changes in vegetation structure and composition along a tropical forest chronosequence: implications for wildlife. *Forest Ecology and Management* **182**: 139–151.

Dunn, R.R. 2004. Recovery of faunal communities during tropical forest regeneration. *Conservation Biology*, **18**(2):302-309

Eccard, J.A., Walter, R.B., Milton, S.J. 2000. How livestock grazing affects vegetation structures and small mammal distribution in the semi-arid Karoo. *J. Arid Environ.* **46**: 103-106

Emmons, L. H. 2000. *Tupai: A Field Study of Bornean Treeshrews.* University of California Press, California.

Giardina, C.P., Sanford Jr., R.L., Døckersmith, I.C., Jaramillo, V.J., 2000. The effects of slash burning on ecosystem nutrients during the land preparation phase of shifting cultivation. *Plant Soil* **220**, 247–260.

Grassman, L.I. jr., Tewes, M.E., Silvy, N.J. & Kreetiyutanont, K. 2005. Ecology of three sympatric felids in a mixed evergreen forest in North-Central Thailand. *Journal of Mammalogy*, **86**:29-38.

Hansen, A.J., Neilson, R.P., Dale, V.H., Flather, C.H., Iverson, L.R., Currie, D.J., Shafer, S., Cook, R. & Bartlein, P.J. 2001. Global change in forests: responses of species, communities and biomes. *BioScience*, **51**(9):765-779

Hoch, G. A. & Adler, G. H. 1997. Removal of black palm (Astrocaryum standleyanum) seeds by spiny rats (Proechimys semispinosus). *Journal of Tropical Ecology* **13**: 51-58

Hutton W., dan Matunjau C. 2010. *Discovering the wonders of the Klias Peninsula.* Sabah, Malaysia: Sabah Forestry Department.

Kalsum, Y. 2007. A comparison of the non-volant small mammal community in and around peat swamp forest of Klias Forest Reserve, Sabah, Malaysia. (*Unpublished*) Universiti Malaysia Sabah.

Kelt, D. A. 2000. Small mammal communities in rainforest fragments in central Southern Chile. *Biologi Conservation.* **92**: 345–358.

Lambert, T.D., Malcolm, J.R. & Zimmerman, B.L. 2006. Amazonian small mammal abundances in relation to habitat structure and resource abundance. *Journal of Mammalogy*, **87**(4):766-776.

Laurance,W.F., Lovejoy, T.E., Vasconcelos, H.L., Bruna, E.M., Dedham, R.K., Stouffer, P.C., Gascon, C., Bierregaard, R.O., Laurance, S.G., Sampaio, E., 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. *Conservation Biology* **16**: 605–618.

Magurran, A. E. 2004. *Measuring Biological Diversity.* Blackwell Publishing: United Kingdom

Lawrence, D., Foster, D., 2002. Changes in forest biomass, litter dynamics and soils following shifting cultivation in southern Mexico: an overview. *Interciencia* **27**: 400–408.

Maisonneuve, C. & Rioux, S. 2001. Importance of riparian habitats for small mammals and herpetofaunal communities in agricultural landscapes of southern Quebec. *Agriculture, Ecosystems and Environment* **83**: 165-175

Marinho-Filho, J.; Rodrigues, F. H. G.; Juarez, K. M. 2002. The Cerrado mammals: diversity, ecology, and natural history. In: The Cerrados of Brazil, Ed. by P. S. Oliveira, R. J. Marquis. New York: Columbia University Press, Pp. 266–284.

Martinez D. R. and Jaksic F. M. 1997. Selective predation on scansorial and arboreal mammals by rufous-legged owls (Strix rufipes) in southern Chilean rainforest. *Journal of Raptor Research* **31**(4): 370-375

McCain, C. M. 2004. The mid-domain effect applied to elevational gradients: Species richness of small mammals in Costa Rica. *Journal of Biogeography.* **31**: 19-31

Md. Nor, S. 2001. Elevational diversity patterns of small mammals on Mount Kinabalu, Sabah, Malaysia. *Global Ecology and Biogeography*. **10**: 41-62

Miura, S., Yasuda, M. & Ratnam, L. C. 1997. Who steals the fruit? Monitoring frugivory of small mammals in tropical rainforests. *Malayan Nature Journal* **50**: 183-193

Morley, R. J. 2000. *Origin and evolution of tropical rainforests*. John Wiley and sons Ltd., England.

Muda, H. 2000. Diet of small mammals in secondary tropical forests in Malaysia. *The Journal of Wildlife and Parks* **22**: 44-52

Nakagawa, M., Miguchi, H. and Nakashizuka, T. 2006. The effects of various forest uses on small mammal communities in Sarawak, Malaysia. *Forest Ecology and Management* **231**: 55–62

O'Farrell, M.J., Donaldson, J.S., Hoffman, M.T., Mader, A.D. 2008. Small mammal diversity and density on the Bokkeveld escarpment, South Africa-implications for conservation and livestock predation. *Afr. Zool.* **43**: 117-124

Palik, B. & Engsrom, R. T. 1999. *Species composition. Dlm. Maintaining diversity in forest ecosystem.* Ed. Hunter Jr., M. C. Cambridge University Press, UK.

Pardini, R., De Souza, S. M., Braga-Neto, R. & Metzger J. P. 2005. The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. *Biological Conservation* **124**: 253-266

Patterson, B. D., Meserve, P. L. and Lang, B. K. 1990. Quantitative habitat associations of small mammals along an elevational transaect in temperate rainforest in Chile. *Journal of Mammalogy* **71**(4): 620-633

Payne, J. and Francis, C. M. 2007. *A Field Guide to the Mammals of Borneo*. The Sabah Society, Kota Kinabalu.

Puan, C. L., Goldizen, A. W., Zakaria, M., Hafidzi, M. N. & Baxter, G. S. 2011. Absence of differential predation on rats by Malaysian barn owls in oil palm plantations. *Journal of Raptor Research* **45**(1): 71-78

Puttker, T., Pardini, R., Meyer-Lucht, Y. & Sommer, S. 2008. Responses of five small mammal species to micro-scale variations in vegetation structure in secondary Atlantic forest remnants, Brazil. *BMC Ecology*, **8**:9

Sala, O.E., Stuart Chapin, F., Armesto, J.J., Berlow, E., Bloomþeld, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., LeRoy Poff, N., Sykes, M.T., Walker, B.H., Walker, M. & Wall, D.H. (2000). Global biodiversity scenarios for the year 2100. *Science,* **287**(5459): 1770-1774

Saunders, D.A., Hobbs, R.J., Margules, C.R., 1991. Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* **5**: 18–32.

Sodhi, N.S., Koh, L.P., Clements, R., Wanger, T.C., Hill, J.K., Hamer, K.C., Clough, Y., Tscharntke, T., Posa, M.R.C., Lee, T.M. 2010. Conserving southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation*, **143**:2375–2384

Southwood, T. R. E. & Anderson, P. A. 2000. *Ecological Methods.* 3rd Edition. Blackwell Science: United Kingdom

Tews, J., Brose, U., Grimm, V., Tielborger, K., Wichmann, M.C., Schwager, M., Jeltsch, F., 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography* **31**: 79–92.

Tilling, S., Farbrother, D., Holmes, D. and Sanders, R. 1997. *Tropical forests and human impacts: Malaysia Case Studies.* Malaysian Timber Council, Malaysia.

Umetsu, F. & Pardini, R. 2007. Small mammals in a mosaic of forest remnants and anthropogenic habitats – evaluating matrix quality in an Atlantic forest landscape. *Landscape Ecology, 22*:517-530

Vaughan, T., J. Ryan, N. Czaplewski. 2000. *Mammalogy, 4th Edition.* Toronto: Brooks Cole.

Vieira, E. M., Iob, G., Briani, D. C. & Palma, A. R. T. 2005. Microhabitat selection and daily movements of two rodents (Necromys lasiurus and Oryzomys scotti) in Brazilian Cerrado, as revealed by a spool-and-line device. *Mammalian Biology* **70** (6): 359-365

Vriends, M. M. & Heming-Vriends, T. M. 2000. Hedgehod: The Complete Pet Owner's Manual Series

Well, K. & Bagchi, R. 2005. Eat in or take away-seed predation and removal by rats (Muridae) during a fruiting event in dipterocarp rainforest. *The Raffles Bulletin of Zoology* **53**(2): 281-286

Wells, K., Pfeiffer, M., Lakim, M. B. & Kalko, E. K. V. 2006. Movement trajectories and habitat partitioning of small mammals in logged and unlogged rain forests on Borneo. *Journal of Animal Ecology* **75**(5): 1212-1223.

Wells, K., Kalko, E. K. V, Lakim, M. B. & Pfeiffer M. 2007. Effects of rain forest logging on species richness and assemblage composition of small mammals in Southeast Asia. *Journal of Biogeography* 1-13

Wells, K., Lakim, M. B. & O'Hara, R. B. 2014. Shifts from native to invasive small mammals across gradients from tropical forest to urban habitat in Borneo. *Biodiversity Conservation* **23**: 2289-2303

Whitmore, T. C., 1990. *An Introduction to Tropical Rain Forests*. Oxford University Press Inc., New York.

Whitten, T., Soeriaatmadja, R. E. & Suraya, A. 1996. *The Ecology of Java and Bali. Vol II. The Ecology of Indonesia Series*. Periplus Editions (HK) Ltd, Singapore.

Whitten, T., Damanik, S. J., Anwar, J. & Hisyam, N. 1997. *The Ecology of Sumatra. Vol 1. The Ecology of Indonesia Series*. Periplus Edition (HK) Ltd, Singapore.

Yasuma, S. & Andau, M. 1999. *Mammals of Sabah part 1: Field Guide Identification*. JICA and Sabah Wildlife Department, Kota Kinabalu.

Yasuma, S., Andau, M., Apin, L., Yu, F. T. Y. and Kimsui, L. 2003. *Identification Keys to the Mammals of Borneo*. Sabah Parks, Kota Kinabalu.

Yasuma, S., Apin, L. & Fred Tuh, Y.Y., 2003. *Mammals of Crocker Range Field Guide*. Park Management Component BBEC Programme, Kota Kinabalu.

Zubaid, A. 1999. Rodents. *Malaysian Naturalist* **53**: 30-33