![UPM logo]

EFFECTS OF URBAN FOREST FRAGMENTATION ON NATIVE MAMMALS IN SELANGOR, MALAYSIA

TEE SZE LING

FH 2018 22

EFFECTS OF URBAN FOREST FRAGMENTATION ON NATIVE MAMMALS IN SELANGOR, MALAYSIA

By

TEE SZE LING

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

June 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

EFFECTS OF URBAN FOREST FRAGMENTATION ON NATIVE MAMMALS IN SELANGOR, MALAYSIA

By

TEE SZE LING

JUNE 2018

Chairman   : Badrul Azhar Md Sharif, PhD
Faculty   : Forestry

Rapid urbanisation has caused major deforestation and habitat fragmentation in the tropics. Yet, the ecological impacts of forest fragmentation on biodiversity are understudied in urban landscapes particularly those that are heavily surrounded by anthropogenic activities. To date, little is known about the conservation value of the patches for maintaining mammalian biodiversity, as each species requires different habitat characteristics. This study uses the camera trapping method to (1) determine the composition of medium- to large-sized mammal species present; (2) identify the dominant species of mammalian community; (3) compare the mammal species composition; and (4) determine the key habitat variables that affect the mammal species richness in three forest patches: AHFR, BCFR, and BFR and one contiguous forest, SLFR. All forest areas are located in Selangor, the most developed and urbanised state in Malaysia. The study was conducted from September 2016 to October 2017 by deploying 30 wildlife cameras at each forest area. A total number of 19 mammal species comprising 11 omnivores, four herbivores, three carnivores and one insectivore from 120 sampling points were recorded. SLFR had the highest number of species compared to the urban forest patches. Only three conservation priority species were recorded, namely the Sunda Pangolin in AHFR and BFR, the Asian Tapir in BCFR and SLFR and the White-handed Gibbon was recorded in the SLFR. Top predators such as Tigers and Leopards were completely absent from the forest patches. This was reflected by hyper-abundance of wild boars. In SLFR, Eurasian Wild Boar, Barking Deer, Long-tailed Macaque and Lesser Mousedeer represented 93% of the species composition. While in AHFR, 98% of the majority species composition made up of Pig-tailed Macaque and Lesser Mousedeer. Eurasian Wild Boar and Pig-tailed Macaque represented 91% and 94% of the species composition in BCFR and BFR respectively. Omnivorous species was the most common found in all study areas may explained by their high tolerance towards modified environments. The mammal species richness responded positively with the number of trees with DBH less than 5 cm, trees with DBH more than 50 cm,

and the number of dead standing trees. Sufficiency of food resources provided by trees with DBH less than 5 cm, hiding places provided by trees with DBH more than 50 cm, and food resources and nesting sites provided by dead standing trees are crucial for every species' persistency. Improving the connectivity between the urban forest patches and continuous forest may be impossible due to land scarcity and urban expansion. This is true particularly for facilitating the movement of ground-dwelling and arboreal mammals. Hence, government stakeholders are recommended to take intervention measures such as species reintroduction and restocking the wild populations in the urban forest patches.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN PENGASINGAN HUTAN BANDAR TERHADAP MAMALIA DI NEGERI SELANGOR, MALAYSIA

Oleh

TEE SZE LING

JUN 2018

Pengerusi   : Badrul Azhar Md Sharif, PhD
Fakulti   : Perhutanan

Pembangunan bandar yang pesat telah menyebabkan kemusnahan hutan dan fragmentasi habitat di kawasan tropika. Namun, kesan ekologi akibat daripada frgamentasi hutan terhadap biodiversiti masih kurang dikaji di landskap hutan bandar terutamanya hutan bandar yang dikelilingi oleh aktiviti pembangunan. Sehingga kini, hanya sedikit diketahui tentang nilai pemuliharaan fragmen hutan dalam mengekalkan biodiversiti mamalia, kerana setiap spesis memerlukan ciri-ciri habitat yang berlainan. Kaedah perangkap kamera digital telah digunakan dalam kajian ini untuk (1) menentukan komposisi spesis mamalia yang bersaiz sederhana dan besar; (2) mengenal pasti spesis dominan dalam komuniti mamalia; (3) membandingkan komposisi spesis mamalia; dan (4) menentukan kriteria habitat yang mempengaruhi kekayaan spesis mamalia di tiga fragmen hutan: Hutan Simpan Ayer Hitam (HSAH), Hutan Simpan Bukit Cerakah (HSBC) dan Hutan Simpan Bangi (HSB) dan satu hutan berterusan, Hutan Simpan Sungai Lalang (HSSL). Semua kawasan kajian terletak di negeri Selangor, negeri yang paling maju dan pesat di Malaysia. Kajian ini telah dijalankan dari September 2016 hingga Oktober 2017 dengan menggunakan 30 buah kamera hidupan liar di setiap kawasan hutan. Sejumlah 19 spesis mamalia dari 120 plot pensampelan terdiri daripada 11 omnivor, 4 herbivor, 3 karnivor dan 1 insektivore telah direkodkan. Hanya tiga spesis keutamaan pemuliharaan iaitu Tenggiling yang didapati hadir dalam HSAH dan HSB, Cipan ditemui dalam HSSL dan HSBC dan Ungka-Tangan Putih dijumpai di HSSL. Pemangsa teratas seperti harimau belang dan harimau kumbang tidak dijumpai di fragmen hutan. Ini dapat ditunjukkan oleh bilangan babi hutan yang tinggi. Komposisi spesis di HSSL diwakili oleh babi hutan, rusa, kera dan kancil sebanyak 93%. Manakala komposisi spesis di HSAH sebanyak 98% diwakili oleh beruk dan kancil. Komposisi spesis di HSBC dan HSB diwakili oleh babi hutan dan beruk sebanyak 91% dan 94% masing-masing. Spesis omnivor merupakan spesis yang paling kerap dijumpai di semua kawasan kajian. Ini boleh dihubungkaitkan dengan tahap toleransi

mereka yang tinggi terhadap persekitaran yang telah diubah suai. Kekayaan spesis mamalia menunjukkan hubungan positif dengan bilangan pokok yang mempunyai DBH kurang daripada 5 cm, pokok yang mempunyai DBH lebih daripada 50 cm, dan bilangan pokok mati yang berdiri. Pokok yang mempunyai DBH kurang daripada 5 cm, pokok yang mempunyai DBH lebih daripada 50 cm, dan pokok mati yang berdiri dapat memberi sumber makanan yang mencukupi, membekal tempat lindung dan tempat tinggal kepada semua spesis yang masih hidup dalam hutan terpisah. Sekiranya ingin menyambungkan fragmen hutan di bandar dengan hutan yang berterusan mungkin sangat mustahil disebabkan kekurangan tanah dan pengembangan bandar yang pesat. Ini adalah benar terutamanya untuk membenarkan pergerakan mamalia arboreal dan yang duduk atas tanah. Oleh itu, pihak kerajaan disyorkan untuk mengambil tindakan untuk melaksanakan langkah-langkah seperti pengenalan semula spesis tertentu dan menebus semula populasi liar di kawasan hutan bandar.

ACKNOWLEDGEMENTS

I certify that a Thesis Examination Committee has met on 29 June 2018 to conduct the final examination of Tee Sze Ling on her thesis entitled "Effects of Urban Forest Fragmentation on Native Mammals in Selangor, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Kamziah bt Abd Kudus, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Mohamad Azani bin Alias, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Shahrul Anuar Mohd Sah, PhD
Professor
Universiti Sains Malaysia
Malaysia
(External Examiner)

RUSLI HAJI ABDULLAH, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 27 September 2018

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Badrul Azhar Bin Md Sharif, PhD
Senior Lecturer
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Norizah Binti Kamarudin, PhD
Senior Lecturer
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Zubaid Akbar Mukhtar Ahmad, PhD
Professor
Faculty of Science and Technology
National University of Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

vii

Declaration by graduate student

I hereby confirm that:
- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: Tee Sze Ling (GS47499)

Declaration by Members of Supervisory Committee

This is to confirm that:
● the research conducted and the writing of this thesis was under our supervision;
● supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of
Supervisory Committee: Dr. Badrul Azhar Bin Md Sharif

Signature: _____
Name of Member of
Supervisory Committee: Dr. Norizah Binti Kamarudin

Signature: _____
Name of Member of Professor Dr. Zubaid Akbar Mukhtar
Supervisory Committee: Ahmad

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1   General Overview of Forest Alteration

The current world population is approximately 7.5 billion. Population growth correlated directly with deforestation (Sodhi et al., 2010). In Southeast Asia, tropical rainforests have become the easiest prey for land transformation (Abdullah & Nakagoshi, 2007; Seto et al., 2012). Malaysia has a total land area of 32.855 million hectares inhabited by 31.7 million people. Among all the other states, Selangor has the highest population of 6.3 million people (19.9%) (Department of Statistics Malaysia, 2017). In Peninsular Malaysia, out of a total land area of 13.2 million hectares, 5.77 million hectares (43.7%) are forested area (Department of Forestry Malaysia, 2017). These areas are under constant threat of being converted into agricultural lands followed by urban areas (Abdullah & Nakagoshi, 2007; Fitzherbert et al., 2008; Lucey et al., 2014).

Landscape modification is the spatial process of changing the landscape through vegetation alteration or anthropogenic modification (Lindenmayer & Fischer, 2006). The landscape can be altered by natural processes or anthropogenic activities (Lindenmayer & Fischer, 2006; Fischer & Lindenmayer, 2007). Natural disasters such as wildfires, flooding, typhoon and lightning are examples of an event that can alter the landscape, but the effects are minor as the landscape can recover in relatively short periods. Anthropogenic-induced modifications (i.e. construction of residential areas, agricultural lands, recreational areas, urbanisation and timber industrialization) are more likely to cause significant impacts on landscapes in terms of degrading landscape quality and uncontrollable expansions with maximum usage (Laurence & Bierregaard, 1997; Lindenmayer & Fischer, 2006).

Forest alteration is either complete or partial. Complete forest alteration commonly results from forest clearing and burning which removes all the vegetation on the land surface. This type of clearing is often used for urban developments such as the construction of residential areas, industrial areas and highways which require huge areas. The adverse impacts of forest clearing are more severe than partial clearing (Meijaard & Sheil, 2008). Partial forest modification includes selective logging system (SMS) in the timber industry, integrated human activities in forest areas, and forest conversion which dissect the forest into trails and smaller patches surrounded by different matrices. All alteration results in forest shrinkage, fragmentation and isolation which have positive and negative effects on the local ecosystem. Although a considerable amount of forest area survives through conversion and hosts some animal species, their conservation value in maintaining the biodiversity remains unclear.

1

1.2 Forest Fragmentation and Isolation

Due to agricultural expansion and urbanisation, vast expanses of forested areas are undergoing deforestation (Fitzherbert et al., 2008; Sodhi et al., 2010; Pozo-Montuy et al., 2013). In Malaysia, about 74% of the population is living in urban areas, and that population is growing. Hence, conservationists predict that more forested areas will be cleared to meet the demand of population growth and national development. Forest fragmentation occurs when the forest connectivity is broken due to disturbances from landscape alterations, smaller isolated patches and smaller populations (Fahrig, 2003; Fischer & Lindenmayer, 2007). The effects of forest fragmentation caused by urbanisation on ecology and biodiversity have not been studied as much as the agricultural impacts. The construction of beltlines for highways, recreational trails inside forested areas, residential areas, industrial areas and telecommunication towers are examples of projects that require large construction areas (Pirnat & Hladnik, 2016). The contiguous forests are now segregated by these anthropogenic landscapes which result in further forest isolation due to urban sprawling. It means that forest shrinkage and fragmentation threaten environmental and terrestrial biodiversity (Abdullah & Nakagoshi, 2007).

Forest isolation is a growing issue. It is caused by forest fragmentation and shrinkage (Fischer & Lindenmayer, 2007). An isolated forest patch is defined as an island surrounded by different matrices. They remain restricted areas, solitary and have lost the connectivity with other habitats (Haddad et al., 2015). It is difficult to determine whether the isolated forest patch is still suitable for wild animals to inhabit and how it affects the species remaining in these patches. Until now, the conservation value of the forest patches is still unidentified. It can vary according to the geographical range, adaptability of each species, the complicated inter-relationships between species and the outer pressures exerted by surrounding matrices (Pardini, 2004; Villaseñor et al., 2015).

1.3 Impacts of Forest Landscape Modification on Mammal Biodiversity

The impacts triggered by forest landscape modification on biodiversity level include habitat loss, habitat fragmentation, habitat isolation, degradation in habitat quality, changes in natural behaviours, imbalance ecosystem and local species extinction (Fischer & Lindenmayer, 2007).

Forest clearance causes the loss of natural habitats and limits the availability of their home range. Wildlife is forced to migrate from the degraded or open areas to other suitable habitats. If they fail to migrate, some species will be trapped in an isolated ecosystem which is detrimental to their long-term survival. The alteration of forest landscapes will also modify the native vegetation species by promoting the growth of fast-growing species. Some forest-specialist mammals that are strongly dependent on the native vegetation might come under stress due to insufficient food resources and nesting sites (Sodhi et al., 2010).

2

Isolated forest patches also have limited genetic transmission. As time passes, the species might be unable to reproduce leading to inbreeding which will produce low-quality progeny. Without a suitable mate or sufficient food resources, the entire species will be wiped out in this urban race. Yet, modified forest landscapes can act as a population catalyst for generalist species such as *Macaca spp.* and *Sus scrofa* (McShea et al., 2009). With a wide range of adaptability, they successfully thrived in the human-modified landscapes.

Forest clearance accelerates the extinction of local species through hunting, poaching and road-kills. The Department of Wildlife and National Parks reported that 1784 wildlife were killed in road accidents since 2011 until 2015. These cases were found commonly on the highways located next to the forested areas. Human activities such as logging and recreational activities also modify the internal structure of forests by constructing logging trails and tracks. With the aid of ready pathways, illegal hunters and poachers can easily go deep inside the forests without worried about future consequences.

1.4   Conservation Efforts in Urban Forest Patches

In addition to conserving a large area of forest, urban forests should be given more attention in order to understand the ecological effects and patterns on tropical rainforest species (Sodhi et al., 2010; Granados et al., 2016). Fragmented forest patches that persist in human-modified landscapes have become a new target for ecologists to identify the significance of urban forest patches in providing refuge sites for wildlife species (Laidlaw, 2000; Meijaard & Sheil, 2008; McShea et al., 2009; Sodhi et al., 2010; Ahumada et al., 2011; Brodie et al., 2015; Granados et al., 2016; Sasidhran et al., 2016; Adila et al., 2017). By having more information about the urban forest patches, a more well-established management system can be implemented to mitigate the ecological impacts caused by forest fragmentation.

1.5   Problem Statement

Medium- to large-sized mammals are classified as umbrella species which are susceptible to ecosystem changes as their life mostly relies on forest resources. They also have a larger home range compared to other animal taxa (Azlan & Sharma, 2006; Tobler et al., 2008; Gardner et al., 2009). Hence, they can be used to determine the effects of forest fragmentation. By identifying their existence in urban forest patches, their ecological acceptance level can be updated, and the habitat quality that affects can be verified. Mammals directly represent the health of the ecosystem which helps formulate targeted ecosystem services such as seed dispersal and nutrient cycling. Hence, quantifying their status in the fragmented urban forest is crucial for conservation measures (Granados et al., 2016).

Forest conversion from agricultural expansion is discussed widely, and its impacts on the ecosystem have been identified (Fitzherbert et al., 2008). Yet,

3

there is limited study about the impacts brought by urbanization on the forest ecosystems. To date, little is known about the urban forest patches that persist in the urban areas. There is no certain answer as to whether urban forest patches can sustain the mammal biodiversity. Even though some species still survive after forest conversion, another question arising is how long they can persist. Past research showed that disturbed forests retain their biodiversity value by becoming a refuge site for mammal species. However, the key environmental drivers which contribute to species survival and the conservation value of these urban patches remain unclear.

Unfortunately, little is known about the habitat quality and faunal biodiversity in forest patches which are surrounded by urban areas in Malaysia. Hence, there is an urgent need to determine the conservation value of these fragmented urban forests in terms of biodiversity especially in the most developed state in Peninsular Malaysia. The effects of habitat disturbance within forest fragmentation on native mammals were examined in this research by using non-intrusive motion-triggered camera traps. The findings of this study are crucial to justify the conservation of forest patches within urban matrices.

1.6   Hypotheses

Urban forest patches have significant conservation values for biodiversity. The species composition and richness in the forest patches represent the ecosystem health.

Three predictions have been made for this research:
1. Urban forest patches favour generalist species as they have wider ecological acceptance range.
2. Higher ecological disturbances in the urban forest patch decrease mammal species richness.
3. Large forest areas have diverse mammal species composition compared to small forest patches as more food resources and shelter choices are available.

1.7   Research Questions

In this study, the effects of urban forest fragmentation on native mammals are examined using non-intrusive motion-triggered camera traps.

The following research questions were assessed:
1. Is there any difference in the mammal species richness between each forest patch?
2. Is there any difference in the mammal species composition between each forest patch?
3. What are the key environmental drivers of mammalian biodiversity in

4

these urban forest patches?

1.8   Objectives of the Study

This study investigates the faunal biodiversity in urban fragmented forest patches. Mammal assemblages in each forest patch will be identified to understand better the effects of urban forest fragmentation on the native terrestrial mammals in the most urbanised state in Peninsular Malaysia.

The specific objectives of this study are:
1. To identify the medium- to large-sized mammal species present in each forest patch;
2. To identify the dominant species of mammalian community in each forest patch;
3. To compare the mammal species composition between each forest patch; and
4. To determine the key habitat variables that affect the mammal species richness in each forest patch.

REFERENCES

Abdullah, S. A., & Hezri, A. A. (2008). From forest landscape to agricultural landscape in the developing tropical country of Malaysia: pattern, process, and their significance on policy. *Environmental Management*, *42*(5), 907-917.

Abdullah, S. A., & Nakagoshi, N. (2007). Forest fragmentation and its correlation to human land use change in the state of Selangor, Peninsular Malaysia. *Forest Ecology and Management*, *241*(1), 39-48.

Adila, N., Sasidhran, S., Kamarudin, N., Puan, C. L., Azhar, B. & Lindenmayer, D. B. (2017). Effects of peat swamp logging and agricultural expansion on species richness of native mammals in Peninsular Malaysia. *Basic and Applied Ecology, 22*, 1-10.

Ahumada, J. A., Silva, C. E., Gajapersad, K., Hallam, C., Hurtado, J., Martin, E., & Sheil, D. (2011). Community structure and diversity of tropical forest mammals: data from a global camera trap network. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *366*(1578), 2703-2711.

Allnutt, T. F., Ferrier, S., Manion, G., Powell, G. V., Ricketts, T. H., Fisher, B. L., Harper, G. J., Irwin, M. E., Kremen, C., Labat, Jean-Noël, Lees, D. C., Pearce, T. A., & Rakotondrainibe, F. (2008). A method for quantifying biodiversity loss and its application to a 50-year record of deforestation across Madagascar. *Conservation Letters*, *1*(4), 173-181.

Andren, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos*, 355-366.

Antonini, Y., Martins, R. P., Aguiar, L. M., & Loyola, R. D. (2013). Richness, composition and trophic niche of stingless bee assemblages in urban forest remnants. *Urban Ecosystem, 16*(3), 527-541.

Azlan, J. M., & Sharma, D. S. (2006). The diversity and activity patterns of wild felids in a secondary forest in Peninsular Malaysia. *Oryx*, *40*(1), 36-41.

Bailey, D., Schmidt-Entling, M. H., Eberhart, P., Herrmann, J. D., Hofer, G., Kormann, U., & Herzog, F. (2010). Effects of habitat amount and isolation on biodiversity in fragmented traditional orchards. *Journal of Applied Ecology*, *47*(5), 1003-1013.

Ballantyne, M., Gudes, O., & Pickering, C. M. (2014). Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia. *Landscape and Urban Planning, 130*, 112-124.

Ballari, S. A., Conicet, C., & Barrios-Garcia, M. N. (2014). A review of wild boar *Sus scrofa* diet and factors affecting food selection in native and introduced ranges. *Mammal Review, 44*(2), 124-134.

Bernard, H., Fjeldså, J., & Mohamed, M. (2009). A case study on the effects of disturbance and conversion of tropical lowland rainforest on the non-volant small mammals in North Borneo: management implications. *Mammal Study, 34*(2), 85-96.

Boyd, S. F. (2003). *Forest composition, structure and wildlife abundance in mixed-dipterocarp forest of Sungai Lalang Forest Reserve, Selangor.* Unpublished master dissertation, Universiti Putra Malaysia, Selangor.

Brady, M. J., McAlpine, C. A., Possingham, H. P., Miller, C. J., & Baxter, G. S. (2011). Matrix is important for mammals in landscapes with small amounts of native forest habitat. *Landscape Ecology*, *26*(5), 617-628.

Broadbent, E. N., Asner, G. P., Keller, M., Knapp, D. E., Oliveira, P. J., & Silva, J. N. (2008). Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. *Biological conservation*, *141*(7), 1745-1757.

Brodie, J. F., Giordano, A. J., Dickson, B., Hebblewhite, M., Bernard, H., Mohd-Azlan, J., & Ambu, L. (2015). Evaluating multispecies landscape connectivity in a threatened tropical mammal community. *Conservation Biology*, *29*(1), 122-132.

Brotcorne, F., Maslarov, C., Wandia, I. N., Fuentes, A., Beudels-Jamar, R. C., & Huynen, M. C. (2014). The role of anthropic, ecological, and social factors in sleeping site choice by long-tailed macaques (*Macaca fascicularis*). *American Journal of Primatology*, *76*(12), 1140-1150.

Chiarello, A. G. (1999). Effects of fragmentation of the Atlantic forest on mammal communities in south-eastern Brazil. *Biological Conservation*, *89*(1), 71-82.

Crooks, K. R., Burdett, C. L., Theobald, D. M., King, S. R., Di Marco, M., Rondinini, C., & Boitani, L. (2017). Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. *Proceedings of the National Academy of Sciences*, *114*(29), 7635-7640.

Cuaron, A. D. (2000). A global perspective on habitat disturbance and tropical rainforest mammals. *Conservation Biology*, *14*(6), 1574-1579.

Department of Forestry Malaysia. (2017). Retrieved from https://www.forestry.gov.my/index.php/en/2016-06-07-02-53-46/2016-06-07-03-12-29 on 5 December 2017.

Department of Statistics Malaysia Official Portal. (2017). Retrieved from https://www.dosm.gov.my/v1/index.php?r=column/cone&menu_id=eGUyTm9RcEVZSllmYW45dmpnZHh4dz09 on 5 December 2017.

Devictor, V., Julliard, R., & Jiguet, F. (2008). Distribution of specialist and generalist species along spatial gradients of habitat disturbance and fragmentation. *Oikos*, *117*(4), 507-514.

DeWalt, S. J., Maliakal, S. K., & Denslow, J. S. (2003). Changes in vegetation structure and composition along a tropical forest chronosequence: implication for wildlife. *Forest Ecology and Management, 182*(1-3), 139-151.

Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., & Münkemüller, T. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, *36*(1), 27-46.

Douglas, D. J., Vickery, J. A., & Benton, T. G. (2009). Improving the value of field margins as foraging habitat for farmland birds. *Journal of Applied Ecology*, *46*(2), 353–362.

Edwards, D. P., Tobias, J. A., Sheil, D., Meijaard, E., & Laurance, W. F. (2014). Maintaining ecosystem function and services in logged tropical forests. *Trends in ecology & evolution*, *29*(9), 511-520.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual review of ecology, evolution, and systematics*, *34*(1), 487-515.

Felton, A., Felton, A. M., Wood, J., & Lindenmayer, D. B. (2006). Vegetation structure, phenology, and regeneration in the natural and anthropogenic tree-fall gaps of a reduced-impact logged subtropical Bolivian forest. *Forest Ecology and management*, *235*(1), 186-193.

Fischer, J., & Lindenmayer, D. B. (2007). Landscape modification and habitat fragmentation: a synthesis. *Global ecology and biogeography*, *16*(3), 265-280.

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Brühl, C. A., Donald, P. F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity?. *Trends in ecology & evolution*, *23*(10), 538-545.

Francis, C. M., & Barrett, P. (2008). *A field guide to the mammals of South-East Asia*. New Holland Publishers.

Fuentes-Montemayor, E., Goulson, D., Cavin, L., Wallace, J. M., & Park, K. J. (2013). Fragmented woodlands in agricultural landscapes: The influence of woodland character and landscape context on bats and their insect prey. *Agriculture Ecosystems and Environment*, *172*, 6–15.

Garden, J. G., McAlpine, C. A., Possingham, H. P., & Jones, D. N. (2007). Habitat structure is more important than vegetation composition for local-level management of native terrestrial reptile and small mammal species living in urban remnants: A case study from Brisbane, Australia. *Austral Ecology*, *32*(6)*,* 669–685.

Gardner, T. A., Barlow, J., Chazdon, R., Ewers, R. M., Harvey, C. A., Peres, C. A., & Sodhi, N. S. (2009). Prospects for tropical forest biodiversity in a human-modified world. *Ecology letters*, *12*(6), 561-582.

Garmendia, A., Arroyo-Rodríguez, V., Estrada, A., Naranjo, E. J., & Stoner, K. E. (2013). Landscape and patch attributes impacting medium-and large-sized terrestrial mammals in a fragmented rain forest. *Journal of Tropical Ecology*, *29*(4), 331-344.

Gibbons, P., Lindenmayer, D. B., Barry, S. C., & Tanton, M. T. (2002). Hollow selection by vertebrate fauna in forests of southeastern Australia and implications for forest management. *Biological Conservation*, *103*(1), 1-12.

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., Peres, C. A., Bradshaw, C. J. A., Laurance, W. F., Lovejoy, T. E., & Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*(7369), 378-381.

Gillman, L. N., & Wright, S. D. (2006). The influence of productivity on the species richness of plants: a critical assessment. *Ecology*, *87*(5), 1234-1243.

Granados, A., Crowther, K., Brodie, J. F., & Bernard, H. (2016). Persistence of mammals in a selectively logged forest in Malaysian Borneo. *Mammalian Biology-Zeitschrift für Säugetierkunde*, *81*(3), 268-273.

Gumert, M. D. (2011). The common monkey of Southeast Asia: Longtailed macaque populations, ethnophoresy, and their occurrence in human environments. *Monkeys on the edge: Ecology and management of long-tailed macaques and their interface with humans*, 3-44.

Gutiérrez, J. R., Meserve, P. L., Herrera, S., Contreras, L. C., & Jaksic, F. M. (1997). Effects of small mammals and vertebrate predators on vegetation in the Chilean semiarid zone. *Oecologia, 109*(3)*,* 398–406.

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., & Cook, W. M. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances, 1*(2), e1500052.

Hedges, L., Lam, W. Y., Campos-Arceiz, A., Rayan, D. M., Laurance, W. F., Latham, C. J., Saaban, S., & Clements, G. R. (2015). Melanistic leopards reveal their spots: Infrared camera traps provide a population density estimate of leopards in Malaysia. *The Journal of Wildlife Management*, *79*(5), 846-853.

Hughes, J., & Macdonald, D. W. (2013). A review of the interactions between free-roaming domestic dogs and wildlife. Biological Conservation, 157, 341-351.

Ickes, K. (2001). Hyper-abundance of native wild pigs (*Sus scrofa*) in a lowland dipterocarp rain forest of Peninsular Malaysia. *Biotropica*, *33*(4), 682-690.

IUCN, 2014. The IUCN Red List of Threatened Species. Version 2014.3: Table 5. Retrieved from http://www.iucnredlist.org on 12 December 2017.

Kawanishi, K., & Sunquist, M. E. (2004). Conservation status of tigers in a primary rainforest of Peninsular Malaysia. *Biological Conservation*, *120*(3), 329-344.

Kerr, J. T., & Deguise, I. (2004). Habitat loss and the limits to endangered species recovery. *Ecology Letters*, *7*(12), 1163-1169.

Konijnendijk, C. C., Nilsson, K., Randrup, T. B., & Schipperijn, J. (Eds.). (2005). *Urban forests and trees: a reference book*. Springer Science & Business Media.

Korhonen, L., Korhonen, K. T., Rautiainen, M., & Stenberg, P. (2006). Estimation of forest canopy cover: a comparison of field measurement techniques. *Silva Fennica 40*(4): 577–588.

Kuijper, D. P., Cromsigt, J. P. G. M., Churski, M., Adam, B., Jędrzejewska, B., & Jędrzejewski, W. (2009). Do ungulates preferentially feed in forest gaps in European temperate forest?. *Forest Ecology and Management*, *258*(7), 1528-1535.

Kupfer, J. A., Malanson, G. P., & Franklin, S. B. (2006). Not seeing the ocean for the islands: the mediating influence of matrix-based processes on forest fragmentation effects. *Global ecology and biogeography*, *15*(1), 8-20.

Laidlaw, R. K. (2000). Effects of habitat disturbance and protected areas on mammals of Peninsular Malaysia. *Conservation Biology*, *14*(6), 1639-1648.

Laurance, W. F., Nascimento, H. E., Laurance, S. G., Andrade, A. C., Fearnside, P. M., Ribeiro, J. E., & Capretz, R. L. (2006). Rain forest fragmentation and the proliferation of successional trees. *Ecology*, *87*(2), 469-482.

Laurance, W. F., & Bierregaard, R. O. (Eds.). (1997). *Tropical forest remnants: ecology, management, and conservation of fragmented communities*. University of Chicago Press.

Lindenmayer, D. B., & Fischer, J. (2006). *Habitat fragmentation and landscape change: An ecological and conservation synthesis*. CSIRO. Australia.

Lopucki, R., & Kitowski, I. (2017). How small cities affect the biodiversity of ground-dwelling mammals and the relevance of this knowledge in planning urban land expansion in terms of urban wildlife. *Urban Ecosystems, 20*(4)*, 933-943.

Lucey, J. M., Tawatao, N., Senior, M. J., Chey, V. K., Benedick, S., Hamer, K. C., Woodcock, P., Newton, R. J., Bottrell, S. H., & Hill, J. K. (2014). Tropical forest fragments contribute to species richness in adjacent oil palm plantations. *Biological Conservation*, *169*, 268-276.

47

Lynam, A. J., Laidlaw, R., Noordin, W. S. W., Elagupillay, S., & Bennett, E. L. (2007). Assessing the conservation status of the tiger Panthera tigris at priority sites in Peninsular Malaysia. *Oryx*, *41*(4), 454.

Magintan, D., Nor, S. M., Ean, T. P., Lechner, A. M., & Azhar, B. (2017). The conservation value of unlogged and logged forests for native mammals on the East Coast of Peninsular Malaysia. *Journal for Nature Conservation, 40*, 113-119.

Mäkeläinen, S., Schrader, M., & Hanski, I. K. (2015). Factors explaining the occurrence of the Siberian flying squirrel in urban forest landscape. *Urban Ecosystems 18*(1), 223-238.

Malaivijitnond, S., & Hamada, Y. (2008). Current situation and status of long-tailed macaques (*Macaca fascicularis*) in Thailand. *Natural History 8*(2):185-204.

Mathai, J., Sollmann, R., Meredith, M. E., Belant, J. L., Niedballa, J., Buckingham, L., Wong, S. T., Asad, S., & Wilting, A. (2017). Fine-scale distributions of carnivores in a logging concession in Sarawak, Malaysian Borneo. *Mammalian Biology-Zeitschrift für Säugetierkunde*, *86*, 56-65.

Matsubayashi, H., Lagan, P., Majalap, N., Tangah, J., Sukor, J. R. A., & Kitayama, K. (2007). Importance of natural licks for the mammals in Bornean inland tropical rain forests. *Ecological Research*, *22*(5), 742-748.

McElhinny, C., Gibbons, P., Brack, C., & Bauhus, J. (2005). Forest and woodland stand structural complexity: its definition and measurement. *Forest Ecology and Management*, *218*(1-3), 1-24.

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological conservation*, *127*(3), 247-260.

McKinney, M. L. (2008). Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosystems*, *11*(2), 161-176.

McShea, W. J., Stewart, C., Peterson, L., Erb, P., Stuebing, R., & Giman, B. (2009). The importance of secondary forest blocks for terrestrial mammals within an Acacia/secondary forest matrix in Sarawak, Malaysia. *Biological Conservation*, *142*(12), 3108-3119.

Meijaard, E., & Sheil, D. (2008). The persistence and conservation of Borneo's mammals in lowland rain forests managed for timber: observations, overviews, and opportunities. *Ecological Research*, *23*(1), 21.

Melo, F. P., Arroyo-Rodríguez, V., Fahrig, L., Martínez-Ramos, M., & Tabarelli, M. (2013). On the hope for biodiversity-friendly tropical landscapes. *Trends in ecology & evolution*, *28*(8), 462-468.

Miller, M. D. (2012). The impacts of Atlanta's urban sprawl on forest cover and fragmentation. *Applied Geography*, *34*, 171-179.

Mohamad, S. W., Rayan, D. M., Christopher, W. C. T., Hamirul, M., Mohamed, A., Lau, C. F., & Siwan, E. S. (2015). The first description of population density and habitat use of the mainland clouded leopard *Neofelis nebulosa* within a logged-primary forest in South East Asia. *Population ecology*, *57*(3), 495-503.

Monamy, V., & Fox, B. J. (2000). Small mammal succession is determined by vegetation density rather than time elapsed since disturbance. *Austral Ecology*, *25*(6), 580-587.

Morelle, K., Podgorski, T., Prevot, C., Keuling, O., Lehaire, F., & Lejeune, P. (2014). Towards understanding wild boar *Sus scrofa* movement: a synthetic movement ecology approach. *Mammal Review, 45*(1)*,* 15-29.

Newbold, T., Hudson, L. N., Hill, S. L. L., Contu, S., Lysenko, I., Senior, R. A., Börger, L., Bennett, D. J., Choimes, A., Collen, B., Day, J., Palma, A. D., Díaz, S., Echeverria-Londonrio, S., Edgar, M. J., Feldman, A., Garon, M., Harrison, M. L. K., Alhusseini, T., Ingram, D. J., Itescu, Y., Kattge, J., Kemp, V., Kirkpatrick, L., Kleyer, M., Correia, D. L. P., Martin, C. D., Meiri, S., Novosolov, M., Pan, Y., Phillips, H. R. P., Purves, D. W., Robinson, A., Simpson, J., Tuck, S. L., Weiher, E., White, H. J., Ewers, R. M., Mace, G. M., Scharlemann, J. P. W., & Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. *Nature, 520*(7545), 45-50.

Nichols, J. D., & Karanth, K. U. (2002). *Statistical concepts: estimating absolute densities of tigers using capture-recapture sampling.* Centre for Wildlife Studies.

Pardini, R. (2004). Effects of forest fragmentation on small mammals in an Atlantic Forest landscape. *Biodiversity and conservation*, *13*(13), 2567-2586.

Pirnat, J., & Hladnik, D. (2016). Connectivity as a tool in the prioritization and protection of sub-urban forest patches in landscape conservation planning. *Landscape and Urban Planning, 153,* 129-139.

Pozo-Montuy, G., Serio-Silva, J. C., Chapman, C. A., & Bonilla-Sánchez, Y. M. (2013). Resource use in a landscape matrix by an arboreal primate: evidence of supplementation in black howlers (*Alouatta pigra*). *International Journal of Primatology*, *34*(4), 714-731.

Pulliam, H. R. (1988). Sources, sinks, and population regulation. *The American Naturalist*, *132*(5), 652-661.

Rayan, D. M., & Linkie, M. (2016). Managing conservation flagship species in competition: Tiger, Leopard and dhole in Malaysia. *Biological Conservation, 204*, 360-366.

Rayan, D. M., & Mohamad, S. W. (2009). The importance of selectively logged forests for tiger *Panthera tigris* conservation: a population density estimate in Peninsular Malaysia. *Oryx*, *43*(1), 48-51.

Richard, A. F., Goldstein, S. J., & Dewar, R. E. (1989). Weed macaques: the evolutionary implications of macaque feeding ecology. *International Journal of Primatology*, *10*(6), 569-594.

Rosenblatt, D. L., Heske, E. J., Nelson, S. L., Barber, D. M., Miller, M. A., & MacAllister, B. (1999). Forest fragments in east-central Illinois: islands or habitat patches for mammals?. *The American Midland Naturalist*, *141*(1), 115-123.

Rovero, F., Martin, E., Rosa, M., Ahumada, J. A., & Spitale, D. (2014). Estimating species richness and modelling habitat preferences of tropical forest mammals from camera trap data. *PloS one*, *9*(7), e103300.

Saito, M., & Koike, F. (2013). Distribution of wild mammal assemblages along an urban-rural-forest landscape gradient in warm-temperate East Asia. *Plos one, 8*(5), e65464.

Salleh, K. M. (1999). The role and function of Universiti Kebangsaan Malaysia permanent forest reserve in research and education. *Pertanika Journal of Tropical Agricultural Science*, *22*, 185-198.

Salm, R. (2005). The importance of forest disturbance for the recruitment of the large arborescent palm Attalea maripa in a seasonally-dry Amazonian forest. *Biota Neotropica*, *5*(1), 35-41.

Sanei, A., & Zakaria, M. (2011). Occupancy status of Malayan leopard prey species in a fragmented forest in Selangor, Malaysia. *Asia Life Sciences Suppl, 7*, 41-55.

Sasidhran, S., Adila, N., Hamdan, M. S., Samantha, L. D., Aziz, N., Kamarudin, N., & Azhar, B. (2016). Habitat occupancy patterns and activity rate of native mammals in tropical fragmented peat swamp reserves in Peninsular Malaysia. *Forest Ecology and Management*, *363*, 140-148.

Schaub, M., Martinez, N., Tagmann-Ioset, A., Weisshaupt, N., Mau-rer, M. L., & Reichlin, T. S. (2010). Patches of bare ground as a staple commodity for declining ground-foraging insectivorous farmland birds. *PLoS One*, *5*, e13115.

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, *109*(40), 16083-16088.

Sodhi, N. S., Koh, L. P., Clements, R., Wanger, T. C., Hill, J. K., Hamer, K. C., & Lee, T. M. (2010). Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation*, *143*(10), 2375-2384.

Sodhi, N. S., Koh, L. P., Brook, B. W., & Ng, P. K. (2004). Southeast Asian biodiversity: an impending disaster. *Trends in Ecology & Evolution*, *19*(12), 654-660.

Soga, M., & Koike, S. (2012). Relative importance of quantity, quality and isolation of patches for butterfly diversity in fragmented urban forests. *Ecological Research, 27*(2), 265-271.

Soga, M., & Koike, S. (2013). Large forest patches promote breeding success of a terrestrial mammal in urban landscapes. *PloS one*, 8(1), e51802.

Soga, M., Tamaura, Y., Koike, S., & Gaston, K. J. (2014). Land sharing vs. land sparing: does the compact city reconcile urban development and biodiversity conservation?. *Journal of Applied Ecology, 51*(5)*,* 1378-1386.

St Pierre, J. I., & Kovalenko, K. E. (2014). Effect of habitat complexity attributes on species richness. *Ecosphere*, 5(2), 1-10.

Struebig, M. J., Kingston, T., Zubaid, A., Mohd-Adnan, A., & Rossiter, S. J. (2008). Conservation value of forest fragments to Palaeotropical bats. *Biological Conservation, 141*(8), 2112-2126.

Struebig, M. J., Turner, A., Giles, E., Lasmana, F., Tollington, S., Bernard, H., & Bell, D. (2013). Quantifying the biodiversity value of repeatedly logged rainforests: gradient and comparative approaches from Borneo. In *Advances in ecological research* (Vol. 48, pp. 183-224). Academic Press.

Tabarelli, M., Peres, C. A., & Melo, F. P. L. (2012). The 'few winners and many losers' paradigm revisited: Emerging prospects for tropical forest biodiversity. *Biologival Conservation, 155,* 136-140.

Taylor, B. D., & Goldingay, R. L. (2010). Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. *Wildlife Research*, *37*(4), 320-331.

Tobler, M. W., Carrillo-Percastegui, S. E., Leite Pitman, R., Mares, R., & Powell, G. (2008). An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. *Animal Conservation*, *11*(3), 169-178.

Turner, I. M., & Corlett, R. T. (1996). The conservation value of small, isolated fragments of lowland tropical rainforest. *Trends in Ecology & Evolution*, *11*(8), 330-333.

Van Dyke, F. (2008). *Conservation biology: foundations, concepts, applications*. Springer Science & Business Media.

Villaseñor, N. R., Blanchard, W., Driscoll, D. A., Gibbons, P., & Lindenmayer, D. B. (2015). Strong influence of local habitat structure on mammals reveals mismatch with edge effects models. *Landscape Ecology, 30*(2), 229-245.

Wells, K., Biun, A., & Gabin, M. (2005). Viverrid and herpestid observations by camera and small mammal cage trapping in the lowland rainforests on Borneo including a record of the Hose's Civet, *Diplogale hosei. Small Carnivore Conservation*, *32*, 12-14.

Woodcock, P., Edwards, D. P., Newton, R. J., Khen, C. V., Bottrell, S. H., & Hamer, K. C. (2013). Impacts of intensive logging on the trophic organisation of ant communities in a biodiversity hotspot. *PLoS One*, *8*(4), e60756.

Zakaria, M., & Rahim, A. (1999). Bird species composition in Ayer Hitam forest, Puchong, Selangor. *Pertanika Journal of Tropical Agricultural Science*, *22*, 95-104.

Zakaria, M., & Topani, R. (1999). Abundance of primates in Ayer Hitam Forest, Puchong, Selangor. *Pertanika Journal of Tropical Agricultural Science*, *22*, 105-109.

Zakaria, M., Silang, S., & Mudin, R. (2001). Species composition of small mammals at the Ayer Hitam Forest Reserve, Puchong, Selangor. *Pertanika Journal of Tropical Agricultural Science*, *24*(1), 19-22.

Zanette, L., Doyle, P., & Trémont, S. M. (2000). Food shortage in small fragments: evidence from an area-sensitive passerine. *Ecology*, *81*(6), 1654-1666.

Ziegler, S. S. (2000). A comparison of structural characteristics between old-growth and postfire second-growth hemlock–hardwood forests in Adirondack Park, New York, USA. *Global Ecology and Biogeography*, *9*(5), 373-389.