



Institute of Biodiversity and Environmental Conservation

**Wildlife Densities and Hunting by the Kenyah and Penan Communities
in the Upper Baram Region, Sarawak**

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**Master of Science
2024**

Wildlife Densities and Hunting by the Kenyah and Penan Communities in the Upper Baram Region, Sarawak

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A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

(Tropical Biodiversity)

Institute of Biodiversity and Environmental Conservation

UNIVERSITI MALAYSIA SARAWAK

2024

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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Date : 31st May 2024

ACKNOWLEDGEMENT

Foremost, all praises to the God, the Almighty for his blessings throughout my research work. I would like to take this opportunity to thank those who have contributed directly or indirectly to my research. This would not be possible without the assistance of many people. I am indebted to all of you.

I would like to express my deepest gratitude to my research supervisor, Professor Dr Mohd Azlan Jayasilan for his continuous support of my master science study. I greatly appreciate his patience, advice and motivation during my research. His invaluable guidance and thoughts has helped me all the time of research and writing of this thesis.

My sincere thanks goes to The Borneo Project, Save Rivers, Keruan and Bruno Manser Fonds for their financial and technical assistance including coordinating trips to the Ulu Baram. I would like to thank Jettie and Fi for their cooperation and advice throughout this journey and for keeping the project in a good track all the way. Thank you also to Celine, Samban and Bryan for taking good care of me while in Miri and feeding me with good food all the time in Ulu Baram. Your insightful comments, thoughts and suggestions really impacted and inspired me throughout this journey.

This endeavour would not be possible without the deepest commitment from local technicians who had been passionately working and assisting on the grounds to collect data. I thank the people of Long Siut, Long Tungan, Long Sait, Long Kerong, Long Spigen and Lepo Gah Tanjung Tepalit for their involvement, unconditional commitment and support in this work. Their perseverance in supporting field work and thoughts in making this project a reality is highly appreciated. Massive thanks to you all.

I am extremely grateful for my friends “Gayah” for their moral support in this long journey. Their endless support is meaningful without which I wouldn’t able to stay positive and motivated along the way. Thank you for listening to my complaints although you could not understand a single thing about my research. Having a good circle of friends really bring the best out of me throughout the journey. Thank you besties!

Lastly, I would like to thank my parents, Sahmat Salle and Hasanah Sapawi for believing in me and showing their endless support and motivation in making it possible for me to complete this research. Massive thanks also goes to my sisters and brother for taking care of the house chores while I was away for field trip or staying in the room to write this thesis. Your understanding, patience and prayers has sustained me this far. Thank you all!

ABSTRACT

Rapid forest conversion of tropical rainforests has caused detrimental effects on wildlife communities. Despite its importance as wildlife habitat, tropical forests play significant roles in the livelihood of many forest-dependent people. This study aims to explore the diversity and abundance of medium to large mammals in the Upper Baram region, Sarawak, Malaysian Borneo, where human and wildlife coexist. Using line-transect method, the study documented 17 species of medium to large mammals, including 13 endemic species of Borneo. Distance sampling method was used to estimate the densities of selected mammals' species, including the Bearded pig (*Sus barbatus*), Long-tailed macaque (*Macaca fascicularis*) and Pig-tailed macaque (*Macaca nemestrina*). The study also assesses the hunting pattern and importance of wildlife in the livelihood of the *Orang Ulu* people, a group of indigenous ethnics in Sarawak living in the Upper Baram forest area. The study recorded 11 hunted animals, with Bearded pig (*Sus barbatus*) as the most hunted species. The results revealed an estimate of more than 5400 kg of wild meat were harvested over the study period. These findings are vital to provide information for future wildlife and forest conservation effort that considers the importance of the forest and its resources for the continuity of the local people traditional lifestyles in the region.

Keywords: Wildlife, mammals, species diversity, species density, distribution, hunting, indigenous communities

Kepadatan Hidupan Liar dan Pemburuan Komuniti Kenyah dan Penan di Kawasan Ulu Baram, Sarawak

ABSTRAK

*Penukaran hutan yang mendadak dan pembalakan di hutan tropika telah memberi kesan buruk kepada komuniti hidupan liar. Selain kepentingannya sebagai habitat hidupan liar, hutan tropika memainkan peranan yang penting dalam kehidupan penduduk asal yang bergantung dengannya. Kajian ini mendalami kepelbagaian dan kelimpahan mamalia bersaiz sederhana ke besar di kawasan Ulu Baram, Sarawak, Borneo Malaysia. Menggunakan kaedah transek garis, kajian ini telah merekodkan 17 spesies mamalia bersaiz sederhana ke besar, termasuk 13 spesies endemik kepada Borneo. Kaedah jarak persampelan telah digunakan untuk menganggar kepadatan bagi beberapa spesies mamalia terpilih termasuk Babi hutan (*Sus barbatus*), Kera (*Macaca fascicularis*) dan Beruk (*Macaca nemestrina*). Kajian ini juga menilai pola pemburuan dan kepentingannya dalam kehidupan seharian komuniti Orang Ulu, iaitu kumpulan etnik orang asal Sarawak yang mendiami kawasan hutan Ulu Baram. Dapatan kajian merekodkan 11 jenis haiwan yang diburu, dengan Babi hutan (*Sus barbatus*) sebagai spesies yang paling kerap diburu. Hasil kajian mendapati dianggarkan sebanyak 5400 kg daging hidupan liar buruan telah diperolehi sepanjang tempoh kajian. Hasil kajian ini penting untuk menyediakan maklumat untuk pemuliharaan hidupan liar dan hutan di masa akan datang yang turut mengambil kira kepentingan hutan dan sumbernya dalam meneruskan gaya hidup tradisional penduduk tempatan di kawasan tersebut.*

Kata kunci: *Hidupan liar, mammalia, kepelbagaian spesies, kepadatan spesies, taburan, pemburuan, komuniti orang asal*

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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
asl	Above Sea Level
eg.	For Example
GDP	Gross Domestic Product
GPS	Global Positioning System
ha	Hectare
HoB	Heart of Borneo
ID	Identification
IUCN	The International Union for Conservation of Nature
km	Kilometre
km ²	Kilometre Square
m ³	Meter Cube
NGO	Non-profit Organization
PLEO	Pooled Local Expert Opinion
SWLPO	Sarawak Wild Life Protection Ordinance
TPA	Totally Protected Area
UNESCO	United Nations Educational, Scientific and Cultural Organization

CHAPTER 1

INTRODUCTION

1.1 Study Background

1.1.1 Borneo as Biological Diversity Hotspot

Borneo, the world's third largest island is a biodiversity hotspot region in Southeast Asia and exceptionally home to 25 species of carnivores, which includes more endemic species than does any other island except Madagascar (Shepherd et al., 2011). The island is shared by the Malaysian states of Sabah and Sarawak, Kalimantan Indonesia and Brunei covered by a thick and dense vegetation of tropical rainforests. Borneo island is recognised as one of the top priority regions in biological conservation for all three dimensions of biodiversity: taxonomic, phylogenetic and trait (Brum et al., 2017). Such areas harbour not only high species richness and endemism but also unique evolutionary lineages and distinct ecological traits emphasising the importance of preserving these regions (Brum et al., 2017)

To date, there are 247 terrestrial and 30 marine mammals, and 673 species of birds are reported to occur in the island, of which 63 mammals' and 69 birds' species are endemic to Borneo (Phillips & Phillips, 2014; Phillips & Phillips, 2018). Borneo tropical rainforests bears some endemic mammals including elusive felids such as Clouded leopard (*Neofelis diardii*), Bay cat (*Catopuma badia*), Flat-headed cat (*Prionailurus planiceps*), endemic carnivores such as Hose's Palm civet (*Hiplogalei hosei*) and home to endangered primates including Orangutans (*Pongo pygmaeus*), Proboscis monkey (*Nasalis larvatus*), and the endemic Naked bat (*Chrysomeres torquatus*) (Phillips & Phillips, 2018).

1.1.2 Main Threats to Bornean's Wildlife

Natural forest conversion is the main threats to the loss of pristine forest cover and wildlife habitat in Borneo island. In 1970s, it is estimated about 75% of Borneo were covered by more than 500,000 km² of intact old-growth forest (Gaveau et al., 2014). However, in 2010, the covered area has reduced to 380,000 km², which is about 53% of the island (Gaveau et al., 2014). Other factor of degradation includes forest fire, however this is prevalent in Kalimantan Borneo compared to the Malaysian parts of the island (Langner et al., 2007).

Logging is the one of the major forest loss in Borneo and has been exacerbated in the recent decades. This alone has been responsible for the loss of many lowland forests (<500 m asl) in the island (Gaveau et al., 2014). In Sarawak particularly, logging activity has accelerated in the 1990s, following the international ban on Indonesia round logs (Samejima, 2020). This is responsible for the vast establishment of logging road network in the state, which also has the lowest proportion of intact forest compared to the other parts of Borneo (Gaveau et al., 2014).

Between 2005-2015, agricultural plantation especially oil palm (*Elaeis guineensis*) is the biggest driver of deforestation across Borneo, and the loss is more intense in Malaysian Borneo than the Indonesian part (Foester et al., 2011; Meijaard et al., 2018). In Sarawak, the expansion of Rubber (*Hevea brasiliensis*) plantation has initiated the loss of forest cover in the state, before the emergence of timber industry (Hon & Samejima, 2020). The expansion of agricultural activity is also linked to the change in hunting patterns of many indigenous communities, particularly those living in the forested area of the region (Okino & Ichikawa, 2020; Kurz et al., 2021).

Many wildlife population in tropical forests receive much pressure from intensive hunting, especially of mammals (Brodie et al., 2014; Benítez-López et al., 2017). In Borneo, hunting of wild animals is widespread, particularly in the rural areas mostly for subsistence purposes (Bennett & Robinson, 2000; Yi & Mohd-Azlan, 2018). In addition, the killing of wild animals meat for sale and trade is also rampant, which frequently involved endangered species to meet human demands, such as for direct meat consumption or traditional medicine purposes (Kirupaliny & Mohd-Azlan, 2012; Gomez et al., 2020; Sahmat & Mohd-Azlan, 2022). Additionally, the selling of a highly-demanded wild animals parts also provide opportunities for some communities to gain economic return (Okino & Ichikawa, 2020).

1.2 Problem Statement

Land-use change has been responsible for the loss of habitat for many tropical forest species. In Borneo, most of its forest cover has been cleared due to logging and agricultural plantation on top of human development, which resulted to fragmented and forest mosaics across its landscapes (Gaveau et al., 2014; Gaveau et al., 2018). This has caused many implications, both for biodiversity and human livelihood (Meijaard et al., 2013). The implications of land-use change on wildlife assemblages have been greatly discussed by many researchers (Bernard et al., 2014; Davison et al., 2019; Maiwald et al., 2020). Of these, mammals communities are greatly impacted as they receive additive pressure from human activities, such as hunting (Brodie et al., 2014; Benítez-López et al., 2017). Studies suggested that modified landscapes benefits some mammals species, however may greatly impact human-sensitive species (Brodie et al., 2014; Maiwald et al., 2020; Tucker et al., 2020).

In Borneo, the alteration of natural forest landscapes resulted from the combination of logging, oil palm plantation and shifting cultivation as practiced by many local

communities across the region (Gaveau et al., 2014; McAlpine et al., 2018; Samejima & Hon, 2020). These areas are usually unprotected by law, which indicates intense factors such as continuous land-use change and human interference, especially in rural areas where human are highly dependent on forest resources for subsistence (Bennett et al., 2000; Gallego-Zamorano et al., 2019). There is a need for research that considers the coexistence of human and wildlife to give insights on the influence of these factors on species assemblages and population, particularly of mammals communities (Samejima & Hon, 2020). This change also impacts the human and nature relationships, such as hunting patterns and its driven factors among the local communities (Okino & Ichikawa, 2020; Kurz et al., 2021). Hence, it is crucial to provide evidence that clearly explains the impact of landscapes change on this relationship.

Often, the existing literature focus on the quantifying species diversity and mammals' assemblages in such disturbed landscapes (Jati et al., 2018; Maiwald et al., 2020). Most of these studies used surrogate approach to assess species population, such as diversity indices and occupancy (Mackenzie et al., 2006; Cheyne et al., 2016;). Yet, there is a paucity of information on species abundance and density, which is imperative for effective conservation strategies and long-term management of species population (Buckland et al., 2015; Gestich et al., 2016; Tucker et al., 2020). Many of the available information focuses on single focal species, especially species of conservation importance (Nijman, 2004; Ahmed et al., 2013; Hearn et al., 2016; Seaman et al., 2019). However, this information is largely absence for many key species, particularly for tropical forest mammals (Ahmad et al., 2020).

1.3 Objectives

The study aims to assess species assemblages in the forest of Upper Baram and hunting practices among the indigenous communities (Kenyah and Penan) in the forest area. This can be achieved through the following set of objectives:

- i. To identify medium to large mammals' species diversity and its distribution in the Upper Baram region.
- ii. To estimate density of selected large mammals in the Upper Baram region.
- iii. To investigate hunting practices and the significance of wildlife in the livelihood of the indigenous communities in the Upper Baram region.

1.4 Chapter Summary

Chapter 1 presents information on Bornean's wildlife and main threats to its habitat and population. The aim and objectives of the study were outlined in the next part of the chapter, and lastly followed by problem statement.

Chapter 2 discusses available literature and previous research relevant to the study topic, including the gaps in the current body of knowledge. The chapter elaborates the important aspects of this study including species diversity studies in Borneo and different forest landscapes, hunting and its significance for the forest-dependent community, the importance of community-based conservation, and the background of methods used in this study.

The third chapter presents findings on species assemblages and large mammals' density in the Upper Baram forest. Here, methods and analysis that were used were explained

in details. This chapter discusses findings based on the first and second study objective, including species diversity, distribution and density of selected large mammals. These were further elaborated with supported information from previous studies in the discussion part.

Chapter 4 focuses on hunting among the indigenous communities in the study area and analysis of hunting return data based on survey results, which is the third objective of this study. The chapter listed out the most hunted wildlife species in the study area. Study findings on the driven factors of hunting practices and its importance for the people were further discussed in this chapter.

In the final chapter, results from both study chapters were discussed and summarized in details. Based on the findings of the study, some suggestions were provided to aid conservation efforts, both at local and regional levels. Further insights into future studies in the study region were also outlined later in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 The Flora and Fauna of Borneo

Borneo, the world's third largest island is a biodiversity hotspot region in Southeast Asia and exceptionally home to 25 species of carnivores, which includes more endemic species than does any other island except Madagascar (Shepherd et al., 2011) . The island is shared by the Malaysian states of Sabah and Sarawak, Kalimantan Indonesia and Brunei covered by a thick and dense vegetation of tropical rainforests. Borneo island is recognised as one of the top priority regions in biological conservation for all three dimensions of biodiversity: taxonomic, phylogenetic and trait (Brum et al., 2017). Such areas harbour not only high species richness and endemism but also unique evolutionary lineages and distinct ecological traits emphasising the importance of preserving these regions (Brum et al., 2017).

To date, there are 247 terrestrial and 30 marine mammals, and 673 species of birds are reported to occur in the island, of which 63 mammals' and 69 birds' species are endemic to Borneo (Phillips & Phillips, 2014, 2018). Borneo tropical rainforests bears many endemic mammals including elusive felids such as Clouded leopard (*Neofelis diardi*), Bay cat (*Catopuma badia*), Flat-headed cat (*Prionailurus planiceps*), endemic carnivores such as Hose's palm civet (*Hiplogalei hosei*) and home to endangered primates including Orangutans (*Pongo pygmaeus*), Proboscis monkey (*Nasalis larvatus*), and the endemic Naked bat (*Chrysomeres torquatus*) (Phillips & Phillips, 2018).

Generally, about 40% of mammals' species in Sundaland realm are endemic to the region, highest than those in the Phillipines and Wallecea hotspot region and the highest in

terms of amphibians' species endemism (~80%) of the whole Southeast Asia (Sodhi et al., 2004). The floristic diversity of the Borneo tropical rainforests is also known to be a centre of distribution and species diversity for several economically important families and genera of flowering plants (Soepadmo & Wong, 1995).

Of the 386 known species of the Dipterocarpaceae, about 75% (291 species) are recorded from Borneo, of which 257 species (about 66%) occur in Sabah and Sarawak alone with each of it plays major important ecological roles such as mass fruiting phenomenon and carbon absorption (Soepadmo & Wong, 1995; Curran et al., 2000; Sodhi et al., 2004). Lee et al. (2002) estimated a small area of Lambir Hills National Park in Sarawak has included about one quarter of all 5000 species of North-west Borneo, indicating a high floristic composition of such forests. Approximately 3,000 magnificent species of orchid can be found in the island which is more than anywhere else on earth (World Wildlife Fund, 2010). Despite of this, the rapid destruction of tropical habitats generally in Southeast Asia due to land use demands has posed serious threats where natural habitats especially the lowland rainforests is being destroyed (Sodhi et al., 2004).

2.2 Threats to Wildlife in Borneo Tropical Rainforests

Anthropogenic activities has found to severely affect the assemblages and distribution of wildlife species in the region (Meijaard & Sheil, 2007), in which wildlife are still hunted and available for sale (Kirupaliny & Mohd-Azlan, 2012) and forest is continuously being cleared for logging and development (Sodhi et al., 2004; Mathai et al., 2016; Gaveau et al., 2018; Alamgir et al., 2020) therefore immediate action shall be considered to mitigate the impacts. Sodhi et al. (2010) listed the need for sustainable timber harvest and oil palm plantation as the main conservation imperatives in Malaysia. However,

the impact of hunting should not be overlooked as it is widespread in the region (Bennett et al., 2000). Importantly, there is a paucity of information on distributions and population statuses of the cryptic mammals' species such as the five felids inhabiting Borneo Island (Wearn et al., 2013). Therefore, a credible, accurate and up-to-date information about carnivore's distribution and ecology is scarce despite of their undoubted importance in Borneo (Mathai et al., 2016).

2.3 Anthropogenic Activities Lead to Habitat Loss in Borneo

Forest conversion, forest fire, hunting and wildlife trade are the responsible cause for habitat and biological loss in Southeast Asia (Sodhi et al., 2004). The tropical forests in Southeast Asia are threatened by high deforestation rates and increasing loss of pristine forests (Langner et al., 2007). In Borneo, the lowland forest cover has changed with a deforestation rate of -1.8% change per year from 2002 to 2005 (Langner et al., 2007). In 1973, it is estimated about 75.7% of Borneo were covered by more than 500,000 km² of intact (unlogged) old-growth forest (Gaveau et al., 2014). The area, however, has been reduced by more than 160,000 km² in 2010, representing the loss of 30.2% forests cover over the last four decades (Gaveau et al., 2014).

Additional cause to land cover change is due to fire which has affected 37% of cultivation forest mosaic, the most severed compared to other land type (Sodhi et al., 2004; Langner et al., 2007). The driven factor is mostly linked to the seasonal land clearing activities of shifting cultivators in the island (Langner et al., 2007). In general, Sarawak natural vegetation encompasses seven forest types, varying according to soil type and elevation which are: beach forest, mangrove forest, peat swamp forest, riverine forest, Kerangas or tropical heath forest, limestone forest, lowland and hill dipterocarp forest and

montane forest (Bennett, 1992). Of these, the lowland tropical rainforest is mostly deteriorated due to severe threats from industrialisation and anthropogenic activities (Gaveau et al., 2013; Gaveau et al., 2017).

Habitat alteration in Borneo has been caused by a range of factors including the expanding oil palm industry (*Elaies guineensis*) across its land area. According to Kato & Soda (2020), land use for oil palm plantation in Sarawak particularly has increased drastically over the past 20 years in which, currently in 2017 more than 1 million ha oil palm planted area were estimated in the state. Remarkably, as in 2018 more than 70% from 1.5 million ha of oil palm plantation area in Sarawak are owned by private estates surpassing those own by government sectors and smallholders (Malaysia Palm Oil Council, 2019). The oil palm plantations in Sarawak in the beginning was mostly developed along the coast, small holders' cultivation however, has contribute to the currently spreading of oil palm plantation throughout the inland hill zones on vast post-swidden area, contributing about 14% of total oil palm plantation area in Sarawak (Kato & Soda, 2012; Ministry of Primary Industries, 2018).

Initially, Sarawak is a late comer in Southeast Asia timber industries compared to Sabah, Indonesia and The Phillippines (Samejima, 2020). Due to its low density of commercial trees without holes, the export of Sarawak timber is lower than that of Phillippines, Sabah and Kalimantan (Samejima, 2020). Previously, the state government did not depend on timber export royalties to the same extent as the Philippines and Sabah except for one valuable tree species called Ramin (*Gonystylus bancanus*), found in peat swamp forests that has been exported out of Sarawak for the total of 1.1million m³ logs in 1965 (Samejima, 2020). Nonetheless the logging production from the state increased drastically

after the export ban on round logs in Indonesia was implemented in 1985 from which, the Japan trading companies and the local companies in Sarawak joint ventures for the supply of round logs in high demand from Japan plywood factories (Gay, 2001; Samejima, 2020). Generally, this might contribute to the establishment of logging road in the state, in which from 1973 to 2010 more than 27, 000 km of primary logging road were established in Borneo Island with Sarawak has the highest density of logging road opened, about 0.89 km² compared to Brunei, Kalimantan and Sabah (Gaveau et al., 2014). Lately as in 2019, there are 4.3 million ha of Permanent Forest Estates gazetted by the Sarawak state government mainly for timber production (Borneo Post Online, 2019).

To date, more than 2 million ha of land use are for agricultural purposes in Sarawak alone (Department of Statistics, 2018). There is significant increase in planted area for main crops (rubber, oil palm, coconut, cocoa, paddy, and pepper) in Sarawak from the year 2014 to 2018 (Department of Statistics, 2018). Nevertheless, these threats if combined will represent higher estimates of extinction risks on tropical biodiversity rather than looking at one type of threat in isolation (Symes et al., 2018). Among another driving forces to habitat loss is shifting cultivation which might be a threat to small carnivores mainly through the temporary loss of the areas under cultivation at any given time as most species were found near slash and burn fields (Mathai et al., 2016).

The increasing human population density also responsible for forest conversion as they are vulnerable to meet the growing resources demands (Sodhi et al., 2010). On top of all, in Sarawak logging has exacerbated the impact of all these factors through the opening logging road, hence increasing accessibility for hunting by outsiders for sale and trade and

hunting executed by logging company employees for sport and subsistence (Gumal et al., 2008).

2.4 Hunting in Rural Areas of Borneo and Sarawak

Hunting for subsistence alone causes many animals extracted per year for many tropical forests (Bennett & Robinson, 2000). In Sarawak, majority of hunting activities in certain areas were for subsistence purposes (Mohd-Azlan & Kirupaliny 2012; Yi & Mohd-Azlan, 2018). According to Bennett et al. (2000), 28.9% of all evening meals sampled in rural communities contained wild meat with the Iban and Bidayuh community being the largest consumer of wild meat in interior parts of Sarawak (Mohd-Azlan & Fauzi, 2006). Hunting in rural communities is therefore mostly by means of subsistence, in which wildlife has been parts of their livelihood diet thus consuming it is a habitual daily need (Bennett & Robinson, 2000). On top of this, lack of accessibility to the nearby town and availability of domestic meat contributed to the need for wild meat in their daily livelihood (Mohd-Azlan & Kirupaliny, 2012).

By contrast, religious and cultural traditions have affected sustainability by controlling which species are hunted (Bennett & Robinson, 2000). Some cultures have special taboos which indirectly provide another safeguard against over-harvesting of certain species (Bennett & Robinson, 2000; Mohd-Azlan & Fauzi, 2006). Fear of divine retribution plays a significant role in enforcement; people believe that transgression of a taboo may result in undesirable events such as illness, death, or the birth of a handicapped child (Horowitz, 1998). For instance, the Ibans in parts of Sarawak will not hunt Orang-utans meanwhile the Muruts in Sabah will not hunt hornbills (Bennett & Robinson, 2000). The religion's law restriction on the killing and eating of wildlife such as in Islam, Buddhism

and Hinduism contribute to higher populations of many species in Muslim areas in Northern Borneo meanwhile in India, this tolerance flourishes the populations of many species of large animals (Bennett & Robinson, 2000). Despite this, overhunting still ensues for many other reasons (Bennett & Gumal, 2001).

A study conducted by Puri (1999) on the hunting activity of the Penan and Kenyah in Kalimantan Borneo stated that hunting has defining the ethnic's cultural feature and remain at the core of Penan economy and cultural identity. In Sarawak, the archeological records from Niah Caves have uncovered numerous animals bone assemblages that were probably hunted by human inhabitants of the caves who were hunter-gatherers back to 40,000 years ago during Terminal Pleistocene era (Piper & Rabett, 2009). In addition to that, the continuous use of wildlife in traditional medicines, ornaments and cultural systems by the indigenous peoples are among the essential driven factors of hunting to meeting their demands (Mohd-Azlan & Fauzi, 2006; Bunya et al., 2012). This evidence proved that hunting activity is ultimately governed by sociocultural aspects of the indigenous people lifestyles thus prevalent across the state.

The sustainability of hunting in Borneo tropical forests has been a focus for debate of many researchers (Caldecott, 1986; Robinson & Redford, 1994; Bennett & Robinson, 2000). Historical record has confirmed the extinction of several valuable species in Borneo including the Giant pangolin (*Manis paleojavanica*) and Sumatran rhinoceros (*Dicerorhinus sumatrensis*) which had succumbed to hunting and habitat loss (Corlett, 2007; Piper & Rabett, 2009). In Sarawak, the most dominant animals in harvest are ungulates such as Sambar deer (*Rusa unicolor*), the two Barking deers (*Muntiacus* spp.) and Bearded pig (*Sus barbatus*), the last is by far the most important single prey species (Caldecott, 1986; Bennett

et al., 2000; Yi & Mohd-Azlan, 2018). These animals are an important human nutrition in remote areas and are often described as game species (Bennett & Robinson, 2000). The impact of hunting, however, does not ultimately affect these species. In some cases where game animals are rare, medium-sized to smaller mammals' species are hunted instead (Caldecott, 1986).

The opportunistic killing of these non-targeted animals is additive to the natural mortality which contribute to the depletion of hunted species including civets, wild cats, and rodents (Bennett & Robinson, 2000; Corlett, 2017; Mohd-Azlan et al., 2017). Small carnivores such as civets could be potentially harvested for sale when large animals are difficult to hunt due to low diversity (Kirupaliny & Mohd-Azlan, 2012). Wadley et al. (1997) study on primates hunting among the Iban community in Indonesian Borneo found that about 31.2% encounters with large mammals (including civets and porcupines) during hunting trips resulting in capture, which is higher than those primates (15.9% capture rate). For instance, Mohd-Azlan et al. (2017) determined that the killing of Sunda Clouded leopard (*Neofelis diardi*) were opportunistic during pig hunting trip by local hunters. Hunting trips were, therefore, equally likely to result in the capture of mammals, including the less preferred species (Wadley et al., 1997).

Brodie et al. (2015) stated that hunting if persistence, is a greater threat to wildlife populations than selective logging in the biodiversity hotspot region of the tropical forests. Therefore, spreading awareness should be encouraged to provide essential information on globally threatened species and the effects of hunting on wildlife as well as gaining local attention on conservation objectives (Mathai et al., 2016).

2.5 Protected Area, Laws and Conservation Efforts in Sarawak

Sarawak has established a system of Totally Protected Areas (TPAs) throughout its state to ensure the viability and continuity of its biological diversity (Forest Department Sarawak, 2020). The designated forest land is under the provisions of National Parks Ordinance 1998 and Sarawak Wild Life Protection Ordinance 1998 (Forest Department Sarawak, 2020). There are three main classifications of these protected lands namely 1) National Parks, 2) Wildlife Sanctuaries, and 3) Nature Reserves with a total of 41 national parks established throughout the state to date (Forest Department Sarawak, 2020). All three categories are fully protected against logging, other habitat disturbance and allowed for limited use by specified and legally gazetted local communities, with the first two are open for tourism under permit (Gumal et al., 2008).

About 42,091 km² of the state area is permanent forest estate, 8161 km² of National Park and Wildlife Sanctuary (Totally Protected Area) and Stateland forest (27,227 km²) (Department of Sarawak, 2018). In 2019, approximately 0.82 million ha of gazetted TPAs land in the state and Sarawak aims to allocate 1 million ha off its land cover as Totally Protected Areas by the year 2020 (Borneo Post Online, 2019). Most of the protected areas in Sarawak were established in the late 20th century (Mohd-Azlan & Lawes, 2011). The idea of establishment of modern parks and nature reserves in Sarawak was first arose in the late 1800's after the realisation of opening large areas of forests for economic development has threatened the natural resources emerged (Mahidin & Sofwan, 2012; Mohd-Azlan, 2014).

Sarawak has more national parks gazetted than any other states in Malaysia, however most of this protected area occur in small patches which is scanty to maintain viable populations of most medium-sized and larger vertebrates and some tree species (Mohd-

Azlan & Lawes, 2011). In contrast, the importance of small patches habitat should not be forsaken in conservation planning as a small land unit selected at random from a small patch of habitat (<1000 ha) with a complex shape predominantly surrounded by degraded forest will tend to have higher conservation value than a similar unit selected from a large habitat patch within a largely intact landscape (Wintle et al., 2019).

Arguably, Sarawak Wild Life Protection Ordinance (SWLPO) 1998 is more lenient than those of Peninsular Malaysia and Sabah in terms of fines for killing or hunting of Totally Protected Species, number of sections and schedules and number of penalties, indicating the low level of wildlife protection provided (Mohd-Azlan, 2014). In terms of higher penalties imposed on wildlife perpetrators, Sarawak has a long way to go in curbing wildlife hunting and trade compared to both Peninsular and Sabah (Radhi & Landau, 2019). Hence, rigorous action needs to be started ahead to achieve the goals as stated in Malaysia National Policy on Biological Diversity 2016-2025 to significantly reduced poaching, illegal harvesting, and trade of wildlife by the year of 2025 (Ministry of Natural Resources and Environment, 2016). Other than the significance of wildlife for the being of Sarawak state's economy and traditional systems of diverse culture and natural resource for the rural peoples, wildlife is inordinately crucial as tourist attraction and to maintain the health of forest ecosystem on which it is dependent (Gumal et al., 2008). Hence, in 1997, Sarawak has prepared a main framework for a systematic management of its wildlife through the development of "The Master Plan for Wildlife for Sarawak" which act as a long-term comprehensive formulation for wildlife conservation and management in the state.

In June 2011, the first Borneo Carnivore symposium, Roads Towards Conservation Action Plans was held in Kota Kinabalu Sabah for the experts to discuss on Borneo's

carnivores which is under serious threats (Shepherd, 2011). The major initiative Heart of Borneo (henceforth, HoB) was established in the year of 2007 as a government led and NGO-supported programme via a joint declaration of Malaysia, Brunei, and Indonesia (Forest Department Sarawak, 2020). The programme aims to conserve the HoB area for the benefit of people who depends upon its resources and sustainable management of land uses (World Wildlife Fund, n.d). HoB plays important role in maximising transboundary linkages and maintaining forest connectivity as a habitat corridor for wildlife. In 2018, Sarawak State Cabinet has approved the extension area of HoB Sarawak to 2.69 million hectares (Forest Department Sarawak, 2020). Under this initiative, more than 123 new species of flora and fauna were discovered mainly in the HoB area from the year 2007-2009 (World Wildlife Fund, 2010).

Despite these legal management action, credible information is needed for the protection actions to be applied rigorously on endangered and of conservation importance species considering limited research resources. Therefore, deep specific understanding of species is the key component in preserving species viability (Mathai et al., 2016).

2.6 Overview on the Socio-economic Activity in Sarawak

Sarawak is the third highest GDP among other states in Malaysia (RM146,006 million) after Selangor and WP Kuala Lumpur with substantial increase from 2016 - 2018 (Department of Statistics, 2018). Generally, Malaysia is one of the top exports for oil palm accounting for 28% of world's palm oil production, after Indonesia with a total import of 54.5% (Malaysia Palm Oil Council, n.d.; Workman, 2019). In Sarawak, palm oil is the major agricultural export of the states, earnings more than RM11 million in the year of 2018 from palm oil and its based products alone (Department of Statistics, 2018). The Sarawak

government targets to expand the oil palm plantation sector into 2 million ha by the year 2020 (Wong, 2018). Nevertheless, natural rubber and pepper are among the small contributors to the state's revenue (RM224.7 million) although there are no established estate of the crops throughout Sarawak (only smallholders cultivation) (Department of Statistics, 2018). As in 2019, the agricultural area in Sarawak is largely concentrated in Miri division which constitutes about 593,000 ha, while Kuching division holds most of the state's commercial area for more than 4,000 ha (Department of Statistics, 2019).

There are marked differences in living standards between urban centres and remote rural areas (Abdullah, 2017). In rural areas, the economy of indigenous peoples in Sarawak mostly depends on their farming, fishing and forest products they harvest in their native land (Kato & Samejima, 2020). The land use patterns of the indigenous people can be classified into four categories namely: *temuda*, *menoa*, *damp* and *pulau*, each of which plays significant important in the livelihood of indigenous communities from practicing Swidden agriculture to water catchments (Choy, 2004). Shifting cultivation in some areas of Sarawak has closely to extinction from the last three decades as employment opportunities and markets for cash crops are plenty, whereby farmers especially in rural areas still maintain the traditional agricultural practice for subsistence such as rice (Hansen & Mertz, 2006).

In terms of protein source, people in rural areas particularly in Sarawak depend on wildlife for meat more than those living in the coastal area, by which it provides indirect economic benefits for rural peoples as commercialised meat would be expensive for most of them (Bennett et al., 2000; Wildlife Conservation Society & Sarawak Forest Department, 1996). Other than due to remoteness from markets, cultural factor is one of the reasons for the rural people to go for wild meat, for instance the Penan in Sarawak did not consume

domestic animals which they considered to be unclean (Bennett, 2008). Apart from agriculture and hunting, rural peoples especially in the river areas fished for their livelihood (Kato & Samejima, 2020). In Kapit division, despite of rural residence, better physical accessibility to the nearest Kapit town has benefit the people economically by selling vegetables and farm surplus as their primary household income (Abdullah, 2017).

Accessibility is significant especially for the rural peoples in Sarawak to allow them to function as an economic unit, to promote access to resources and opportunities (Abdullah, 2017). With a vision to accelerate the socio-economic growth in the state, a major leap has been undertaken by the State government through the construction of Pan Borneo Highway in 2015 that connects the South and East side of Malaysian states in Borneo. In alignment with Malaysia's 2020 vision to become a fully industrialised country, ensuring the availability of energy particularly electricity supply has thrust the enhancement of Sarawak's hydro-electric potential, which leads to the construction of the largest dam in Southeast Asia, the Bakun Dam (Choy, 2004).

However, the construction of dams, instead of promoting sustainable energy supply has create tensions and consequences between government and indigenous communities' livelihood as the proposed project area would flood all communities' Swidden land and primary forest area in addition to the need for resettlements (Sovacool & Bulan, 2013). Consequently, the construction of highway and hydroelectric dams in Sarawak will greatly affect the area of core forest and shrink forest connectivity (Alamgir et al., 2020). As in 2017, the hydroelectric power dams of Bakun and Murum construction between 2011 to 2014 have been approximately to permanently flooded 83,362 ha of forest in the state (Gaveau et al., 2017).

2.7 Indigenous Peoples Forest Dependency

Forest plays important role to mankind by providing resources for food, medicines, shelters, in part of ecosystem services in nature and interwoven into human culture (Ritter & Dauksta, 2013). The tropical forest is vital in regulating and controlling global weather through the absorption and creation of rainfall and the exchange of atmospheric gases (Ekhuemelo et al., 2016). Forest products such as bushmeat and timber have provided direct economic benefits local communities (Kumpel et al., 2008; Meijaard et al., 2013). Other than its practical utilization and function, forest products also have tangible values in terms of cultural functions and spiritual purposes in human society (Meijaard et al., 2013; Ritter & Dauksta, 2013).

Indigenous people in Borneo have a long standing with the use of forests resources for many reasons, from land space for house site, agricultural activity, water catchment area, timber, food, and medicines and for the purpose religious and cultural use (Nelson et al., 2015; Sait et al., 2018). In Sarawak, the Iban in Banting mostly relies on forest resources for wild food and technical use while the Bidayuh community in Padawan use wild plants for medicinal herbs and bamboo as building materials and handicraft (Sait et al., 2018). Interestingly, many research have been done focusing on the use of wild plants in traditional medicines by indigenous people indicating its crucial role for their health and wellbeing (Kulip, 2003; Ripen & Noweg, 2017).

On top of this, the use of non-timber products for handicrafts is extensive in Borneo. There are 14 species of plants were identified to be used by the Kadazandusun people for building and handicrafts purposes alone (Andersen et al., 2003). In Belaga district for instance, the *Orang ulu* people make handicrafts and utilitarian such as baskets, mats, baby

carrier and headband from wild plants (eg. rattan, bamboo, and palm leaves) from nearby forests (Sahari, 2012). However, logging and the development of Murum Dam have implicated the reduction of forest cover thus led to the depletion of wild materials. Communities' resettlements which are distant from forest area has impacted the peoples in obtaining sufficient supply for their handicrafts (Sahari, 2012).

Historically, human utilization on wildlife dated back to the Early Holocene era whereby people hunt on wildlife especially of ungulates and primates (eg. Bearded Pig, Gibbon, Deer) for sustenance (Barker et al., 2011). The Niah Caves evidence shows that human population during Mesolithic and Neolithic era relied completely on forest products such as wild plants (eg. nuts, fruits, sago palm, tubers) and animals for subsistence (Barker et al., 2011). The human-animal relationship does not bound for sustenance purposes as animals are prominent in spiritual aspects of indigenous people in Borneo (Meijaard et al., 2013). The Kelabit and Penan in Sarawak for instance, believe in the existence of animal's spirits and conceived that wild animals are given by the Great Spirit for humans use (Janowski, 2016).

2.8 Traditional Ecological Knowledge and its Importance in Conservation

Traditional Ecological Knowledge can be viewed as a body of knowledge, beliefs and practices that are developed and maintained by communities and are transmitted from one generation to the next which contextualizing their interactions with surrounding environment (Bruchac, 2014; UNESCO, 2018). It is a network of knowledges that are adapted based on their experiences on how to utilize, manage and preserve natural resources to ensure the survival of their community (Bruchac, 2014; Sait et al., 2018). This knowledge is often passed orally from one generation to the next, in formal and informal modes by

different means (eg. storytelling, oral traditions, ritual practices, and laws) among their community members (Bruchac, 2014; Sait et al., 2018).

The knowledge of indigenous peoples is often interwoven into their cultural identity, as depicted in their traditional myths, ceremonies, magic which is deeply integrated with their understanding of natural world (Nicholas & Lasimbang, 2004). Local communities have much of essential knowledge on managing forests resources sustainably and can be a main component in wildlife conservation outside protected area (Mathai et al., 2016). The importance of Traditional Knowledge System has frequently been highlighted in governing policies which emphasize its role in supporting biodiversity conservation across different regions (UNESCO, 2018).

As stated in Aichi Biodiversity Target Goal E Target 18 - which centred the importance of traditional knowledge and practices of indigenous and local communities, and their active participation in biodiversity conservation subject to national legislation and obligations by the year 2020, and in addressing Article 8(j) of the Convention on Biological Diversity—that recognizes the knowledge, innovations and practices of the indigenous and local communities embodying traditional lifestyles, initiatives should be taken to put in place procedures to better enable traditional communities to protect and control their knowledge (Nicolas & Lasimbang, 2004).

Indigenous knowledge traditions are beneficial for researchers to gain information and insight as the local peoples are more familiar with their surrounding environment and its biota and this localized knowledge can assist in explaining and contextualizing scientific data (Bruchac, 2014). In South Africa for instance, the use of citizen science-based track survey in wildlife population study presents key advantages to conservation in terms of cost

reduction, higher yields on detection, in part of comprehensible survey and the participatory of local communities in conservation study that is lack in conventional methods (Keeping et al., 2018).

The participation of local communities in North Borneo has successfully supported the forest conservation initiatives near the Crocker Range Park whereby their involvement is beneficial in shaping the sustainable harvest of their forest and the development of land use map zone (Ioki et al., 2019). Whilst in fisheries, the adaptation of *tagal* system in Sabah and *tagang* system in Sarawak are the initiatives that have been implemented to conserve and protect freshwater ecosystem from rapid depletion by controlling harvest activity (Ubaidillah et al., 2018; Foo, 2019). These systems are purely adapted from the indigenous people practice by using their traditional knowledge in protecting freshwater resource and its sustainability for their own use (Ubaidillah et al., 2018; Foo, 2019).

Traditional livelihood which centred on forest foraging and subsistence farming had kept native communities attached to the skills and knowledge of this gift of nature (Ripen & Noweg, 2017). Thus, conversations and cooperation with local people indicated an awareness of the conservation goals of an area (Horowitz, 1998). The traditional knowledge of the indigenous community, especially in farming and medicine, represents a form of knowledge that has been inherited from generation to generation by the indigenous society. In-depth research into this aspect of traditional knowledge serves as a contribution to society at large (Halim et al., 2013).

Nicolas and Lasimbang (2004) view that documentation of indigenous knowledge and forest products should be properly documented as they can be used to check and even nullify the grant of patents based on indigenous knowledge and forest products that are

already available in the public domain. In view of this aspect, it is necessary to preserve and properly document to keep a record of the diversified utilisation of various plant and animal species. As the utilisation of ethnobotanical resources is recognised to have several benefits, which among others, includes the realization of direct and indirect use value (Ripen & Noweg, 2017), wildlife's role in this aspect should be addressed to provide an essential step toward biodiversity and biocultural conservation.

2.9 Approaches in Assessing Wildlife Population in Tropical Rainforests

Sampling animal population is a component of the larger processes of science or management instead of standalone activities by providing fundamental information on the status of biological diversity in the wild (Mackenzie et al., 2006). Much research have been devoted in attempt to evaluate wildlife populations particularly in Borneo (Bernard et al., 2014; Hearn et al., 2016; Mathai et al., 2016; Wearn et al., 2017). When the entire area of interest cannot be surveyed, space must be sampled in a manner that is maximally useful to study objectives and that permits inference about the entire area of interest (Mackenzie et al., 2006). Generally, as census or complete counts of animals' number are often impractical, expensive, and time-consuming, several approaches have been developed to estimate abundance or relative abundance of animals' population (Balme et al., 2009).

One of the most preferred techniques is camera-trapping, the deployment of self-triggered cameras in study area to capture images of animals. The proliferation of camera trap studies has allowed more robust inference on relative abundance of highly cryptic species that has been possible before (Wearn et al., 2013). This technique, however, has limitations such as camera malfunction; especially in high humidity of tropical rainforests, the need for regular operational maintenance e.g battery change, data management issues

and susceptibility to theft/vandalism (Bernard et al., 2013; Mathai et al., 2010; Newey et al., 2015; Wearn et al., 2013) therefore causing imperfect data collection and affect final conclusions and reports.

Another method to estimating density and/or abundance from incomplete count is via capture-recapture methods (Wilson & Delahay, 2001; Thomas et al., 2002). The methods provide robust population estimates with known levels of precision and accuracy, giving that the underlying assumptions of any model are met for the population of interest (Wilson & Delahay, 2001). Capture-recapture methods can be useful for populations that aggregate at some locations each year and can produced estimation of survival and recruitment rates (Thomas et al., 2002). However, trapping carnivores at the intensity required to produced such estimates is not always possible, as it can be practically difficult, labour-intensive, prohibitively expensive and often more sensitive to failures of assumptions than distance sampling (Wilson & Delahay, 2001; Thomas et al., 2002).

In studying animals with such low density, distance sampling has been frequently used to estimate their density and abundance (Strindberg et al., 2017). Distance sampling encompasses a class of methods: line transect survey and point survey (Thomas et al., 2002). These approaches are effective when the object of interest is in a dispersed population and occur in low density in which, it allows the estimation of absolute density for a population even if not every individual is counted (Buckland, 1993; Thomas et al., 2002). Distance sampling have been proven to effectively study a wide range of fauna such as Cetaceans (Barlow et al., 2011), Koala abundance (Dique et al., 2003), Bird's density (Greene & Efford, 2012) and highly adaptable for the purpose of Polar bear sampling using helicopter (Aars, 2019).

Owing to this limitation, some authors preferred to combine multiple methods in their study design to maximise detection probability of their interest species such as those conducted by Mathai et al. (2010), Wearn et al. (2013), Fragoso et al. (2016), and Keeping et al. (2018). Mathai et al. (2010) has successfully detected small carnivores in his study using multiple approaches by combining line transect and camera-trapping methods in Upper Baram, Sarawak. Carnivores detected via line transects (direct sighting) including Malay weasel (*Mustela nudipes*), Yellow-throated marten (*Martes flavigula*), Common Palm civet (*Paradoxurus hermaphroditus*), Masked Palm civet (*Paguma larvata*), Binturong (*Arctictis binturong*), Short tailed mongoose (*Herpestes brachyurus*) while Otters and Malay civet (*Viverra zangalunga*) were detected using signs survey. These observations proved the usefulness of line transects method in studying wildlife populations in tropical rainforests of the region.

2.10 Distance Sampling and Line Transect Survey

Distance sampling is a group of methods that allow estimation of density (D =number per unit area) and/or abundance of biological populations (Buckland et al., 2001). The two main approaches in distance sampling theory are line transect and point transect (Buckland et al., 2001). Both methods have been useful in studying diverse array of taxa, including trees, shrubs and herbs, bird, fish, land and marine mammals (Thomas et al., 2002). The basic concept is that standardised survey is performed by the observer(s) along a series of line or point searching for object of interest such as animals or clusters of animals (Thomas et al., 2002).

Distance sampling is the extension of quadrat sampling methods (Buckland, 1993; Thomas et al., 2002). There are two forms of quadrat sampling: strip transects and point

counts, in which its fundamental assumption is that all objects within the strip or circle are counted (Thomas et al., 2002). However, Thomas et al. (2002) view that this assumption is difficult to meet and inefficient for many populations especially for scarce species.

Distance sampling extends the quadrature methods by relaxing the assumption that all objects within the strip or circle are counted (Thomas et al., 2002; Miller et al., 2013). While in distance sampling, the measured distances of objects within the circle or strips is used to estimate its probability of detection (Thomas et al., 2002). Barraclough (2000) simplified the advantages of distance sampling over plot/quadrature methods by Buckland et al. (1993) as follows:

The key to distance sampling analyses is to fit a detection function $g(y)$, which is the probability of detecting an object given that it is at distance y from the random line (Buckland et al., 2001) to the observed distances and use this fitted function to estimate the proportion of object missed by the survey (Barraclough, 2000; Thomas et al., 2002; Thomas et al., 2019). From here, point and interval estimates for density and abundance of objects in the study area can be obtained (Thomas et al., 2002).

According to Miller (2019), estimates of density or abundance can be calculated using R package Distance. By estimating the detection function's parameters, the distance from the function can be integrated out to get "average" probability of detection which can be used to correct the observed counts. The sum of the corrected counts gives an estimate of abundance in the area covered by the surveys, which can be multiplied up to the total study area (Miller et al., 2019). More details on distance sampling techniques see Buckland et al. (2001) and Buckland et al. (2015).

In line transects sampling, the only assumption is that a narrow strip around the centreline is censused (Buckland et al., 1993). A straight line transect is traversed by an observer and perpendicular distance are measured from the line to detected animal as in Figure 2.1 (Buckland et al., 1993).

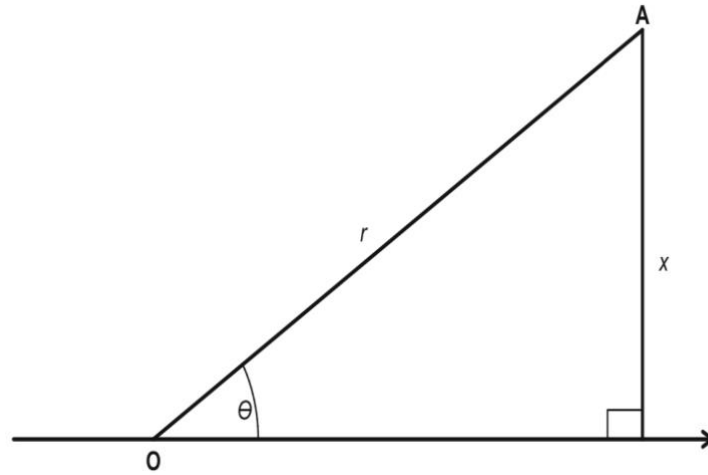


Figure 2.1: The illustration of animal detection from a line transect. The observer (O) detects animal sighting as at A (Animal). The observer can record either the perpendicular distance (x) or the radial distance (r) and the angle θ , as $x = \sin \theta r$. Image reproduced from Buckland et al. (2015).

In line transect sampling, we assume that object are uniformly distributed with respect to the line (Miller et al., 2013). According to Buckland et al. (1993), there are three critical assumptions to achieving reliable estimates of density from line transect:

- i. Objects directly on the line are always detected with probability 1 or $g(0)=1$.
- ii. Objects are detected at the initial location, prior to any movement in response to the observer.
- iii. Measurement are exact. Distances, angles and grouped objects are measured/counted correctly.

All objects at zero distance are detected, that is $g(0) = 1$, in which detection on or near the line should be nearly certain. Design of surveys must be fully consider to assure that this assumption is met but its importance cannot be overemphasised (Thomas et al., 2002) . The objects are detected at their initial location. In the case where animals move from its original for some distance prior to being detected, the measured distance is from the random line to the location of detected, not the animal's original location (Buckland et al., 2015). Recorded distance is exact without measurement errors, recording errors or heaping. Reliable estimates of density may be possible even if the assumption is violated. The effect of inaccurate measurements of distances can be often be reduced by careful analysis (e.g grouping), however it is better to gather good data in the field rather than to rely on analytical methods.

The main assumption of conventional line transect sampling is that lines are placed independently of animal locations, in which lines should be placed according to a randomized design such as a systematic grid of equally-spaced lines that randomly placed over or randomly superimposed on the survey region (Buckland et al., 2001; Buckland et al., 2015). This placement ensures that animals available for detection are on average uniformly distributed in terms of to distance from the line as stated by Buckland et al. (2015).

According to Buckland et al. (2015), field methods employed during data collection should be developed with the three main model assumptions: which is 1) animals on the line or point should be detected with certainty, 2) animals should be detected at their initial location before any movement, and 3) that distances should be measured without error. It is important that observers are trained to understand these assumptions, and how to ensure that they are met prior to data collection in the field. There are three estimation of probability

approaches in line transects sampling: 1) the detection function, $g(x)$, 2) the effective (half) strip width and 3) the probability of density function. In general, the estimation of animal density through line transect is by the formula:

$$\hat{D} = \frac{n}{2wL\hat{P}_a} \quad \text{Equation 2.1}$$

From Figure 2.1, perpendicular distances x is measured from the line to the detected object of interest, by which detection distances r and detection angles θ are recorded, thus perpendicular distances are calculated as $x = r \sin \theta$, suppose k lines of length $l_1, \dots, l_k$ (with $\sum l_j = L$) are placed accordingly to a randomised position and n animals are detected at perpendicular distances $x_1, \dots, x_n$. Suppose that animals further than some distance w from the line (truncation distance) are not recorded. Given that $a = 2wL$ is the surveyed area within which n animal is detected and let P_a be the probability that a randomly chosen animal is detected within surveyed area and suppose the estimate of $\hat{P}_a$ is available (Equation 2.1).

In order to estimate $\hat{P}_a$, the detection function $g(x)$ can be defined as the probability that an object at distance x from the line is detected, in which $0 \leq x \leq w$ by assuming $g(0)=1$ at which, we are certain to detect animal on the line (Figure 2.2). Once the recorded perpendicular distances are plotted into a histogram, we need to find a suitable model to fit it to the perpendicular data.

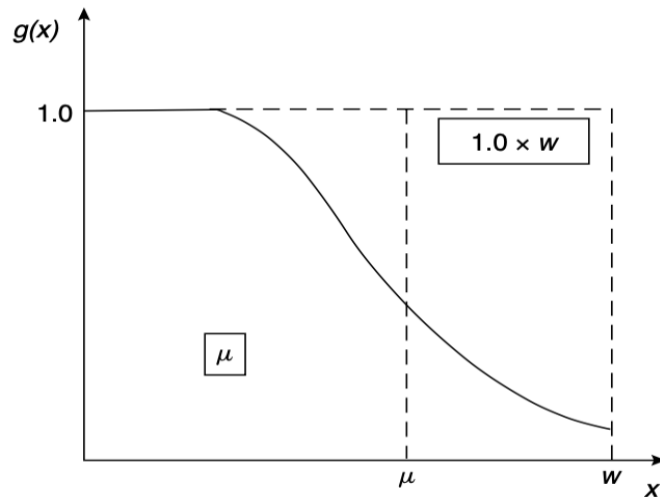


Figure 2.2: The detection function plot. Under the $g(x)$ function, the probability that an animal within distance w may be represented by the proportion of rectangle that is under the curve, which gives $P_a = \mu/w$, and the area under the curve is $\mu = \int_0^w g(x)dx$ while the area of the rectangle is $g(1)=1$. Image reproduced from Thomas et al. (2002)

In modelling the detection function, it is preferable to consider what covariates are worth recording. There are different types of potential covariates, some may be static (eg. do not vary over time, such as altitude) or dynamic (vary over time, such as sea state), covariates also might be associated with individual detections (such as animal behaviour, cluster size, gender, species) or with effort (such as observer, habitat) (Buckland et al., 2015). For data analysis, there is an increasing trend towards conducting distance sampling analyses using the statistical software R, rather than using the Distance software (Buckland et al., 2015).

CHAPTER 3

MEDIUM TO LARGE MAMMALS' DIVERSITY, DISTRIBUTION AND DENSITY OF SELECTED MAMMALS IN THE UPPER BARAM FOREST, MIRI, SARAWAK

3.1 Introduction

Tropical forest is known to hold high species number of wildlife as one of the world's biodiversity hotspot regions (Shephard et al., 2011). Yet, ongoing pressures on its biodiversity has exacerbated over the recent decades (Alamgir et al., 2020; Gallego-Zamorano et al., 2020). Anthropogenic activities such as extensive plantation, logging and deforestation for human development have caused dire implications on tropical biodiversity, especially in Asia and Africa (Phillips et al., 2017). Among the tropical regions, Southeast Asia has the highest relative rate of deforestation and is predicted to lose up to 42% of its biodiversity by 2100 (Sodhi et al., 2004).

The island of Borneo, one of the world's biodiversity hotspots has high endemism of biodiversity in Southeast Asia. However, there is increasing evidence that its wildlife population are severely affected and downsized in response to habitat loss and defaunation (Benítez-López et al., 2017; Phillips et al., 2017; Nuttall et al., 2021). This has profound effects especially on Bornean terrestrial mammals, as they are greatly affected by disturbance whilst playing important role as dispersers (Benítez-López et al., 2019; Gallego-Zamorano et al., 2020). Despite this, our understanding on the biological and ecological backgrounds of most mammals' species remains poor, including studies for the evaluation of its remaining numbers (Ripple et al., 2014).

Over the past decades, anthropogenic activities have dramatically changed the landscape of Borneo (McAlpine et al., 2018). More than 179,000 km² of Borneo are logged forest, with additional 10% of Borneo's region has been cleared for industrial oil palm and timber plantations (Gaveau et al., 2014). In the last four decades, the lowland forests are the most threatened with massive deforestation which has led to fragmented forest landscapes (Gaveau et al., 2014). The expansion of agricultural plantation such as oil palm plantation (*Elais guineensis*) was responsible for pervasive forest degradation across the region (Meijaard, et al., 2018).

Forest intactness was suggested to be a great factor affecting wildlife communities (Jati et al., 2018). To date, little research was done into how wildlife communities inhabit the mosaic landscape developed by recent human activities (Samejima & Hon, 2020). Research focusing on wildlife in heterogenous landscapes is relevant to elevate our understanding on landscape changes impact towards wildlife communities. There is little information available on mammals' communities in secondary forests around villages and rural areas in Southeast Asia (Samejima & Hon, 2020).

Many studies have focused on quantifying the impacts of such disturbance to species richness and distribution, but very little were found to address Bornean terrestrial mammals' densities (Udevitz & Gould, 2012; Buckland et al., 2015; Ahmad et al., 2021). Density estimation is crucial for conservation strategies, the evaluation of species conservation status and answer ecological questions (Gestich et al., 2016). This piece of data is much more informative, but their application is generally limited by the lack of such data (Santini et al., 2018). In the case of Bornean mammals, this critical information is often lacking, hampering targeted conservation plans and effective deployment of resources (Mathai et al., 2013).

To date, density studies in Borneo has focused on species of conservation interest, such as Sunda Clouded leopard (*Neofelis diardii*) and Borneo orangutan (*Pongo pygmeus*) (Wilting et al., 2012; Seaman et al., 2019). Plus, most density studies were often conducted in protected areas, although this area does not account for external factors such as hunting and rapid forest loss across Borneo (Ahmad et al., 2021). Nevertheless, information on density of other Bornean species is still undoubtedly scarce (Bennett et al., 2000; Ahmad et al., 2021). More research is needed to supply recent reliable information about species population especially in a region where forest loss and defaunation progressively occur (Scriven et al., 2015; Benitez-lopez et al., 2017).

In assessing wildlife abundance, one of the most used methods is the distance sampling method. Distance sampling method is widely used by researchers due to its robustness and lenient assumptions compared to other methods such as camera traps and cue count (Buckland et al., 2015). The two main methods of distance sampling are 1) line transect survey and 2) point survey (Thomas et al., 2002). These approaches are effective when the object of interest is in a dispersed population and occur in low density in which, it allows the estimation of absolute density for a population even if not every individual is counted (Buckland, 1993; Thomas et al., 2002).

This study estimates wildlife's diversity and density of selected large-sized mammals in the Upper Baram Forest region Sarawak, Malaysian Borneo. The need for long term population management studies was discussed using this information. The distribution of selected species that were close to human settlements was analysed and the possible long-term consequences of their declining population in the forest remnants were further

discussed. The recommendation on research priorities and intervention that should contribute to the future of wildlife conservation in the Upper Baram Forest was concluded.

The study was conducted in the Upper Baram forest area with the *Orang Ulu* people as the main inhabitants of the region. The indigenous communities are highly dependent on the forest and its resources in their daily livelihood. Despite its importance for both communities and wildlife, the forest is currently unprotected and continuously losing its area due to deforestation mostly for logging with additional forest clearance for agricultural plantation. In this study, local communities from the study area involved in the field sampling and data collection process.

3.2 Materials and Methods

3.2.1 Study Site

The Upper Baram or '*Ulu Baram*' is in Northeastern Sarawak and administered under Miri division. The *Ulu Baram* is the upper part of the Baram River, which is also known as '*Batang Baram*' in Sarawak. The river, with a length of 400 km extending from the Kelabit highlands to the South China Sea. The annual rainfall of the Upper Baram is 3564 mm with high spatial and temporal variations (Vijith & Dodge-Wan, 2021). The vegetation comprises of Mixed Dipterocarp Forests with undulating hills ranging to about 300 meters and mountain highlands extending to the Kalimantan Border. The highest peak in the study area is Gunung Murud Kecil with more than 1600 metre above sea level, which is located nearby to one of the Penan Selungo settlements called Long Sait.

The Upper Baram is the main settlements for the indigenous communities of the *Orang Ulu* ethnic groups, such as the Kenyah, Penan and Kayan people. The *Orang Ulu* people have traditionally lived in the forest of the Upper Baram region and depend on the

forest for daily resources including materials, food, shelter, and medicine. Most of the local communities' economy is currently based on fishing, hunting, and farming including slash-and-burn practice for paddy and crops cultivation (eg. Pepper (*Piper nigrum*), Rubber (*Hevea brasiliensis*)). Small portion of the villagers raise livestock. The establishment of logging road networks across the landscapes acts as the main connection for the local communities apart from travelling using boat to the nearby town and villages.

Generally, logging operation is ongoing in the Baram region with the presence of some active logging camps. Most of the remaining intact forest can be found further up of the region particularly around its subsidiaries, although logging has started to occur in the area in the recent years. Further down towards to the central part of Baram, much of the region especially its lowland areas have been cleared mainly for the extraction of timber. There are patches of areas that have been previously logged have regrowth into secondary forest and currently covered with shrubs and grass vegetation.

The six villages within the surveyed area are 1) Tanjung Tepalit (3°14'16.0"N 114°49'18.0"E), 2) Long Tungan (3°09'41.2"N 115°10'58.3"E), 3) Long Siut (3°12'28.0"N 115°11'05.6"E), 4) Long Krong (3°17'7.7634"N 115°12'46.44"E), 5) Long Spigen (3°13'36.05"N 115°11'53.56"E), and 6) Long Sait (3°18'13.42"N 115°11'30.54"E) (Figure 3.1). These are some of the *Orang Ulu* villages that are located near the *Batang Baram* Miri, Sarawak. Most of these villages are located close to the main *Batang Baram* and its subsidiaries.

The main community from the villages is from the *Orang Ulu* ethnic groups; mainly of the Penan and Kenyah. Long Siut, Long Tungan, and Lepo Gah Tanjung Tepalit are dominated by Kenyah's settlements while Long Spigen, Long Sait and Long Kerong are

Penan Selungo villages (Table 3.1). Two of the villages; Long Tungan and Lepo Gah Tanjung Tepalit are located near the main *Batang Baram* river, while Long Siut, Long Spigen and Long Sait are located at one of the tributaries called the *Selungo* river.

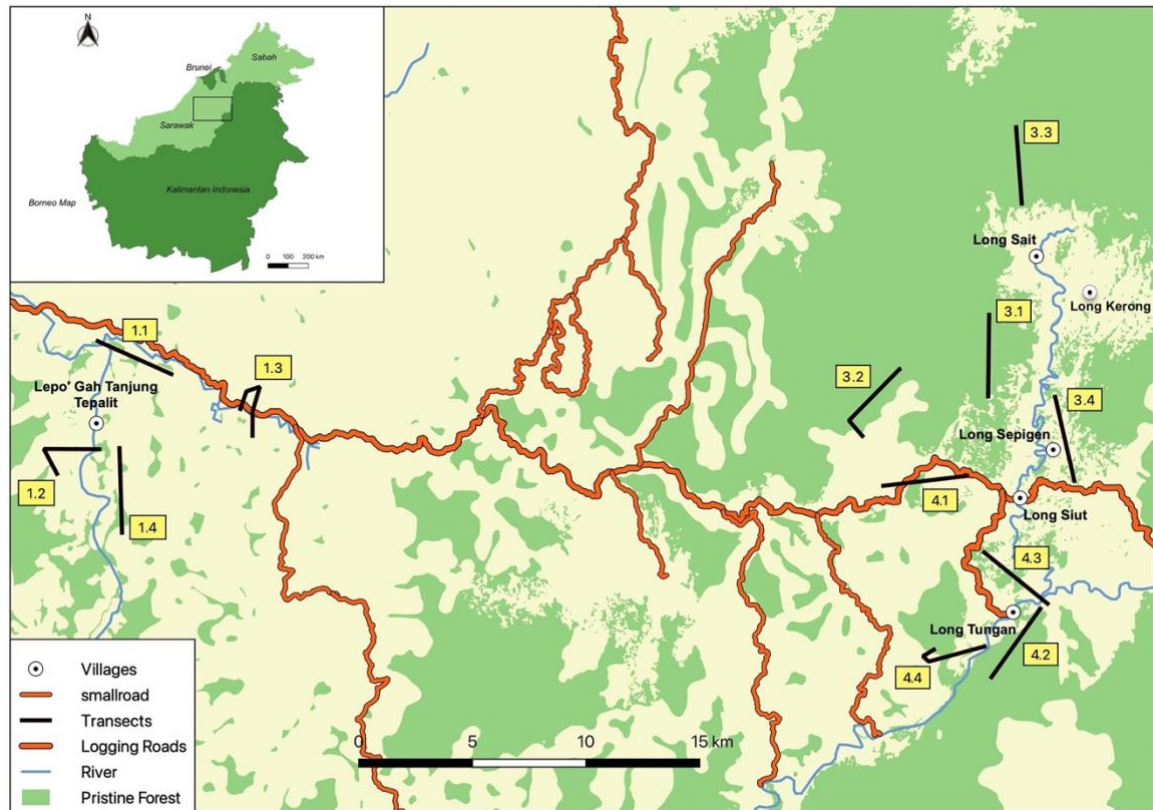


Figure 3.1: Location of study sites in the Upper Baram region, Sarawak. The figure showing study transects (n=12) placed randomly within the three study clusters. All transects were 4 km long and distanced at >300 m apart to increase independent detection. In place where difficult terrains were impossible to traverse, the transect will be turned to 90 degrees right or left until the end. Forest cover as observed are abundant in the upper parts of the Baram river, and lessen further down the river.

The lowland dipterocarp forest of the Upper Baram is an important habitat for many Borneo endangered species including Sun bear (*Helarctos malayanus*), Sunda Clouded leopard (*Neofelis diardii*) and the elusive Bay cat (*Catopuma badia*) (Mathai et al., 2014). Meanwhile, the highlands parts of the region are known to host many mammals species endemic to Borneo, including the Grey langurs (*Presbytis* spp.), Hose's civet (*Diplogalei hosei*) and Bornean Ferret badger (*Melogale everretti*) (Mathai et al., 2014).

3.2.2 Study Design

Four straight lines were established, each four km length in each village cluster which made up to a total of 12 line transects over the study area. The transects were placed in a stratified random fashion with the distance of 300 meters apart to maximize independent detection of animals (Figure 3.1). Transect length was selected to increase area covered by the study. The 300 meters apart may appear linear in nature but often these transect were separated by steep terrain, rivers, villages, logging roads and active farmland areas. As such the likelihood of individuals especially game animals crossing to nearby transects are low. Additionally, the study design also considered other studies conducted in tropical rainforest (Bersacola et al., 2014; Ahmad et al., 2021).

In rare situations when impassable barriers were encountered (such as cliff) that could not safely be traversed, the transect extended in the opposite direction to its four km end point and if this was not possible, it turned instead to the right at a 90° angle and continued until the four km end point. Transects walk started a week after the establishment to allow wildlife to adapt back to their routines after the disruption of the cleared paths. The transects were walked in the first two weeks of every month to ensure that data collection was done at almost the same time and to reduce differences in sampling time. In total, all 12 transects (48 km) were surveyed once per month, with a combined survey effort of 288 km over eight months of sampling occasions.

The transects were randomly placed and cut across different forest types in the study area, thus unique to each other. Two of the established transects were located in community forest reserve. Transect 1.4 is located within the Lepo Gah Tanjung Tepalit (Cluster 1) community forest reserve, called *Uket* (the name of the area itself), while Transect 4.2 lies

within the *Baie Kerumun Jamok* (Jamok's forest reserve) in Kenyah Jamok cluster (Cluster 4). In these community forest reserves, no harvesting activities are allowed, including the hunting of wild animals and log harvest.

3.2.3 Data Collection

Twelve individuals from the local communities assisted in the sampling work for eight sampling occasions, inconsecutively from Mac 2020 to April 2021. This was due to the implementation of movement control order on the outbreak of pandemic Covid 19. Transects were walked once per month and started early morning (0730) randomly. The average time to complete each transect walk is eight hours. Hunting on the transects lines was prohibited throughout the survey period, especially during data collection process. Local communities were not allowed to use the transect for hunting. Additionally, the communities have their own traditional hunting ground.

Each group of observers was equipped with a smartphone to record information. All information collected from the field sampling was recorded into a mobile device installed with the Cybertracker Software Version 3.514 (Liebenberg & Steventon, 1997). Before the commencement of this survey, training was provided at various occasions to the technicians to ensure the correct practice of distance sampling protocols including the use of tools such measuring tape and GPS, data recording and animal identification. Monthly monitoring and reporting on the field was held to minimize biases. Plus, all the communities members are hunters and have great experience in hunting.

Upon encounter with animal, the observer would stop walking and record the species name, and number of animals detected. The location (latitude and longitude) of the detection was also recorded using Global Positioning System (GPS). The distance of animal from the

observation point was measured using a 100 metre measuring tape and the angle of the animal from the transect was recorded using a compass. The technicians must ensure that all measurements were taken correctly and no heaping of measurements was allowed to avoid bias in distance measured as described by Buckland et al. (2015). Additionally, the mean distance measured in this study was approximately 30 meters. Therefore, the bias between the use of measuring tape and range finder is expected to be low. These measurements were used to calculate the perpendicular distance of animal from the transects.

In the beginning of every transect walk, the observers recorded following information: transect ID, cluster, date, time, and weather. Data was retrieved at the end of every month from the Cybertracker app using ArcGIS software. The final data was managed and organized in Excel prior to analysis.

3.2.4 Data Analysis

3.2.4.1 Species Diversity, Relative Abundance and Distribution

The statistical software R Studio version 4.1.3 (R Core Team, 2022) was used to carry out all analysis. The diversity indices (Shannon-Weiner Index (**H**), Simpsons Index (**D**) and Evenness Index (**J**) were generated using BiodiversityR and Vegan package. Transects were classified and renamed as in Table 3.1 for data reporting and presentation. Graphs were also plotted via ggplot2, dplyr and tidyverse R packages. Distance packages in R software can be used to estimate population abundance and density as described by Miller et al. (2019). In this study, almost all of the species did not have sufficient detection data to run abundance and density estimation. Therefore, relative abundance was used to demonstrate the when estimating density is not possible.

Table 3.1: Study cluster, community ethnicity and transect number. There were four village clusters involved in the beginning of the study. However, only three of the clusters fully committed to the study. Cluster 2 was excluded due to consent issues.

Cluster/Village	Ethnicity	Transect Cluster Label	Transect Number
Cluster 1: Lepo' Gah Tanjung Tepalit	Kenyah	1.1	1
		1.2	2
		1.3	3
		1.4	4
Cluster 3: Long Sait/Long Spigen	Penan	3.1	5
		3.2	6
		3.3	7
		3.4	8
Cluster 4: Long Tungan/Long Siut	Kenyah	4.1	9
		4.2	10
		4.3	11
		4.4	12

Species relative abundance was calculated using the formula:

$$Relative\ Abundance\ (\%) = \frac{Isi}{\sum Nsi} \times 100 \quad \text{Equation 2.1}$$

where Isi is the total number of observations per species, and $\sum Nsi$ is the total number of observations for species population. Species relative abundance were generated using pooled and single transect detections.

The heatmap of animals' distribution was generated using QGIS software version 3.22.10 (QGIS Development Team, 2021). The locations of animal's detection as recorded

via GPS during observation were saved and organized in Excel file before exporting it into QGIS software to generate heatmaps.

3.2.4.2 Distance Sampling Analysis

Species with less than 40 observations were excluded from the density analysis as insufficient observation led to the failure of fitting the detection function. Only three species were identified (Bearded pig, Long-tailed macaque and Short-tailed macaque) with sufficient data has proceeded to density estimation analysis using DISTANCE package. Conventional distance sampling (CDS) method was used to model the population density.

Model with the lowest AIC value were chosen for each species (Table 3.2). The detection function models were fitted using R package Distance (R Core Team, 2022). Distance data for all species were truncated to improve model fitting and reduce bias. The distance data for all species was inspected and the right truncation at 50 m distance was identified as the effective strip width (W) to avoid biases from outliers (Buckland et al., 2001). In this study, the 50 m truncation distance was set based on the distribution of the distances. Distances beyond 50 meters made up only less than 9% of the total data collected and with probability of detection to be around 0.15. Additionally, some truncation increases the robustness of the analysis (Buckland et al., 2015).

Models with uniform, half-normal, and hazard rate key functions and cosine, simple polynomial, and hermite polynomial adjustments were explored. Akaike's Information Criterion (AIC) was used as a reference for choosing the best model. Model with the lowest AIC value were chosen for each species (Buckland et al., 2015).

Table 3.2: Models with the lowest AIC value chosen for the Bearded pig, Pig-tailed macaque and Long-tailed macaque.

Species	Model fitted	Formula
Bearded pig <i>Sus barbatus</i>	Half-normal	~1
Pig-tailed macaque <i>Macaca nemestrina</i>	Uniform with cosine adjustment term of order 1	NA
Long-tailed macaque <i>Macaca fascicularis</i>	Half-normal	~1

3.3 Results

3.3.1 Species Diversity

Effort surveyed was 96 km that accumulated up to 240 hours over the eight sampling occasions. This has resulted to a total of 486 detections, consists of 17 medium to large mammals' species from seven families. The highest number of species recorded was from family Viverridae (four species), followed by Cercopithecidae (four species), and Cervidae (three species). Species with the highest detection was the Pig-tailed macaque (*Macaca nemestrina*), followed by Long-tailed macaque (*Macaca fascicularis*), and Bornean Yellow muntjac (*Muntiacus atherodes*) and Bearded pig (*Sus barbatus*) (Figure 3.2). The relative abundance percentage for species at each transect is as depicted in Figure 3.6.

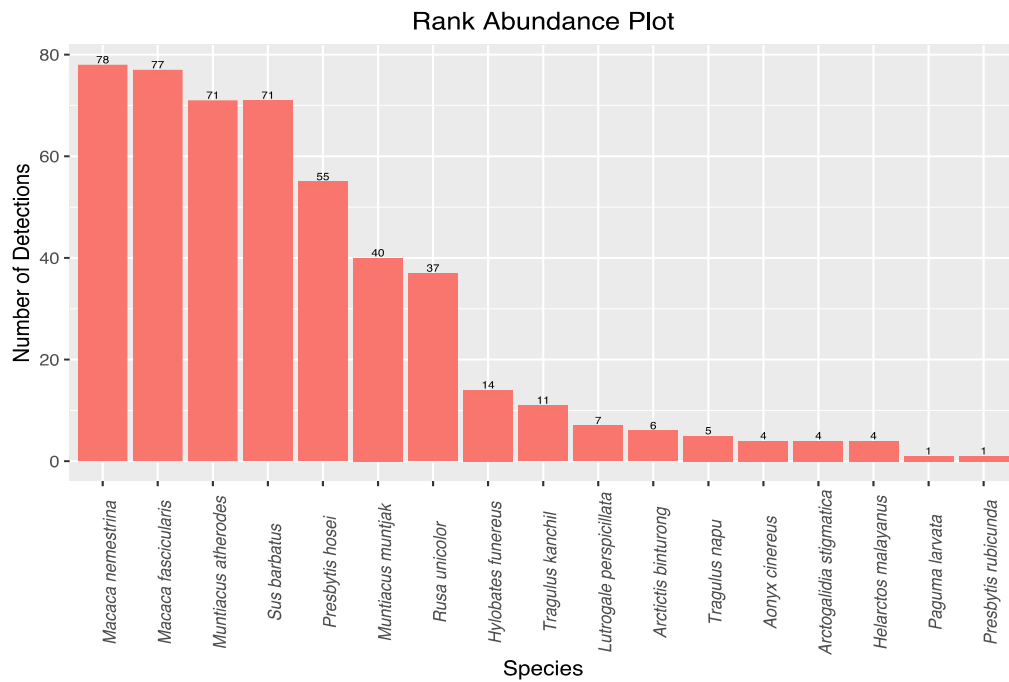


Figure 3.2: The rank abundance graph showing 17 species and number of detections recorded via sighting method. The Pig-tailed macaque (*Macaca nemestrina*) was species detected the most, followed by Long-tailed macaque (*Macaca fascicularis*) and Bornean Yellow muntjac (*Muntiacus atherodes*) and Bearded pig (*Sus barbatus*).

The highest species richness was recorded from Transect 6 and 7 with 12 species (71% of total species) detected respectively, whereas Transect 1 recorded the lowest species richness (6 species) (Table 3.2). Transect 7 recorded the highest Shannon-Wiener H , which depicts high diversity. Transect 5 recorded the highest Simpson's D index, while transect 9 and 2 recorded the highest evenness index (J). More species are expected to be observed in the study region with increasing number of sampling efforts (Figure 3.3) and number of individuals sampled (Figure 3.4). This suggest that sampling saturation could be achieved with increased sampling duration and number of observations at all transects (Figure 3.5).

Table 3.3: Diversity Indices and species richness of each transect. Diversity Indices were computed for overall and each transect.

	Overall	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Species Richness	17	6	9	8	7	10	12	12	9	9	9	11	7
Shannon-Wiener (H)	2.29	1.51	2.07	1.80	1.51	2.09	2.11	2.16	1.96	2.06	1.98	2.05	1.80
Simpson's (D)	0.88	0.73	0.86	0.80	0.69	0.87	0.86	0.86	0.82	0.86	0.84	0.84	0.82
Evenness (J)	0.81	0.84	0.94	0.87	0.78	0.91	0.85	0.87	0.89	0.94	0.90	0.85	0.92

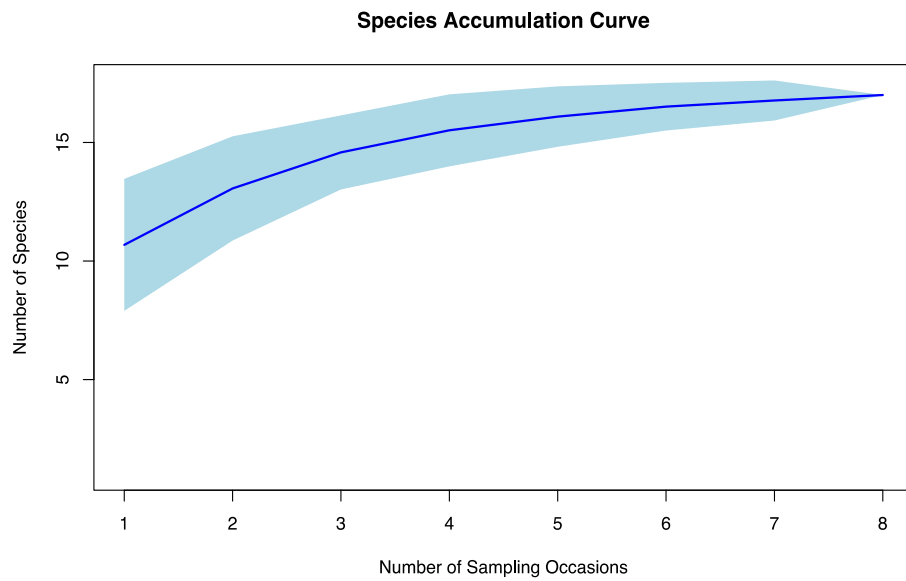


Figure 3.3: The species accumulation curve is not reaching a plateau for eight sampling occasions. Number of species is predicted to increase as more observation (number of sampling occasions) conducted. The shaded region in blue corresponds to the standard deviation.

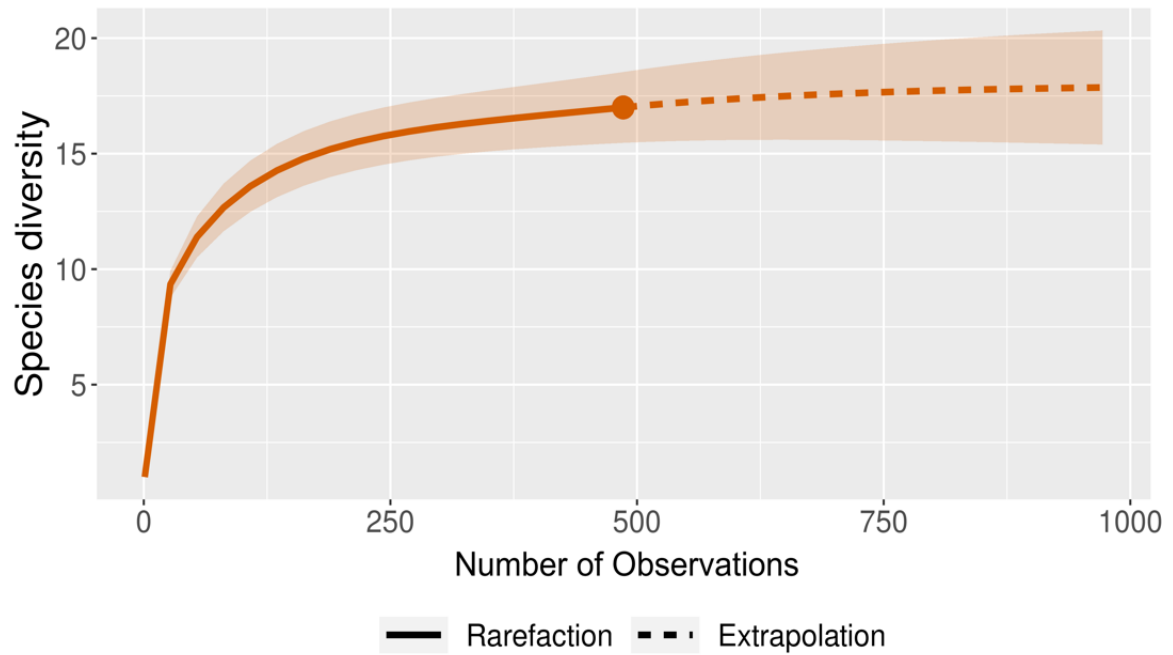


Figure 3.4: Pooled rarefaction curve of all transects surveyed showing that species richness is predicted to increase with increasing number of observations. The shaded area corresponds to standard deviation.

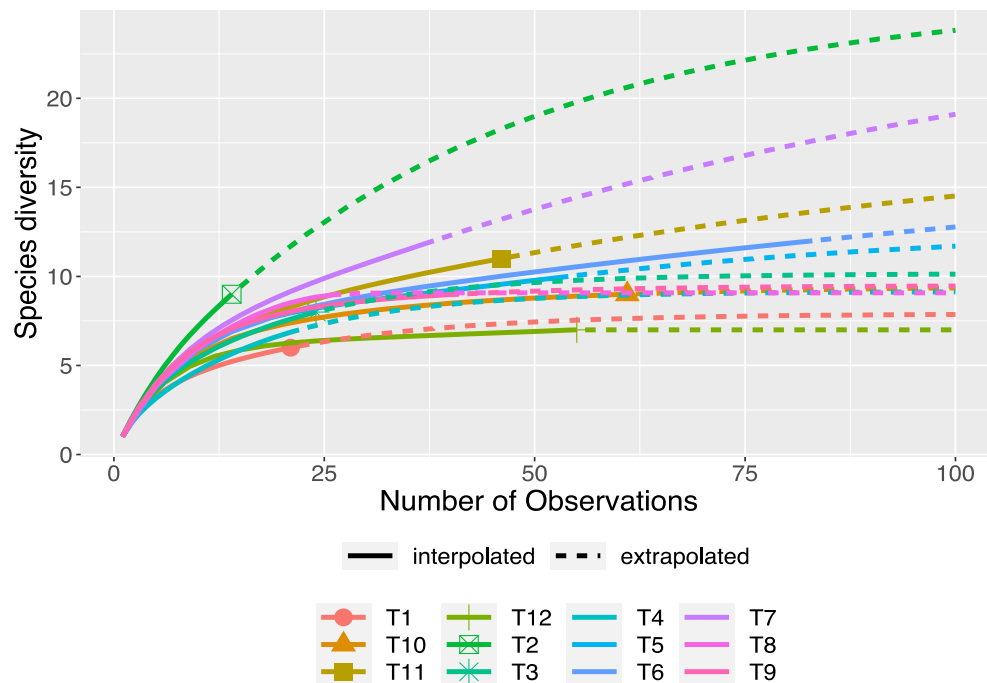


Figure 3.5: Rarefaction curves of species richness for each study transect in study area. Transect 2, 7, 11, 6 and 4 are still increasing and not converge, which indicates that there could be species that have not yet been observed, especially of rare species.

A major portion of the species encountered (53%) are classified as Vulnerable (VU) according to IUCN Red List (IUCN, 2022) (Table 3.3). This includes the Sambar deer (*Rusa unicolor*), Bearded pig (*Sus barbatus*), Long-tailed macaque (*Macaca fascicularis*), Pig-tailed macaque (*Macaca nemestrina*), Binturong (*Arctictis binturong*), Smooth-coated otter (*Lutrogale perspicillata*), Bornean Sun bear (*Helarctos malayanus*), Hose's langur (*Presbytis hosei*), and Red langur (*Presbytis rubicunda*). While two species detected are listed as Near Threatened (NT), including the North Borneo gibbon (*Hylobates funereus*) and Small-Clawed otter (*Aonyx cinereus*). Of these, the Hose's langur (*Presbytis hosei*) and Red langur (*Presbytis rubicunda*) are classified as Totally Protected species under the SWLPO 1998 (Table 3.3).

The survey reported some notable endemic species such as the Bornean Striped Palm civet (*Arctogalidia stigmatica*), Red langur (*Presbytis rubicunda*) and the Bornean Sun bear (*Helarctos malayanus*). The Red langur (*Presbytis rubicunda*) was detected once at Transect 6 while the Bornean Sun bear (*Helarctos malayanus*) was detected four times at Transect 1, 5, 9, and 11. The Bornean Striped Palm civet, (*Arctogalidia stigmatica*) was detected at four independent times at Transect 5,6,7 and 8 (Figure 3.7).

The distribution heatmaps for selected mammals' species show that most of the abundant species were concentrated at Cluster 3 and 4. This includes the Long-tailed macaque (*Macaca fascicularis*), Pig-tailed macaque (*Macaca nemestrina*), Hose's langur (*Presbytis hosei*), Bearded pig (*Sus barbatus*), Bornean Yellow muntjac (*Muntiacus atherodes*), North Borneo gibbon (*Hylobates funereus*), Barking deer (*Muntiacus muntjac*) and Sambar deer (*Rusa unicolor*).

Table 3.4: Checklist of wildlife recorded at the Upper Baram study clusters via sighting method with overall Relative Abundance (%). Abbreviations: RA= Relative Abundance; No.= Number of encounters; IUCN= IUCN Red List (2022); LC=Least Concern; NT=Near Threatened; VU=Vulnerable; EN=Endangered; SWLPO 1998= Sarawak Wild Life Protection Ordinance 1998; TP= Totally Protected; P= Protected; NP= Not Protected.

Family	Species/Scientific name	No. of detection	RA (%)	IUCN Status	SWLPO 1998
Cervidae	Barking deer <i>Muntiacus muntjak</i>	40	8.97	LC	NP
	Bornean Yellow muntjac <i>Muntiacus atherodes</i>	31	6.95	NT	NP
	Sambar deer <i>Rusa unicolor</i>	37	8.30	VU	NP
Suidae	Bearded pig <i>Sus barbatus</i>	72	16.14	VU	NP
Tragulidae	Greater mousedeer <i>Tragulus kanchil</i>	11	2.47	LC	NP
	Lesser mousedeer <i>Tragulus napu</i>	5	1.12	LC	NP
Cercopithecidae	Long-tailed macaque <i>Macaca fascicularis</i>	77	17.26	VU	P
	Pig-tailed macaque <i>Macaca nemestrina</i>	78	17.49	VU	P
	Hose's langur <i>Presbytis hosei</i>	54	12.11	VU	TP
	Red langur <i>Presbytis rubicunda</i>	1	0.22	VU	TP
Hylobates	North Borneo gibbon <i>Hylobates funereus</i>	14	3.14	EN	P
Viverridae	Bear cat <i>Arctictis binturong</i>	6	1.35	VU	P
	Masked Palm civet <i>Paguma larvata</i>	1	0.22	LC	P
	Borneo Striped Palm civet <i>Arctogalidia stigmatica</i>	4	0.90	LC	P
	Smooth-coated otter <i>Lutrogale perspicillata</i>	7	1.57	VU	P
	Small-clawed otter <i>Aonyx cinereus</i>	3	0.67	EN	P
Ursidae	Sun bear <i>Helarctos malayanus</i>	4	0.90	VU	P

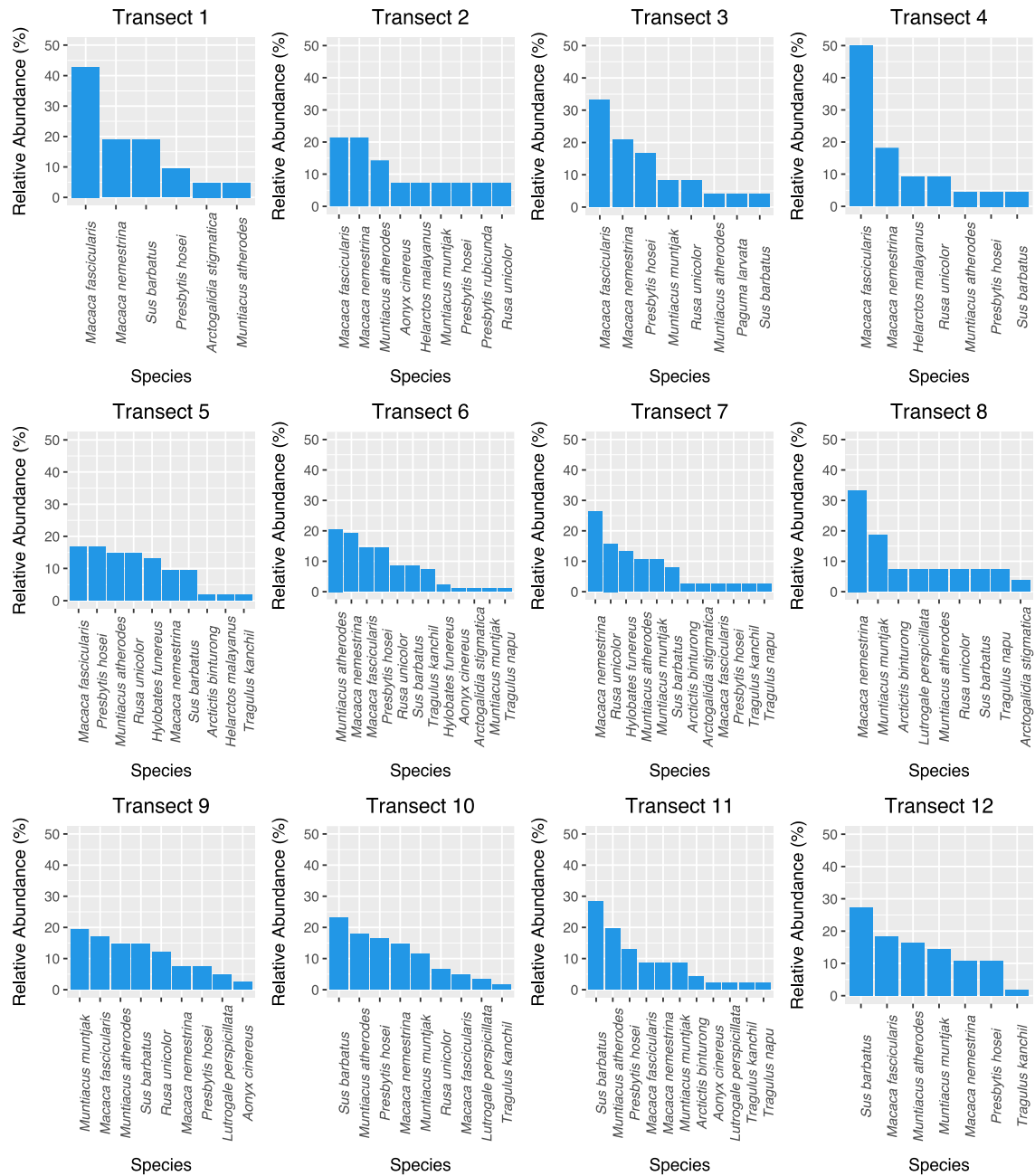


Figure 3.6: Showing the relative abundance of species per transect. Transect 6 and 7 recorded the highest species richness (n= 12) followed by Transect 11 (n=11). Primates were recorded at high relative abundance at most of the transects, except for transects 6, 9, 10, 11 and 12 which were dominated by Ungulates.

Medium- to Large-sized Mammals Distribution

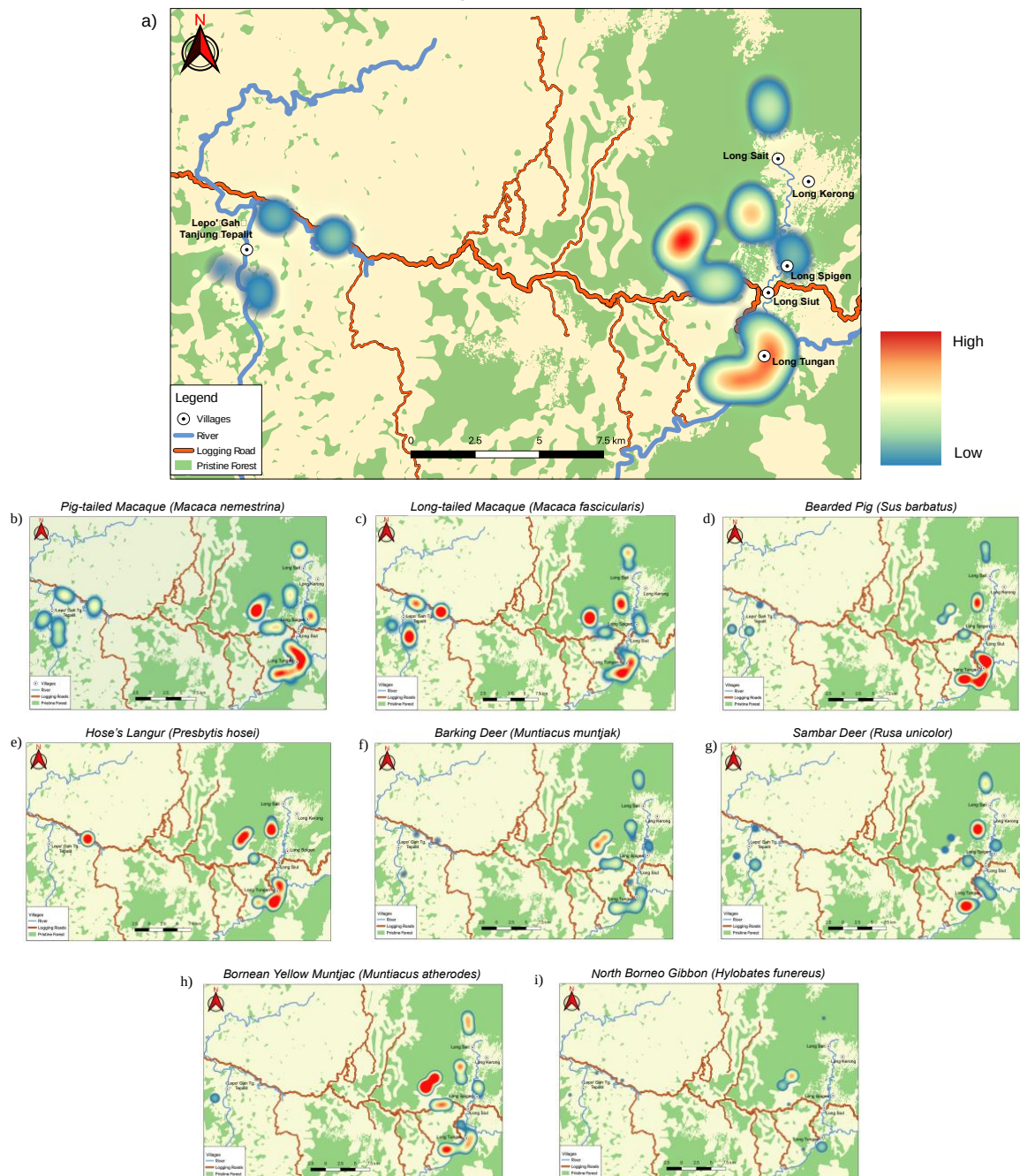


Figure 3.7: The heatmaps of selected mammals' species visualizing species distribution based on detections as recorded using GPS at study transects. The first map (a) shows the distribution of all medium to large mammals' species at study area. Map (b) to (i) are the distribution maps for selected species with high detections.

3.3.2 Densities of Selected Large Mammals Species

The density of selected large mammals' species was estimated by using the line transect data from August 2020 to February 2021. Only three species were identified to yield sufficient data that allow in generating the fitted detection functions (Figure 3.8).

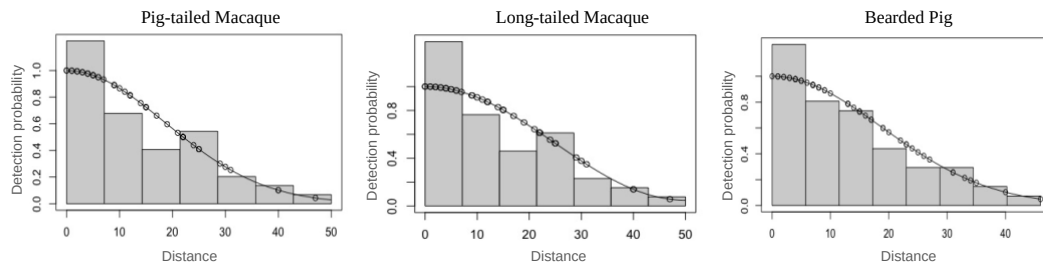


Figure 3.8: The detection function $g(x)$ for the Bearded pig (*Sus barbatus*), Pig-tailed macaque (*Macaca nemestrina*) and Long-tailed macaque (*Macaca fascicularis*). All data were truncated at 50 meters in the analysis.

Species with the highest population density estimated was the Long-tailed macaque (*Macaca fascicularis*), with $D=27.10/\text{km}^2$, followed by the Pig-tailed macaque (*Macaca nemestrina*) ($D=18.20/\text{km}^2$) and the Bearded pig (*Sus barbatus*) with $D=10.22/\text{km}^2$ (Table 3.5). All estimated species are classified as vulnerable according to IUCN Red List (IUCN, 2022).

Table 3.5: Density estimates and abundance for three large mammals in the Upper Baram region. Abbreviations: D=Density; CV%= coefficient of variation; LCL=Lower Control Limit; UCL= Upper Control Limit; km^2 = kilometer square; VU= Vulnerable.

Species	Scientific names	IUCN Status	No. of detection	D (/km ²)	CV%	LCL – UCL (95%)
Bearded pig	<i>Sus barbatus</i>	VU	55	10.22	25.34	6.01 – 17.40
Pig-tailed macaque	<i>Macaca nemestrina</i>	VU	49	27.10	24.82	16.13– 45.54
Long-tailed macaque	<i>Macaca fascicularis</i>	VU	42	18.20	20.97	11.82 – 28.03

3.4 Discussion

3.4.1 Medium to Large Mammals Diversity of the Upper Baram

Multiple disturbances such as logging and habitat conversion continue at a rapid rate in the Upper Baram Forest area, which has contributed to a change in its natural forest landscapes. This can cause a drastic decreased in populations of some wildlife, although other species may be adapting to the new mosaic landscape (Samejima & Hon, 2020). Logging, otherwise, has proved to cause less impact on species assemblages, and this effect can be predominantly observed among herbivorous and generalist species (Maiwald et al., 2020; Samejima & Hon, 2020).

The study results suggest that the heterogenous landscapes in the study area is vital to support many wildlife species, despite ongoing disturbances. In total, the study recorded 17 species of medium- to large-sized mammals, which is relatively higher compared to previous research, irrespective of dissimilarity in terms of method used and effort (Table 3.6). A study conducted in a human-disturbed landscape yielded the same count for medium to large mammals' species, despite the differences in the assemblages of species detected (Samejima & Hon, 2020) (Table 3.6). Similar study in the nearby forest management unit has recorded seven species of carnivore using the same method (Mathai et al., 2010).

The results revealed that area covered with more intact forest most likely to harbour more species in contrast with degraded areas. The lowest species richness was recorded at Cluster 1 transects (Transect 1, 2, 3 & 4). This forest area is heavily degraded and fragmented compared to Cluster 3 and 4, which made it favourable to generalist species such as the Bearded pig (*Sus barbatus*) and Long-tailed macaque (*Macaca fascicularis*), but harbour less habitat-specific species. The findings is consistent with previous studies by Jati et al.

(2018) which found that ungulates and primates are abundant in degraded forests surrounding villages than primary forests. This is most likely as the species are lowly affected by disturbances due to their resilience and tolerable toward habitat changes and modification (Bersacola et al., 2019; Maiwald et al., 2020).

Table 3.6: Studies on wildlife diversity with number of mammals' species recorded in some protected areas and other sites in Sarawak Borneo.

Location	No. of medium to large mammals' species recorded	Method	Effort (Total Distance walked/Number of days)	Source
Upper Baram (Study area)	17	Line Transect	98 km	This study
Pulong Tau National Park, Sarawak	28	Camera Trapping	2095 camera days	ITTO & FDS (2017)
Sela'an-Linau Forest Management Unit, Upper Baram	7	Line Transect	789.125km transects walk	Mathai et al. (2010)
Anap Sustainable Management Unit, Bintulu Sarawak	17	Camera Trapping	41467 camera days	Samejima & Hon (2020)

Hunting is prevalent in the study area and have been found to directly affect species population, abundance, and diversity (Bennett et al., 2000; Brodie et al., 2015; Yi & Mohd-Azlan, 2018). Nevertheless, the study found a high detection of frequently hunted species including the Bearded pig (*Sus Barbatus*), Long-tailed macaque (*Macaca fascicularis*), and Pig-tailed macaque (*Macaca nemestrina*). This probably indicates that the hunting pressure

in the area is relatively low compared to other places, in which the scarcity in individual animals can be prominently observed in the presence of hunting (Kato & Samejima, 2020; Loke et al., 2020; Kurz et al., 2021). The persistence of some species population to overcome this threat is most likely due to its high fecundity and behavioural ability to quickly recolonize disturbed areas (Steinmetz et al., 2010; Cheyne et al., 2016). Also, the study found that transect 6 and 7 yields the highest species richness compared to other transects. This is most likely because Transect 6 and 7 were located further away from the villages and road, therefore limiting daily access to hunters. This could partly explain why these transects have been recorded with more species than others.

In the case of hunting, the response of different species towards this factor is vary. The results shows that the total number of detections for the Sambar deer (*Rusa unicolor*) was relatively low compared to other species. The distribution of this species is high in Cluster 4 and Cluster 3, but lower in Cluster 1 forest area. A study found that Sambar deer prefer open habitat, and shows greater abundance in area that is close to the river (Simcharoen et al., 2014). Despite the preferrable habitat, it is suggested that the Sambar deer's population in the study area is poorly recovered in response to hunting. The plausible explanation is that Sambar deer (*Rusa unicolor*) population has slower rate of recovery compared to other Ungulates, possibly due to excessive hunting of males for its large body size, thus impairing the reproduction of the species (Steinmetz et al., 2010). In addition, the hunting of males Sambar deer also usually associated for its antlers as a trophy and decoration (Mohd-Azlan & Fauzi, 2006).

There were four endemic primates species detected in the study area including the Red langur (*Presbytis rubicunda*), a highly arboreal primate species and currently listed as Vulnerable (VU) on the IUCN Red List 2022. The species was known to rely on taller

emergent trees to avoid predators and use the relatively high canopy to travel and feed (Bersacola et al., 2014). Previous study suggested that undisturbed dipterocarp forest can support relatively high densities of the Red langur (Bersacola et al., 2014). There is a need for a further investigation on their population where the species persists particularly in such disturbed habitat.

The distribution of the Red langur (*Presbytis rubicunda*) was found to be allopatric with the endemic Hose's langur (*Presbytis hosei*). In the Baram region, the Hose's langur (*Presbytis hosei*) shares their home ranges with other abundant Primates species such as Macaques (Ramlee, 2011). The species known distribution range is from Niah, North Sarawak up to Kinabalu and West to the Kayan river in Kalimantan (Phillipps & Phillipps, 2018). The results showed that the Hose's langur (*Presbytis hosei*) is still abundant in the Upper Baram forest despite the shrinking of its habitat over the last decades. The study recorded 55 detections of Hose langur (*Presbytis hosei*) in the entire observation period, which was the fourth most common species reported by this study.

The remaining forest of the Upper Baram is a preferred habitat for the North Borneo gibbon (*Hylobates funereus*). The species is the most common gibbon in the hill forest of North Central Borneo to East Kalimantan (Phillipps & Phillipps, 2018). The North Borneo Gibbon (*Hylobates funereus*) mostly utilize the forest canopy layer during their diurnal activity especially for the female with infants and found to be able to survive in logged forest (Inuoe et al., 2016; Phillipps & Phillipps, 2018). The results supported this as the species was found to be well-distributed in the study area including the highly degraded area, despite being absence at some transects.

The Bornean Striped Palm civet (*Arctogalidia stigmatica*), a highly arboreal and nocturnal civet species was detected at a relatively low rate in the region. There were four independent records of this species, and all were found at Cluster 3 transects (Transects 5,6,7 and 8). Their high arboreal behaviour thus explains the low detection, as they were exclusively found in area of the study region where continuous forest with tall canopy trees is abundant. This indicates that the species has habitat specialization, and the main reason for such preference is likely due to its feeding behaviour (Duckworth & Nettleback, 2007; Phillipps & Phillipps, 2018). Previous studies via camera-trapping failed to record the presence of this species although its distribution was known to occur within those areas, which possibly suggest their rare activity on the ground (Mathai et al., 2010; Bernard et al., 2014; Maiwald et al., 2020).

Many of specialist carnivores such as the Clouded leopard (*Neofelis diardii*), Bay cat (*Catopuma badia*) and Marbled cat (*Pardofelis marmorata*) were not recorded in this study. The lack of field observations on the species possibly due their nocturnal behaviour, which has lowered the chance for detection during daylight, despite owing to their cryptic nature. Alternatively, there is a high possibility of detecting this species at night. However, traversing the transects at such time is impractical as the tropical forest terrain is very challenging with its dense canopy (Mathai et al., 2013). Nevertheless, the presence of carnivores also can be indirectly observed via the relationships between the presence of Sambar deer (*Rusa unicolor*) as an indicator for the occurrence of Clouded leopard (*Neofelis diardi*), with the presence of the latter species always accompanied by the presence of Leopard cat (*Prionailurus bengalensis*) and Marbled cat (*Pardofelis marmorata*) (Cheyne et al., 2016). A study in the nearby forest management unit found many species of carnivores including the Clouded leopard (*Neofelis diardii*), Marbled cat (*Pardofelis marmorata*) and

Leopard cat (*Prionailurus bengalensis*), which further support this relationship (Mathai et al., 2010).

Some species from the study were recorded at a relatively low detection, including the Small-clawed otter (*Aonyx cinereus*), Sun bear (*Helarctos malayanus*), Lesser mousedeer (*Tragulus kanchil*) and Masked Palm civet (*Paguma larvata*). All these species were currently endangered due to compounded threats from habitat loss and hunting (Brodie et al., 2015). The study also recorded an undescribed race of an endemic species of Borneo, the Tufted Ground squirrel (*Rheithosciurus macrotis*), which was previously only recorded in Maliau Basin, Sabah and Pulong Tau in Northwest Sarawak (Phillippps & Phillipps, 2018).

3.4.2 Comparison on the Density of Selected Large Mammals

The estimation of density and species abundance is essential for effective monitoring and management of its population in the wild (Buckland, 2015). In Borneo, much of density studies focus on species of conservation importance especially Primates such as Proboscis monkey (*Nasalis larvatus*), Orangutan (*Pongo pygmaeus*) and endangered carnivore including Sunda Clouded leopard (*Neofelis diardii*) (Brodie & Giordano., 2012; Aziz & Laman., 2018; Seaman et al., 2019). To date, there is little information available on species density for other species from Borneo.

The study presents the latest density estimation for Bearded pig (*Sus barbatus*) and two macaques species, the Pig-tailed macaque (*Macaca nemestrina*) and Long-tailed macaque (*Macaca fascicularis*) in Sarawak. This estimation are the rough reflections of true densities of the population in the region. Due to the scarcity of data on species density, the results were compared with existing densities study carried out in Kalimantan Borneo by

Ahmad et al. (2021). The study is the only available literature on Bearded pig's density survey using distance sampling method in Borneo.

There are some inconsistencies in terms of method used and habitat surveyed between these two studies. Ahmad et al. (2021) used pooling local expert opinion (PLEO) method in estimating the density estimates as described by Hoeven et al. (2004). This method incorporates local expert knowledge to estimate species density in addition to conventional distance sampling, with the aim to save cost and time in surveying animals. This includes conducting interview survey to ask for estimates among hunters from the local communities (Hoeven et al., 2004). Hence, this method is impossible for study conducted in area in the absence of hunters or local individuals.

In terms of surveyed area, the compared study was conducted in a nature reserve, which possibly depicts less disturbances on wildlife habitat. In contrast to this, the study was conducted in unprotected forest with continuous anthropogenic disturbances, especially from logging and land clearance activity. The compared study covered a total of 167 km², which is much larger in contrast to area covered by this study. The findings revealed that there is not much different in term of density estimates with the compared study. As shown in Table 3.7, there is less differences in the density estimates of Bearded pig (*Sus barbatus*) and Pig-tailed macaque (*Macaca nemestrina*). Meanwhile for the Long-tailed macaque (*Macaca fascicularis*), the estimation value difference is much higher compared to the other two species. This is possible as the results of inconsistency in research designs and effort. However, our estimates are relatively higher for the three species, considering the differences in total area covered and effort.

Other species surveyed in this study were unable to proceed to density estimation due to the lack of detection over the sampling period. This includes Muntjacs (*Muntiacus* spp.), Sambar deer (*Rusa unicolor*) and Hose's langur (*Presbytis hosei*) that yield less than 40 detections overall. Small sample size of these species is insufficient to able the fitting of detection function. According to Buckland (2015), 60-80 observations are required to ensure reliable estimates of densities for species of interest in distance sampling. Therefore, it is highly recommended to increase survey effort to achieve sufficient detection data for a better model fit and reduce bias. This is crucial in distance sampling as bias decreased with increasing sample size (Gonzalez et al., 2017).

Table 3.7: Comparison of densities of selected mammals from our study area with a study in Kalimantan Borneo. ind/km²= individual per kilometer square.

Species	Bearded pig (<i>Sus barbatus</i>)	Pig-tailed macaque (<i>Macaca nemestrina</i>)	Long-tailed macaque (<i>Macaca fascicularis</i>)	Survey Method	Study Site	Effort	Source
Density estimates (ind/km ²)	10.22	18.20	27.10	Line transect, Distance sampling	Upper Baram, Sarawak	12 line transects, 2.4 km ²	This study
Comparison study density estimates (ind/km ²)	12.04	26.75	23.63	Point Transect, PLEO Method	Gunung Niut Nature Reserve, Kalimantan, Indonesia	8-10 points, 167 km ²	Ahmad et al. (2021)

Nevertheless, the results must be interpreted with appropriate caution. In our study, covariate was not included during model fitting. The incorporation of covariates into detection function modelling is vital to increase the reliability of density's estimation

(Buckland et al., 2015). The use of habitat as covariate for instance, is usually done by many researchers to improve estimation (Bersacola et al., 2014). Yet, the robustness of distance sampling itself is sufficient to counteract such variation (Buckland et al., 2015). On the other hand, the use of generalized method for field sampling for all species is less preferably as some species has specific behaviours that might avoid observers. For instance, specific field work method for the detections for primates should be considered (Bersacola et al., 2014).

3.4.3 Conclusion

This study presents some vital aspects on the species diversity, abundance, distribution, of medium to large mammals in the remaining lowland forest of Sarawak, Borneo. It is concluded that despite the disturbed forest landscapes, the study area is an important reservoir for many mammals species, including the endangered and endemic ones. For instance, the detection of key species such as Hose langur (*Presbytis hosei*), Civet species and Sun bear (*Helarctos malayanus*) shows that the forest area is capable to support their population.

On the other hand, the findings demonstrate that the alteration in natural habitat provides suitable niche for generalist species (winners) and perhaps losing some of the primary forest species. This suggests that the heterogenous landscapes is crucial in providing suitable habitat for various hunted species that are mostly habitat generalist (Bearded pig, deer, mousedeer), in response to the reduction of pristine forest cover. Additionally, the information on population density for Bearded pig (*Sus barbatus*) and Macaques (*Macaca* spp.) is crucial to supply more data on wildlife abundance across its range. This acts as a baseline for future research particularly for other mammals' species. In general, these findings are hopeful to aid in formulating framework and devise strategies for future conservation work in the forest region.

3.4.4 Suggestions and Recommendations for Future Studies

More effort is needed in walking the transect to collect sufficient data for density estimates analysis. All assumptions should be followed accordingly to avoid biases in estimation (Buckland et al., 2015). On the other hand, the use of camera-trapping method is usually preferred for study concerning rare species as it is unlikely to impact animal's behaviour by the presence of human, other than less human effort required (Silveira et al., 2003). Studies of camera-trapping usually yields more species as this method does not involve human interference while surveying animals.

The combination of techniques in assessing wildlife in the region is highly suggested such as the use of camera traps. This is highly recommended for the detection of rare and elusive animals that tend to avoid the presence observers. Diversifying the technique to include harp trap and live capture is required if small species are intended to be captured and studied such as squirrels and bats. Based on available data on literature, there are some aspects that needs attention by future work on density estimates of wildlife in the region such as:

- i. Density estimation for other ungulates and primates' species, especially those that are considered endangered.
- ii. Collect more data to possible fitting detection function and density estimation.
- iii. Long-term studies on species density in the forest region to monitor the effect of land-use change on wildlife population.

CHAPTER 4

HUNTING PATTERN OF THE KENYAH AND PENAN COMMUNITIES

4.1 Introduction

Hunting has been one of the socioecological factors contributing to wildlife population decline in many regions of the world (Kurten et al., 2013; Benítez-López et al., 2019). Although several studies have demonstrated the combined effects of hunting with other defaunation drivers on wildlife communities, the growing evidence has shown that the consequences of hunting is far more detrimental (Brodie et al., 2014; Tilker et al., 2019, Gallego-Zamorano., 2020). The impact of hunting on wildlife communities have been well documented, with mammals' populations being the most severely affected (Brodie et al., 2014; Benítez-López et al., 2019). More than 50% of mammal's abundance were reduced across the tropics, and large mammals' abundance is predicted to have an average decline of 40% due to hunting alone (Benítez-López et al., 2019).

Much of scientific literature have documented the drivers of hunting which is vary across geographical and social systems. In Southeast Asia, for instance, hunting is primarily driven by bushmeat harvest for subsistence, and its utilization is highly intertwined in the traditional lifestyles of the communities (Bennett et al., 2000; Bennett & Robinson, 2000; Fa et al., 2022). While in Central Africa, hunting is largely driven by commercial trade (Abernethy et al., 2020). Hunting of wildlife is highly associated with the loss of ecological functioning and population decline for many rainforest species, with a large proportion of hunting offtakes by human across all regions is found to be dominated by large-bodied mammals' species (Kurten et al., 2013; Deith & Brodie., 2020; Abernethy et al., 2020).

Many factors were found to regulate hunting practices, such as accessibility, geographical and socioecological background (Tilker et al., 2019). The increasing road establishment, growing human population, widespread adoption of firearms and vehicles has facilitates the efficiency and capacity of hunting (Ripple et al., 2016; Yi & Mohd-Azlan, 2018). However, the growing development and modernisation in the recent decades may alter human hunting behaviour. A recent study suggests that the changes in natural forest landscapes has direct impact on hunting patterns (Kurz et al., 2021). In some cases, the modernisation of traditional lifestyles also reshape the behaviour of human towards hunting practices (Okuno & Ichikawa, 2020; Abdul-Latiff et al., 2021).

In Borneo, the most dominant animals in harvest are ungulates such as the Sambar Deer (*Rusa unicolor*), the two Barking deers (*Muntiacus* spp.) and Bearded pig (*Sus barbatus*), the last is by far the most important single prey species (Caldecott, 1986; Bennett et al., 2000; Yi & Mohd-Azlan, 2018). Nevertheless, hunting does not ultimately affect these species. In some cases where game animals are rare, medium-sized to smaller mammals' species are hunted instead (Caldecott, 1986). The opportunistic killing of these non-targeted animals is additive to the natural mortality which contribute to the depletion of hunted species including civets, wild cats, and rodents (Bennett & Robinson, 2000; Corlett, 2017). Small carnivores such as civets could be potentially harvested for sale when large animals are difficult to hunt due to low diversity (Kirupaliny & Mohd-Azlan, 2012).

Globally, wild meat is a crucial part of human subsistence across the tropics (Fa et al., 2022). Hunting for wild meat is stimulated by many human different utilizations of faunal resources. Therefore, it is strongly important to identify sociocultural and biological aspects that needed to be considered in order to assess the significant of hunting and its sustainability

in areas where human and wildlife are highly dependent (Uolla et al., 2004). Understanding this relationship is vital in formulating conservation framework that accountable for both human and nature (Bennett et al., 2000). Hence, more documentation on hunting practices across Borneo is needed to supply this information. Many studies have reported the significance of hunting for many community groups, however only little have analysed the drivers of hunting at household level (Bennett et al., 2000; Kato & Samejima, 2020; Fa et al., 2022).

The study investigates the hunting practice, its pattern and factors associated with hunting activity in the Upper Baram region, Miri Sarawak. The Upper Baram region is the rural part of the state, where wild meat is mostly hunted to meet human demands due to the scarcity of domestic meat. The area is mainly dominated by the Kenyah and Penan people, from the *Orang Ulu* ethnics group. The local communities are practicing their traditional lifestyles, highly engaging in subsistence activities including hunting and swidden farming and depend on forest for resources. The hunting survey was carried out in the span of 12 months to elicit relevant information pertaining the activity from the local communities.

The study hypothesized that the most hunted animals' species within the region is of Ungulates as concluded by previous studies, with the consumption of Bearded pig is high in the absence of religion restriction (Caldecott, 1986; Bennett et al., 2000; Bennett & Robinson, 2000; Yi & Mohd-Azlan, 2018). In addition to this, the existence of traditional taboos related to wildlife hunting was expected in the traditional livelihood of both ethnics. Also, there should be differences in terms of hunting pattern and forage area utilized by both ethnic groups.

4.2 Materials and Method

Simple random sampling method was used in data collection process. Interview survey was carried out over 12 months from six villages in the study area. The target participants in this study were hunters from local communities who execute hunting in and around the forests. Interview session was done upon the return of hunters from their hunting session.

In this study, interview sessions were assisted by groups of technicians comprised of local communities' members. There are three groups of technicians altogether, each with 2-3 members representing their respective villages. Before the commencement of this survey, training was provided to the technicians to ensure the correct practice of protocols while interviewing the respondents and recording data.

Structured interview questions with closed answers were constructed and prepared in the form of offline questionnaire using the Cybertracker Software Version 3.514 (Liebenberg & Steventon, 1997). Questionnaire was designed to obtain fundamental information on hunting events, its purpose, type of animals killed and hunting location. Android mobile phone was used to record data during interview survey.

4.2.1 Study Area

Long Siut (3°12'28.0"N 115°11'05.6"E), Long Tungan (3°09'41.2"N 115°10'58.3"E), Long Spigen (3°13'38.6" N115°11'59.4"E), Long Krong (3°17'7.7634"N 115°12'46.44"E) and Lepo Gah Tanjung Tepalit (3°14'16.0"N 114°49'18.0"E) are the *Orang ulu* villages located near the Batang Baram Miri, Sarawak. Long Siut, Long Tungan, and Lepo Gah Tanjung Tepalit are the Kenyah's settlements while Long Spigen, Long Kerong and Long Sait are the Penan villages. Two of the villages; Long Tungan and Lepo Gah

Tanjung Tepalit are located near the main river, while Long Siut and Long Spigen are located near one of the Batang Baram subsidiaries called the Serungo river. Details on the vegetation and geographical characteristics of the study area are as explain in Chapter 3 (part 3.2.1 study site).

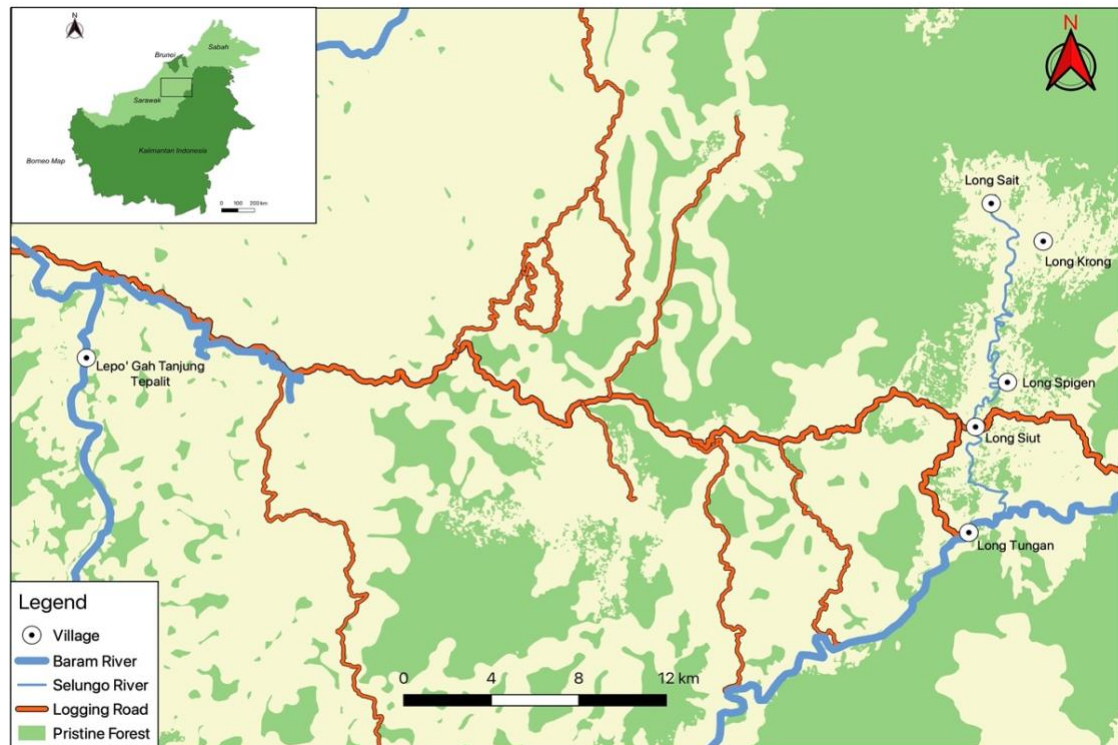


Figure 4.1: Map of study area showing six participating villages in the Upper Baram forest area, Miri, Sarawak.

4.2.2 Data Collection

The questionnaire comprised of 36 questions in offline form (Appendix A) was developed using Cybertracker Software Version 3.514 (Liebenberg & Steventon, 1997). The interview sessions were carried out upon the return of hunters from their hunting trip. The questionnaire started with general information about the respondents such as name, village, followed by essential questions pertaining hunting and animals obtained during the trip. The

questionnaire also includes the type of animals caught, type of weapons used, and place of animal caught.

At the end of each interview survey, the hunters had to mark the location where hunting was executed with 'X' in a printed map of the study area. The coordinate of the point was also recorded in the questionnaire. The photo of the map was taken and saved into the questionnaire form in the Cybertracker application. The form was retrieved at the end of every month and exported into Excel file format prior to analysis.

4.2.3 Data Analysis

All analysis were conducted using R software (R Development Core team, 2020). Packages such as ggplot2 , dplyr and ggrepel were used for data visualization while dismo and gbm packages were used to run boosted regression tree analysis.

4.2.3.1 Hunting/Killing location

The location of where hunting took place was marked on a map of the study area at the end of interview session. The photo of the marked map was taken and saved in the questionnaire form of the Cybertracker application. The latitude and longitude of the marked hunting locations were listed and organized in an excel form before exported to QGIS software to generate the heatmap.

4.2.3.2 Boosted Regression Tree analysis

BRT analysis was used to determine the association between variables. Boosted Regression Tree (BRT) models is the combination of two algorithms: regression tree group of models and boosting methods to optimize predictive performance (Elith et al., 2008). One of the uses of BRT in ecological study is the identification of major environmental determinants of short-finned eel (*Anguilla australis*) distribution by Elith et al. (2008).

Another recent use of BRT is to recognize the demographic variable that associated with the outcome of survey answers in a socioecological Hornbills perceptions study by Philoveny et al. (2021)

Table 4.1: Detailed description on five predictor variables with successful hunting return as the response variable used in boosted regression tree analysis.

Predictor Variables	Description	Option & Abbreviation
Overnight trip	Hunting conducted in overnight or only daily trip	Yes or no
Group hunting	Hunting conducted in group or by individual	Yes or no
Type of hunting ground	Types of hunting area where hunters went to kill animal.	Primary Forest (PF) Secondary Forest (SF) Riverbank/Stream (RB) Agricultural Land (AL) Road/Trail (R/T) Salt Lick (SL) Ponds, Unstated area (Other)
Hunting method	Method used during hunting. (Multi selection)	Walking (W) Hunting from boat (HB) Hunting from car (HC) Flushing Dogs (FD)
Weapon used	Type of weapon used by hunters to kill animal (Multi selection)	Shotgun, Spear, Snare, Parang, Blowpipe

4.3 Results

A total of 279 hunting interviews were carried out over twelve months period. More than 40% (114 out of 279) of hunting session recorded were successful, while the remaining percentage reported no hunting return. Of these, 276 of the respondents are Kenyah people, while only two of them are Penan. The study recorded 11 species comprises of eight families with a total of 143 individuals killed, representing an estimated biomass of 5429 kg. Of these, five species were listed as Vulnerable (VU) according to IUCN Red List (IUCN, 2022). Some species were labelled at genus or family level as only common name was reported by hunters.

Four out of eleven species hunted were of ungulates including the Bearded pig (*Sus barbatus*), Sambar deer (*Rusa unicolor*) and Muntjacs (*Muntiacus* spp.). Species with the highest number of individuals killed was Bearded pig (*Sus barbatus*) with $n=79$, followed by Mousedeer (*Tragulus* spp.) with a total of 13 killed, and Sambar deer (*Rusa unicolor*) ($n=11$). While Muntjacs (*Muntiacus* spp.) recorded 3 individuals killed, followed by Otters (family Mustelidae) and Sun bear (*Helarctos malayanus*) with the least number of individuals killed ($n=1$ respectively) (Table 4.2).

It is estimated more than 5429 kg of meat were harvested by the local communities throughout the survey period (12 months). The biggest portion of wild meat harvested was from the Bearded pig (*Sus barbatus*) which constitutes about 73% of total harvest. This was followed by Sambar deer (*Rusa unicolor*) which make up about 20% of total wild meat harvest (Table 4.2).

Table 4.2: List of species hunted and consumed for its wild meat as recorded from the survey. The animal with the most number of individual killed was Bearded Pig (*Sus barbatus*), followed by Mouse-deer (*Tragulus* spp.) and Sambar Deer (*Rusa unicolor*).
*Individual weight as noted by hunters during the survey. For species killed where weight was not noted, approximate weight from literature is used.

Species	No of Individuals hunted	IUCN Status	Estimated Weight per individual (Kg) & Source	Total (Kg)
Bearded pig (<i>Sus barbatus</i>)	79	VU	50*	3950
Mousedeer (<i>Tragulus</i> spp.)	13	NA	4*	52
Sambar deer (<i>Rusa unicolor</i>)	11	VU	98*	1078
Civets (Family Viverridae)	10	NA	5.5 (Phillips & Phillips 2018)	55
Long-tailed macaque (<i>Macaca fascicularis</i>)	10	VU	10*	100
Pig-tailed macaque (<i>Macaca nemestrina</i>)	9	VU	9 (Phillips & Phillips 2018)	81
Porcupine (Family Hystricidae)	4	NA	2 (Payne & Francis 2007)	8
Monitor lizard (<i>Varanus salvator</i>)	3	LC	5*	15
Muntjacs (<i>Muntiacus</i> spp.)	2	NA	20 (Phillips & Phillips 2018)	40
Otter (Family Mustelidae)	1	NA	5 (Phillips & Phillips 2018)	5
Sun bear (<i>Helarctos malayanus</i>)	1	VU	45*	45
Total	143			5429

The mean value of wild meat harvested over the 12 months is 452 kg. The highest amount of wild meat was reported from the second month of the survey, which made up to 1326 kg, about 24% of the total wild meat harvest. The lowest amount of harvest was reported from the tenth month of the survey, which is only 50 kg (about 1% of the total harvest). The differences in the amount of wild meat harvested per month is largely influenced by the reasons of hunting, such as the need of wild meat for festivity, guests or special celebration. Additionally, the outbreak of African Swine fever towards the end of the survey period causes a drop in Bearded pig's population in the region, which explains the depletion in hunting yields. Also, the outbreak of pandemic Covid-19 has restricted the movement of the communities in the area including hunting activity and affected data collection process.

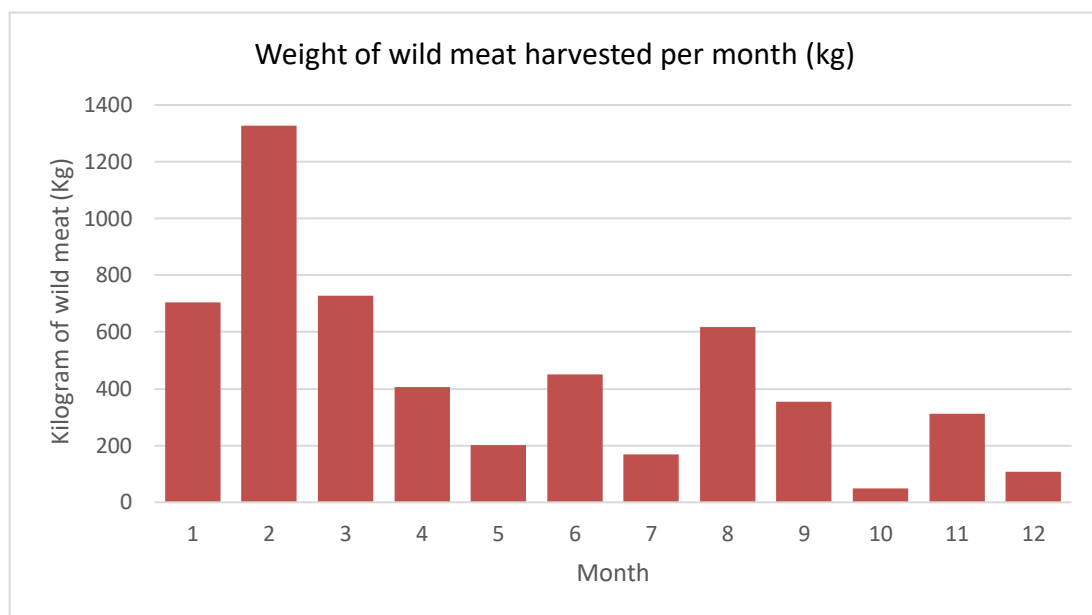


Figure 4.2: The graph showing the weight of wild meat harvested per month in the study villages. The second month of the survey shows the highest amount of wild meat harvested while the tenth month reported the lowest amount of wild meat observed. The reduction in the amount wild meat as observed towards the end of the survey period was due to the effect of African Swine fever outbreak and pandemic Covid-19.

4.3.1.1 Drivers of hunting

The main purpose of hunting is the provision of wild meat for multiple reasons (Figure 4.2). The major cause was for the consumption of household (40%), followed by meat for sale and trade (37%), and meat to share with other households (20%). A small portion of respondents went hunting to acquire wild meat for festival and celebration also for visiting guests.

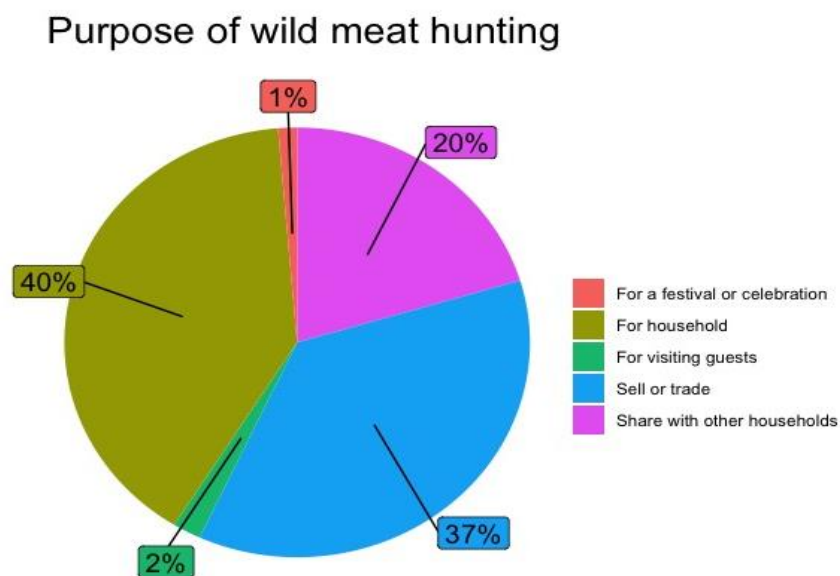


Figure 4.3: Showing the purposes of hunting to gain wild meat for multiple occasions. The consumption for hunter's household is the highest followed by the use for sale and trade and sharing meat with other households.

4.3.1.2 Hunting Patterns

A large percentage (67%) of hunting sessions reported were planned trips, while the remaining 33% were unplanned. A total of 70 hunters (61%) went hunting alone while the other 39% of them went hunting in group consists of two to nine people, with the average of five people per group. More than half (57%) of hunting session recorded were daily trip. Of these, only 37% of the sessions contributed to hunting return, while overnight trip reported higher successful rate with 46% of the sessions contributed to hunting return.

4.3.1.3 Hunting Equipment

Hunting using shotgun is prevalent among hunters, with more than 80% of hunting sessions reported the use of shotgun. Small portions of them used spear and set up snare to catch animals (Figure 4.3). The use of blowpipe in hunting was recorded at a small percentage (1%). It was also reported that the hunters use machete as a complementary tool during hunting.

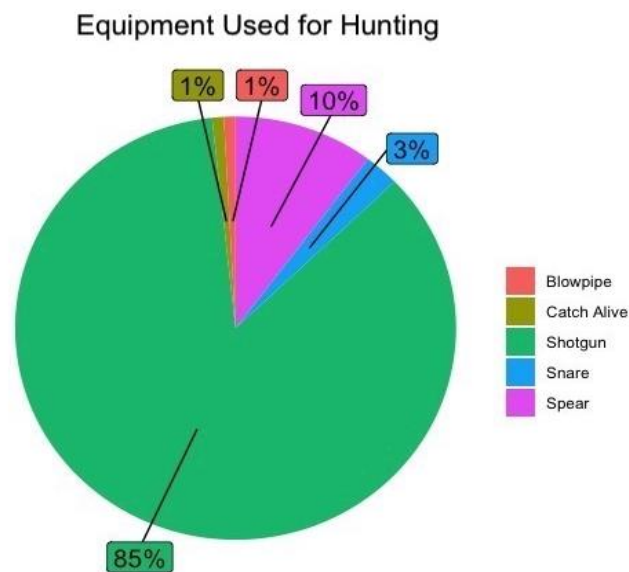


Figure 4.4: Shows the percentage (%) of weapon used by local communities to hunt animals. The use of shotgun is mostly preferred by hunters, followed by the use of spear.

4.3.1.4 Travel method and hunting strategies

Walking plus using boat to travel is the most preferred travel method to hunting ground. More than 40% of them used this combined travel method to the hunting ground (Figure 4.4). Less than 30% of hunters only walk to the hunting ground while small portion of them use only boat to their hunting ground. Most hunters adapted multiple techniques in search for animals. The most preferred hunting technique is by walking on a hunting trail (32%), followed by hunting from boat (23%), sit and wait (18%), the use of hunting dogs (13%), and tracking (11%).

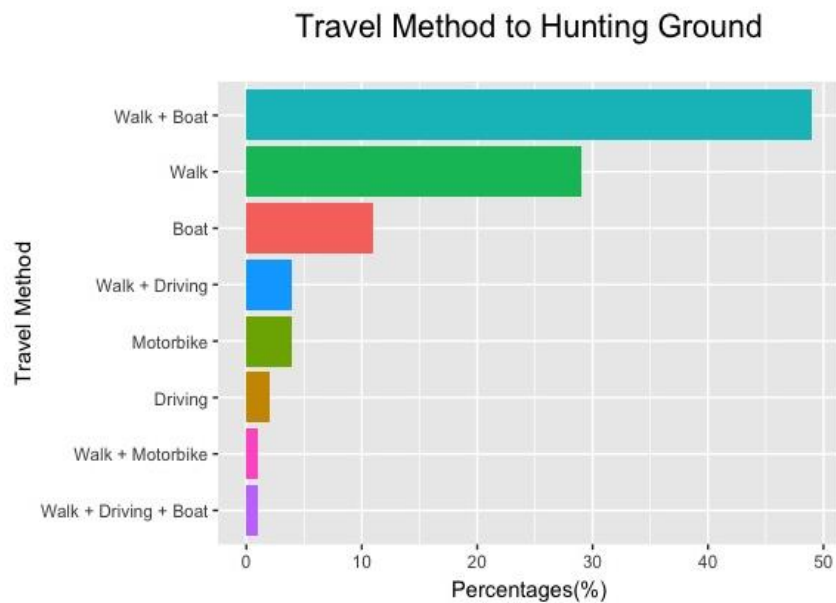


Figure 4.5: The percentage of hunters using different travel methods to their hunting ground. The combination of walking and using boat during hunting is mostly preferred, followed by walking and travel by boat.

4.3.1.5 Hunting grounds of the Kenyah and Penan communities

A map from 92 hunting locations as marked by hunters was generated. The study found that most of the hunting locations concentrated near the *Batang Baram* river and its subsidiaries. All hunting points recorded were at the elevation range of 100-650 m, with the lowest point reported at 112 m and the highest at 615 m above sea level.

In Lepo' Gah Tanjung Tepalit area, the hunting points were concentrated within 5 km radius from the village centre, while in the Selungo and Kenyah Jamok area, most of the hunting locations were recorded within approximately 10 km radius from the central village (Long Siut) whereas one hunting point was exceptionally located further from both areas, about 17 km from Long Siut (Figure 4.5).

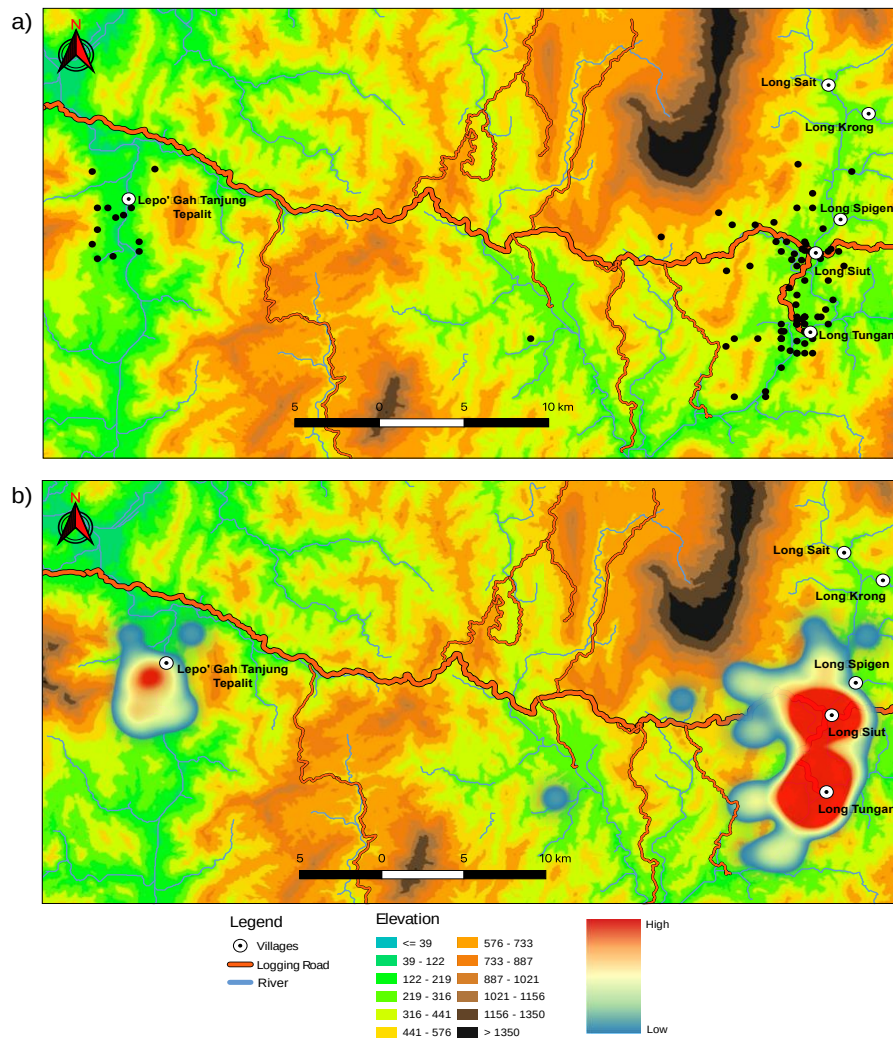


Figure 4.6: Map (a) showing hunting points where killing took place as reported by hunters during the hunting return survey. Most of the killing locations occurred near or along the river and road close to the villages. Map (b) shows the heatmap of hunting locations reported in the study area. The hunting point intensity is high around the villages and decreases as the distance further from the villages.

4.3.1.6 Boosted Regression Tree (BRT) Analysis on successful hunting return

Boosted Regression Tree (BRT) analysis showed that hunting ground strongly influence hunting return by more than 66% (Figure 4.6). This is followed by weapon used by 33.5%. Hunting method, group hunting and overnight hunting was found to have no influence on successful hunting return. Summary on the percentage of influence of the predicted variables are as in Table 4.3.

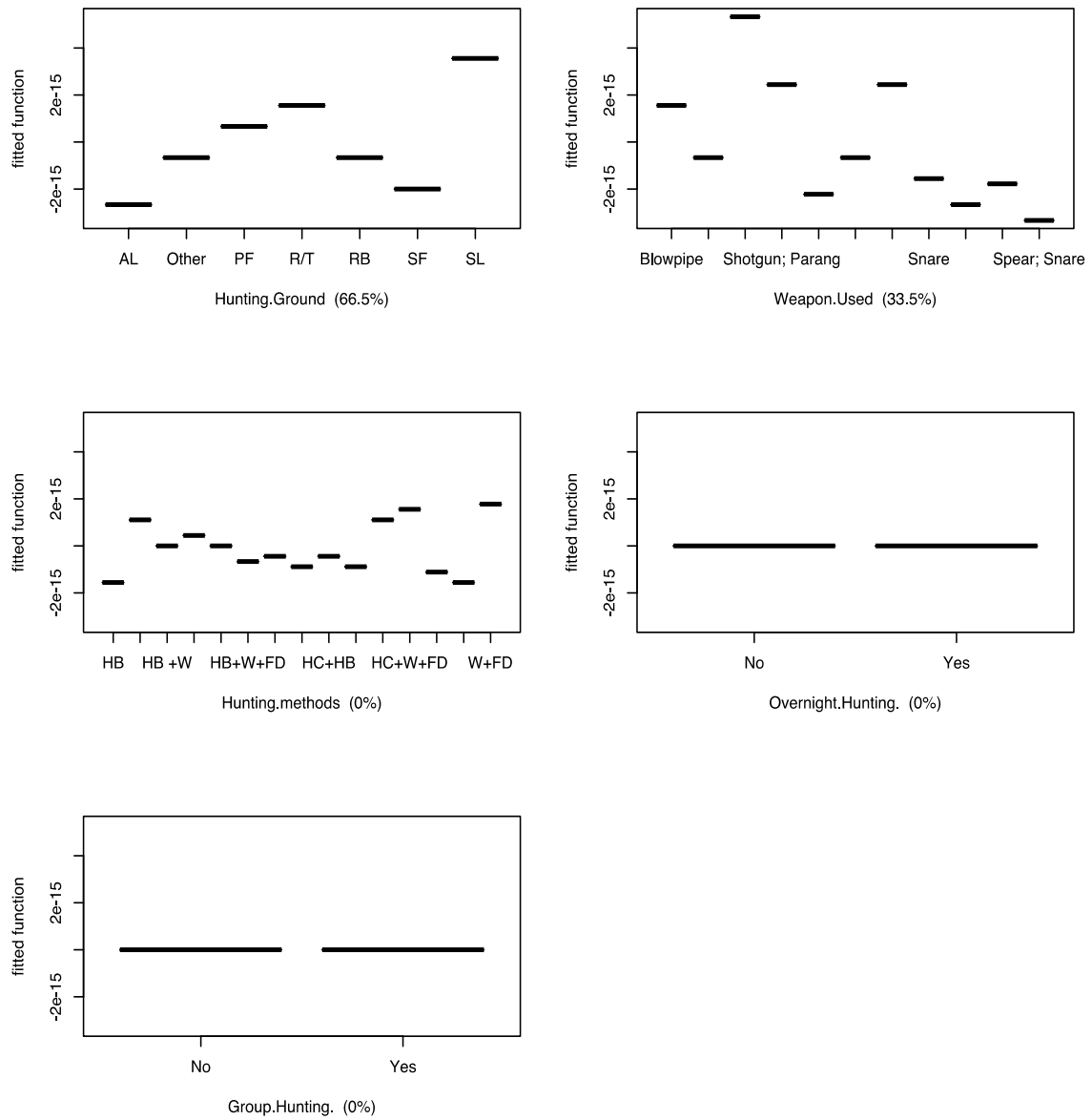


Figure 4.7: Boosted Regression Tree models plots that relate the predictor variables; types of hunting ground, hunting methods, weapon used in hunting, hunting in group, and overnight hunting with the successful hunting return as the response variable with learning rate of 0.001 and tree complexity of 5. Details on variables are as in Table 4.1

Table 4.3: Summary of the relative influence (%) of significant variables for Boosted Regression Tree model on 278 hunting return data developed using tree complexity of 5 and learning rate of 0.001.

Predictor	Relative Contribution (%)
Hunting ground	66.5
Weapon Used	33.5
Hunting methods	0
Group Hunting	0
Overnight Hunting	0

The study reported seven main categories of hunting grounds where the killing of hunted animals took place in the study area (Figure 4.7). It was reported that, 43 out of 114 of the successful hunting return events (37%) occurred in agricultural land, followed by riverbank/stream (31 out of 114) and secondary forest (21 out of 114). Only small portion of killing occurred in the primary forest (9 out of 114) and along road/trail (6 out of 114).

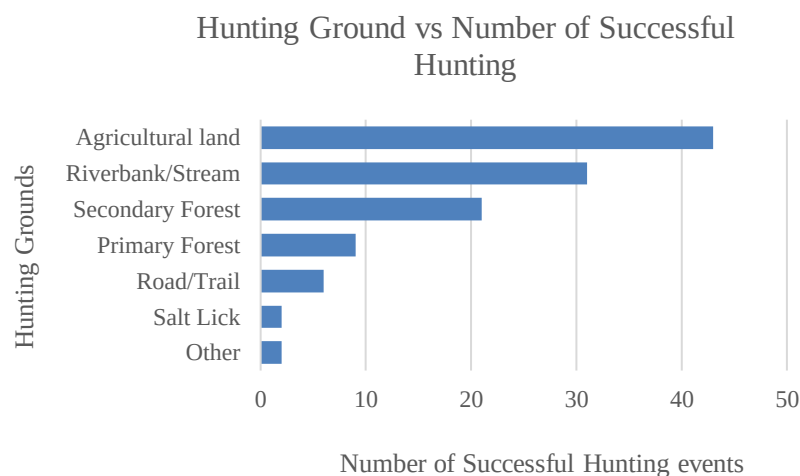


Figure 4.8: The graph showing number of successful hunting event (n=114) against type of hunting grounds as reported from the survey. Majority of the successful hunting (37%) were reported from agricultural land, followed by Riverbank/Stream (27%), secondary forest (18%) and primary forest by 8%. Other included pond and unstated areas.

4.4 Discussion

4.4.1 Hunted Species in the Upper Baram Area

From the result, more than 50% of species hunted were of large-bodied mammals. Of these, five of the species were listed as Vulnerable (VU) in the IUCN Red List (IUCN, 2022). The results support the findings of other study that large-sized species, including primates, ungulates, and rodents, with an average adult body mass equal to or greater than 1 kg are the most hunted (Robinson & Redford, 1994; Fa et al., 2022). From the available literature on hunting in Borneo, there is no huge difference in terms of preferred hunted species across the range, although the presence of traditional taboos has direct influence on this (Puri, 1999; Bennett et al., 2000; Wong, 2012; Yi & Mohd-Azlan, 2018).

The results highlighted that a large portion of the hunted meat in the study area was from the Bearded pig (*Sus barbatus*), which contributed about 73% of the total weight dressed. Bearded pig is a heavily consumed terrestrial game animal for indigenous, non-Muslim communities throughout Borneo, and is also widely considered the favourite type of wild meat among many of these communities (Bennett et al., 2000). In East Kalimantan, Puri (1999) reported similar trends in the use of Bearded pig's meat as in Sarawak and Sabah. Pigs are the dominant source of meat and fat in the diets of the local Penan and Kenyah tribes, although fish may be an important source as well.

Sambar deer (*Rusa unicolor*) meat constituted about 20% of the hunted meat, the second most hunted after Bearded pig (*Sus barbatus*). In Borneo, Sambar deer (*Rusa unicolor*) is usually preferred in areas where Bearded pig (*Sus barbatus*) is not favoured, especially in Muslim dominated communities (Sahmat & Mohd-Azlan, 2022). Apart from hunted for its meat, Sambar deer was also preferred by some communities for its medicinal

properties (Sahmat & Mohd-Azlan, 2022). The species is currently listed as Vulnerable (VU) in the IUCN Red List 2022 (IUCN, 2022). Thus, the species population is suggested to be greatly affected by hunting pressure as the species has slower rate of recovery compared to other Ungulates (Steinmetz et al., 2010).

The study also reported the killing of one Sun bear (*Helarctos malayanus*), which is one of the endangered species in Borneo. The study found that Sun bear (*Helarctos malayanus*) was killed for its meat, although the survey only has one record of this species. This is most likely due to its large size which is a common favourable attribute for many hunters. However, many studies have reported the significance use of the species in traditional medicines (Gomez et al., 2020; Abdul-Latiff et al., 2021).

The results revealed that primates such as Macaques (*Macaca* spp.) were also hunted species in the region, which accounted about 3% of the total weight dress gained. The reason for this preference is most possibly due to its social behaviour, which provide chances for the captured of more individuals at once (Abdul-Latiff et al., 2021). Macaques have been reported to be widely hunted across Borneo for its meat and the killing of this species is usually associated with pest control activity (Sahmat & Mohd-Azlan, 2022). During the survey, the local people claimed that macaques bring nuisance as they destroy crops and cultivation planted by the communities. Hence, it is concluded the killing of these species can be considered as opportunistic to impede human-wildlife conflict in the area.

The scarcity of large-sized species would lead to the hunt of smaller animals which leads to the opportunistic killing of previously unfavoured species (Uolla et al., 2004; Mohd-Azlan et al., 2017). For instance, studies have shown that Bearded pig (*Sus barbatus*) is important for rural people's nutrition, which also highlights the ability of the species

population to persist while supplying wild meat for many decades. In early 2021, the depletion of Bearded pig's population was reported in the Upper Baram due to the outbreak African Swine fever in Borneo. The disease was found to severely affect Bearded pig's population in Sabah and Sarawak, including the domestic farm industry.

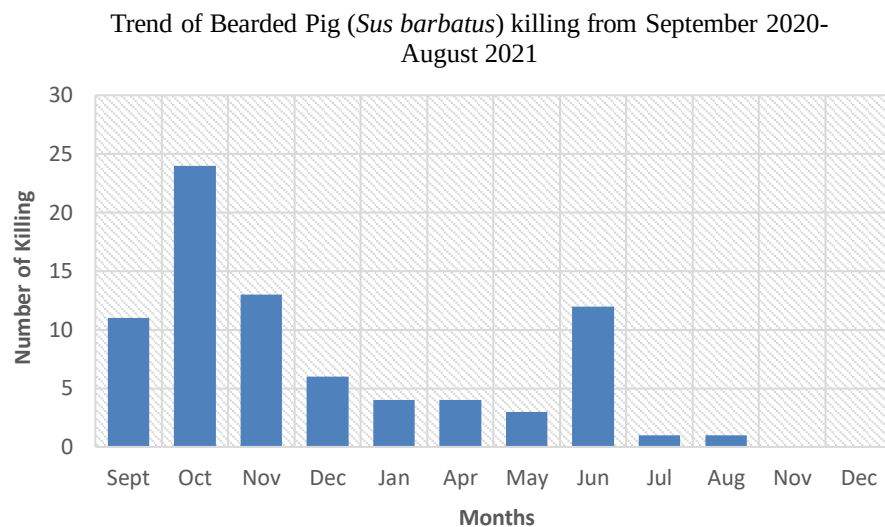


Figure 4.9: Graph showing the trend of Bearded pig's killing as reported from the hunting return survey from September 2020 to August 2021. The steep decline in killing of the species can be observed in the 8th and 10th month of the survey, meanwhile no killing of Bearded pig were reported in the last two months of the hunting survey, which probably indicates the scarcity of the species in the wild due to African Swine Fever.

Most of the local communities claim the scarcity of Bearded pig (*Sus barbatus*) in the wild after the African Swine fever outbreak. The conspicuous drop in Bearded pig's population has inevitably leads to the killing of other smaller species as fallback diet, although some communities in the study area turn to fish as their protein source as well. The killing of Bearded pig drastically dropped towards the end of the survey period (Figure 4.8). During this period, the killing of some smaller mammals' species including Civets, Otter, Porcupine and Mousedeer were reported, which accounted about 2% of the total weight dress.

4.4.2 The Driven Factors of Hunting of the *Orang Ulu* Communities

The driven factors of hunting and wild meat utilization often diverse across people of different social and geographical backgrounds (Wong et al., 2012; Loke et al., 2020). The survey results shows that the main driven factor of hunting in the study area is for direct consumption (40%), followed by wild meat for sale and trade. The consumption of wild meat in the study area can be divided into three categories, which are 1) for household consumption, 2) sharing with other households, and 3) for festivity or celebration. A large portion of direct consumption reported (40%) was for household consumption, in which the wild meat obtained by hunter was mainly for their family members in the same household, while 20% of the direct consumption reported was for sharing of wild meat with other households.

A large portion (37%) of wild meat harvest in the study area is for the purpose of sale and trade. However, it is uncertain if the sale and trade of the hunted wild meat only occurs within the local communities, as wildlife trade are commonly reported across the region (Kirupaliny & Mohd-Azlan, 2012; Gomez et al., 2020; Okuno & Ichkawa, 2020). Nonetheless, wild meat, therefore is important as an economic source for the local people in the study area. This is also widely reported by other studies across different communities in Borneo (Bennett et al., 2000; Yi & Mohd-Azlan, 2018; Kurz et al., 2021). Hence, it is concluded that the Kenyah and Penan people in the study area mostly depending on wild meat for subsistence and plays role in local communities' economy.

On the other hand, there is an increase in the market value of the wild meat over the years, which further highlights its importance as a valuable commodity (Kirupaliny & Mohd-Azlan., 2012). For instance, the price of domestic pork meat at recent time in Sarawak is

around RM 23.00 to RM 25.00 per kg (Kirupaliny & Mohd-Azlan., 2012). Based on the collected data, replacing the cost of the average amount of wild meat obtained with domestic pork meat price consumed is about RM 90,000 to RM 98,000 per year. Hence, the cost of such protein source is extremely high, especially for people with low-income rate in the rural areas to fulfil their dietary needs.

Nevertheless, the study lacks the data on the harvest of wildlife for other reasons, such as for traditional medicinal practices or cultural ornaments. Wildlife harvest for these purposes is widely documented by many authors across Borneo (Bennett et al., 2000; Mohd-Azlan & Fauzi, 2010; Okino & Ichikawa, 2020; Sahmat & Mohd-Azlan, 2022). Moreover, the killing of wildlife as pest control should be further investigated, as human and wildlife are in close contact in the area. There is a need for further investigation of the utilization of wildlife in these regards, which also contribute to the compounded factors of hunting and threats specifically for many Bornean mammals.

4.4.3 Hunting Methods of the Kenyah and Penan People in Upper Baram Region

There are some significant aspects that shaping the hunting practice of the indigenous peoples across tropical forests ecosystem which includes geographical, social, and cultural attributes (Bennett et al., 2000). The study found that the use of shotgun during hunting is prevalent in the study area, compared to the conventional use of snares and spear. This is widespread as reported across many communities in Borneo (Yi & Mohd-Azlan, 2018; Loke et al., 2020; Kurz et al., 2023).

The results reported no distinct type of hunting method used by local communities in the study area, such as ambushing during pig migration crossing the river as reported by Mohd-Azlan et al. (2016) in other parts of Sarawak and Puri (1999) in Kalimantan. However,

hunting with dogs is common, as has been reported in Sabah and other parts of Sarawak (Kato & Samejima, 2020; Kurz et al., 2021). This technique is stated as the most successful method of hunting by Puri (1999) in Kalimantan in search of animals in the wild.

Hunting patterns strongly influenced by type of hunting grounds. The use of car during hunting is usually preferred in oil palm plantation where it is accessible by such vehicle (Kurz et al., 2023). While in areas that are inaccessible with vehicle, hunters usually travelled by foot or even use small boat in search of animals. The results show that the hunters need to travel to the hunting grounds within 10 km radius from nearest villages. Due to the heterogenous landscapes of the forests, hunters use multiple travel method during hunting.

4.4.4 Hunting Grounds of the Local Communities in the Upper Baram Forest

Land-use change has been found to alter wildlife population and hunting activities particularly in tropical forests ecosystem (Kurz et al., 2023). This is consistent with the findings on other indigenous communities in Borneo (Kato & Samejima, 2020). Land-use change due to logging have been responsible for accelerating hunting activity in many affected regions (Bennett & Gumal, 2001; Kato & Samejima, 2020).

The results found that the hunting ground of the local communities in the Upper Baram is around the main river and its tributaries. It is concluded that the specified area is important for the communities to harvest wild meat and probably other forest resources as well. The hunting locations is concentrated within approximately 5 km radius from the central village in the Lepo Gah Tanjung Tepalit area and 10 km radius from the central village in the Selungo and Kenyah Jamok area. The differences in the hunting radius is most likely due to the mode of transport used. In Lepo Gah Tanjung Tepalit, the hunters mostly

went hunting using boat and travel by foot. However, in Selungo and Kenyah Jamok area, the use of motorbike was reported from the hunters which allow them to travel further in the forest. In addition, there is only one village in Lepo' Gah Tanjung Tepalit area, while five villages near Kenyah Jamok area. Therefore, the hunting radius of five villages are wider than a single village. These distances indicate the longest distance of a hunter could travelled in the study region. Most of these hunting sites are accessible by foot which includes neighbouring natural primary and secondary forest.

There were less hunting activity recorded in the upper part of the Selungo river where the Penan lives. The plausible explanation to this is most likely due to accessibility, in which in the absence of road, hunters are limited to travel further into the forest (Kato & Samejima, 2020). Walking by foot in such dense forest would require much energy and time consuming for the hunters, including to carry the killed animals back to their villages. Therefore, the alternative way for the people to hunt is via small boat to ease the travel and logistics of the hunters. In addition, the Selungo area is generally has higher altitude compared to other parts of the study area. Higher ground is usually not favourable for hunters as game animals such as Bearded pig (*Sus barbatus*) usually occur in human-modified landscapes and less likely to be found in higher areas. Therefore, high altitude grounds would undoubtedly yield less hunting return although much energy is needed to travel in this area.

In contrast to this, lower area such as in Kenyah Jamok and Lepo Gah Tanjung Tepalit can be considered as a good hunting ground as the fragmented landscapes attract more animals especially of generalist species. Consequently, there is a high probability for significant decline in wildlife abundance and population within or nearby area of the villages as stated by Bennett & Gumal (2001). As extirpation of individuals animals ensues due to hunting, this will eventually reduce the abundance of animals in the region. Thus, it is

suggested that hunting should be done at locations distant from the villages to allow wildlife populations to recover in other areas (Silvius, 2004).

The hunting grounds acts as an important space for the local communities to obtain wild meat and other forest resources. Protecting these areas are vital to ensure the viability of the animals and food security for the people living therein. Effective sustainable plan and interventions is necessary to balance between the need for livelihood and ensuring a long-term wildlife population.

4.4.5 Boosted Regression Tree (BRT) Analysis on Successful Hunting Return

From the BRT analysis, the study pinpoints the main factors that highly influence and contribute to successful hunting with return based on our data. The identification of these factors is imperative in assessing the implications of hunting on wildlife population. The results demonstrate that type of hunting grounds is the strongest variable in ensuring successful hunting return with more than 50% influence. Hunting methods, which includes techniques in catching animals (eg. sit and wait, hunting from boat, the use of flushing dogs) is the second influential factor with a value of 30%.

The findings concluded that anthropogenic activities that contribute to the modifications of natural habitat, including logging and land clearance are highly accountable for accelerating excessive hunting. This provides more opportunity for hunting to flourish, mostly due to easy access to wild animals in the forest (Bennett & Gumal, 2001; Kurz et al., 2021). More importantly, our results show that most of successful hunting return were reported to occur in the estate area, which is preferable for some species due to the abundance of food source, especially for generalist feeders. The high abundant of these

preferred species, especially large-sized animals alongside the presence of road will undoubtedly attract more people to the area for hunting.

4.4.6 Conclusion

The study revealed that hunting is an important part of the Kenyah and Penan people livelihood in the Upper Baram forest area. Hunting plays significant cultural roles as well as the main protein source and as an economic source of the local communities. It is concluded that human, particularly those living in the rural parts of this region rely highly on wild meat for subsistence in their daily livelihood, and the loss of this resource would undoubtedly affect their quality of life.

In addition, the presented maps here are fundamental to provide insights into the effect of land-use change on hunting activity in the Upper Baram region (Figure 4.5). The maps also visualized the extent of space use for hunting by local people, which is beneficial for management intervention of the communities' resources.

Hence, conservation effort should consider these socioecological factors that shape the local hunting practices. The depletion of wildlife in the forest has negative repercussions not only for rural households who depend on this source, but also affects the habitat itself as targeted species often perform important roles in ecosystem functions. Therefore, urgent action is needed to formulate framework that considers the viability of wildlife population an in align with the community needs in the region.

CHAPTER 5

GENERAL DISCUSSION

5.1 Upper Baram as a Potential Region for Wildlife Corridor and Conservation Unit

The study revealed that the occurrence and distribution of mammals' species in the Upper Baram forest is greatly influenced by habitat modifications and hunting pressure. In these mosaics landscapes, many generalist species was found to dominate, with the presence of several endangered species despite the disturbances. This has given insights into their distribution in the remaining forest area of the region. Despite being abundance, most of the ungulates and primates are frequently hunted by the local. It is concluded that wild meat plays significant role for the local communities due to multiple factors, largely for subsistence and economic source.

Understanding species assemblages in a human-disturbed landscape is vital to inform conservation practices. There has been a wide range of studies examining the impact of anthropogenic activities on species richness and abundance (Symes et al., 2018). In tropical forests ecosystem, forests area has been cleared mainly due to land uses for logging, agricultural plantation, and human development (Gaveau et al., 2018). These activities have resulted to the loss of natural habitat for many wildlife species in the region and greatly reduced its distribution (Gallego-Zamorano et al., 2020).

The loss of Borneo's lowland forest area is rampant and occurs a rapid rate over the recent years (Gaveau et al., 2014). The lowland areas are known to harbour high diversity compared to highlands, yet it has been highly altered and modified due to land-use change (Ocampo-Peñuela et al., 2020). As a consequence, forest patches can be found scattered

across the landscapes, including its network of protected areas and forest reserve. Today, much of the forests in Borneo are in the interior parts of the island and mountainous area, within which remained mostly intact over the recent decades (Gaveau et al., 2014; Ocampo-Peñuela et al., 2020).

Landscape modifications has resulted to the loss of natural habitat and functionally connected habitat (Ocampo-Peñuela et al., 2020). This causes edge effects upon the wildlife communities in the forest patches and negatively affect species richness due to species-area relationship, as large areas harbour more species than small habitat areas (Connor & McCoy, 2017; Reider et al., 2018). At species level, habitat loss can alter species functionality and viability, which contribute to the change in prey-predator relationship balance, the loss of habitat-specific species and the declining of species population (Maiwald et al., 2020; Kurz et al., 2021). The effect could also be conspicuous for many arboreal mammals with large home range and high dependency on forest with tall trees to survive (Inoue et al., 2016).

The study found that in a human-disturbed landscape, generalists' species are found to be in abundance. Generalist feeders such as ungulates and primates can flourish in such disturbed habitat, owing to their inherent ability to reproduce faster, wide diet, and short reproductive cycle (Bersacola et al., 2019; Maiwald et al., 2020). However, it is more likely that hunting in the region would intensify as disturbances persist, thus adding pressure to the existing mammals' population in the future. The depletion of prey may influence the abundance of sympatric predator including Clouded leopard (*Neofelis diardi*) due to prey scarcity (Cheyne et al., 2016). In addition, continuous logging, expansion of agricultural plantation, and clearance for human settlements over the upcoming years would undoubtedly increase the accessibility to wild animals, which possibly threatens many mammals species

in the region (Bennett & Gumal, 2001; Okino & Ichikawa, 2020; Kurz et al., 2021). Although habitat modification for agricultural plantation was found to support some mammals' species, the abundance of these viable population would be reduced compared to those in natural forest habitat (Kurz et al., 2021).

Given the accumulating evidence on the dire implications of these changes on wildlife population, connecting remnant forest patches is important to provide a main pathway for species with a broad distribution range to move and thrive in their remaining population (Brodie et al., 2014). A functionally connected landscape is essential for maintaining healthy populations across generations as it provides access to resources, sustains metapopulations, and allows gene flow (Sodhi et al., 2011; Ocampo-Peñuela et al., 2020). In Borneo, the available functionally connected habitat was reduced at a substantial rate from 1973 to 2015 (Ocampo-Peñuela et al., 2020).

Hence, the findings suggests that the Upper Baram forest area is imperative as a potential habitat connectivity for wildlife in the region. This might serve as stepping-stones to increase habitat connectivity for many species, as the forest area is surrounded by a network of protected areas including the Kayan Mentarang National Park, Pulong Tau National Park and Ulu Temburong National Park (Meijaard et al., 2018). It is crucial to formulate framework to maintain the viability of many mammals that rely on the forest. The establishment of landscape connectivity should be properly formulated in achieving conservation goals, whether for the benefit of single species or groups of species (Brodie et al., 2014).

On the other hand, highlands area are insufficiently protected as they are not many such areas available, thus effort should also focus on rehabilitating its lowland area nearby

highlands, which could be an important habitat for many wildlife. Much of the lowland forest in Borneo have been decreasing rapidly in the recent decades (Gaveau et al., 2014). Preserving the lowland area is vital to allow species population to recover after much disturbances. This is as clearly explained by source-sink theory, in which species in higher population acts as a source of individuals to area where less individuals occur (Hansen, 2011). This also can be achieved by connecting the fragmented lowland landscapes, as small protected areas are valuable reservoirs for biodiversity and more effective when there is no history of intense tree removal (Alroy, 2017). This effort should act synergistically with other conservation strategy to impede the implications of anthropogenic activities on forest loss (Meijaard et al., 2011; Ocampo-Peñuela et al., 2020).

Overall, available data on species diversity and density should be used for monitoring population responds towards landscape change across Borneo tropical forests. More research might be needed to support this effort, and the data provided here is a baseline for future work in the region. Further assessment on the implications of habitat loss on species density can contribute to regional plans for preserving and restoring Borneo's irreplaceable and highly threatened remaining primary forest.

5.2 Understanding the Link between Social Culture and Wildlife

Wildlife has been a central of livelihood for many people in tropical forests. Much research has documented the utilization of wildlife across many regions (Mohd-Azlan & Fauzi, 2006; Okino & Ichikawa, 2020; Abdul-Latiff et al., 2021). Some species are important to provide meat, while other species hold unique significance in human culture (Bennett et al., 2000; Kurz et al., 2021; Sahmat & Mohd-Azlan, 2022). Of these, species such as large mammals and birds were usually preferred by hunters (Fa et al., 2022). This shows that

different social groups often have special ways of perceiving wildlife according to their culture and lifestyles. Therefore, the complex interaction between human and wildlife especially in a diverse tropical forests ecosystem requires its own way of managing faunal resources.

The study shows the dependency of local communities on wildlife is rather high. The data gathered from this study can be used to monitor the changes in animal distribution and relative abundance especially for the bearded pig as they were severely affected by African Swine Flu (ASF). The use of hunting ground rights by the local community regulates the hunting activities within a community. The hunting ground rights acclaimed by each community also prevents outsiders into their area further deliberates on sustainability and therefore enforces their rights to utilise unprotected species for personal consumption under Sarawak Wild Life Protection Ordinance 1998.

From the study, it is concluded that wild meat continues to be a principal source of protein for the Kenyah and Penan people in the Upper Baram, although the communities also turn to fishing to supply this needs. This is widespread in many parts of Borneo, especially for people in the rural area due to limited access to other available protein sources (Puri, 1999; Bennett & Robinson, 2000; Yi & Mohd-Azlan, 2018). More importantly, wild meat also acts as an important economic source for the local people in the study area, which is corresponding to the findings of other studies (Yi & Mohd-Azlan, 2018; Okino & Ichikawa, 2020; Kurz et al., 2021).

Study shows that hunting has been responsible for many species loss and contribute to a long-term threat for more than 90% of primates and ungulates species (Brodie et al., 2015). There are many factors that exacerbate hunting as stated in many literature (Bennet

et al 2000; Kato & Samejima, 2020). For instance, continuous forest clearance activity such as logging would facilitate the penetration of hunters into forested area, both from local communities and outsiders (Bennett & Gumal, 2001; Kurz et al., 2021; Fa et al., 2022). As discussed in Chapter 4, forest modifications provide more opportunity for hunters to access wildlife. Since forest patches is favourable habitat for generalist feeders, more hunters will be attracted into these areas as the target animals are abundant. This is due to the reduction of dense forest floor which is beneficial for hunters to traverse further into the forest (Kurz et al., 2021). In this study, the mapping of hunting locations demonstrates the effect of habitat modifications on hunting activities and patterns in the Upper Baram region. This information is crucial to develop a balance solution which is beneficial for both communities and wildlife populations.

As social and wildlife are intimately link, some aspects of traditional culture should be utilized to support conservation goals. Most communities have a set of taboos that they are abated to. In the Upper Baram for instance, the Penan communities in the Selungo area has their own traditional hunting rules that they follow to maintain faunal resource in the forest area. They will not hunt on a mother with its juveniles to allow them grow into adults. The main reason is to prevent the depletion of individuals animals. There are several intervention measures and its rationale that can be considered by the community to impede overhunting in the forest region:

- i. Hunt only adult animals. Avoid killing animals in gestation and its young.
- ii. Do not hunt in community preserve forest to allow animal population to replenish.
- iii. Hunt or kill as needed for personal consumption only.

- iv. Forbid the killing of endangered animals and promote local measures to protect its remaining population.
- v. Aware to the presence of invaders especially outsiders who come to the village area for hunting.

The study, however, did not consider the effect of hunting on species density and abundance due to limitation of sampling unit to provide conclusion on this matter. This highlights the need for future studies to provide more data and long-term research to investigate the impact of local hunting on wildlife population and diversity assemblages in the region. This is beneficial to inform conservation interventions particularly in area where human and wildlife coexist.

5.3 Priority for Community-based Conservation of the Upper Baram Forest Area

Based on all the important aspects that were discussed in the previous section, it is concluded that community and environment are interdependent. The idea of engaging community in conservation has been long introduced in forest protection effort (Ulloa et al., 2004). Community-based wildlife management allows people to obtain subsistence and cash benefit from hunting, while at the same time promoting conservation (Puertas & Bodmer, 2004).

One frequently used tool in conservation is protected areas. These areas, however, can lead to dispute when it comes to the inclusion of the local communities' land, as this regulates their daily use of faunal resource (Ulloa et al., 2004). Thus, the intervention of local communities in preserving biodiversity is vital as a complementary tool in enhancing the efficiency of modern conservation effort. As documented by many authors, the local

people own a complex body of knowledge of the environment as reflected in their strategies to protect and preserve natural resources (Nicholas & Lasimbang, 2004; Ripen & Noweg, 2017). For the communities, protecting the forest region is as significant as protecting their heritage and cultural identity.

In the Upper Baram forest, the Kenyah communities demarcated a special area in their land as a protected area where hunting or harvesting of any forest products including timber from the area are prohibited. In the Kenyah Tanjung Tepalit communities, they called the preserved land area as “Uket”, while the Kenyah Jamok communities’ preserved land is known as the “Baie Kerumun Jamok”. For the Penan, they are prohibited from cutting down trees for timber in water catchment area near their villages. All hunting and any forest products harvesting activity are prohibited in the area.

The ultimate reason behind the community forest reserve is to ensure that the animals and forest resources in the area can replenish and recover, also to secure resources from overharvest and depletion. In other cases, the Penan Selungo is actively practicing their traditional way of cultivation by using the same area repeatedly in the forest. The area where paddy was grown before, will be replanted again after a few years once the soil is ready for another planting session. This practice is beneficial to limit excessive forest clearance to support cultivation purposes.

It is clearly depicted that the cognizant of the *Orang Ulu* communities in the study area is currently raising. Other adaptation to conservation effort that have been actively conducted in the Upper Baram is including the “tagang” system, which aims to preserve and protect their fish resources from excessive harvest and depletion. This is also potentially opportunistic as an ecotourism product for the Upper Baram people to attract local and

foreign tourists. Apart from acts as an economic source, this ecotourism is an advantage to provide tourist attraction product with development interventions. Actively involved local inhabitants in management of forest to create positive coexistence between the inhabitants of a region and the preservation of that region.

Hence, all the efforts that were outlined here reflects the cognizant of the indigenous communities of the Upper Baram in protecting their forest. This also shows their commitment in ensuring a sustainable harvest of forest resources for their own use. The existence of this traditional practices opens the potential for effective, innovative resource management by indigenous peoples, if they are integrated with, and in some cases substituted for western scientific concepts for management (Silvius, 2004).

5.4 Insights for Future Studies

There are still many biodiversity aspects of the Upper Baram forest that needed to be studied. This study, have provided necessary information on the occurrence, densities, distribution, and hunting pattern by local communities of medium- to large-sized mammals in which some of this information are currently scarce in literature. Some aspects that can be investigated in the future are as follows:

- i. The response of anthropogenic activities towards the density of endangered species.
- ii. Bird survey and its density study could be used as a complementary tool for comprehensive biodiversity monitoring in the forest region.
- iii. Long-term studies on impact of forest degradation and its impact on species assemblages.

- iv. Understanding the effect of localized community-preserved forest on wildlife abundance and conservation in the region.

The recommendations are ideally based on current body knowledge and gaps in the existing study in the Upper Baram Forest and Borneo Island generally. Cooperation and commitment from multidiscipline are crucial to ensure that relevant information are made available, and with that the possible action could be executed on the ground in achieving conservation goals for the sustainability of both wildlife and community's livelihood needs.

REFERENCES

- Aars, J., Marques, T.A., Buckland, S.T., Andersen, M., Belikov, S., Boltunov, A., & Wiig, O. (2009). Estimating the Barents Sea polar bear subpopulation size. *Marine Mammal Science*, 25(1), 35-52. [10.1111/j.1748-7692.2008.00228.x](https://doi.org/10.1111/j.1748-7692.2008.00228.x)
- Abdullah, R.G. (2017). Accessibility and development. A case study from rural Sarawak, Malaysia. *International Journal of Business and Society*, 18(S4), 791-799.
- Abdul-Latiff, M.A.B., Afiqah, M.A., Zahari, F., Othman, N., Haris, H., Najmuddin, M.F., & Md-Zain, B.M. (2021). The ethnozoology, wildlife utilisation and hunting practices of the Semoq Beri tribe in Pahang. In Abdullah, M.T., Bartholomew, C.V. & Mohammad, A. (Ed.), *Resource use and sustainability of Orang Asli indigeneous communities in Peninsular Malaysia* (pp. 109-136). Cham, CH: Springer Nature Switzerland AG.
- Abernethy, K.A., Coad, L., Taylor, G. Lee, M.E., & Maisels, F. (2013). Extent and ecological consequences of hunting in Central African rainforests in the twenty-first century. *Philosophical Transactions of the Royal Society B*, 368(1625). <http://dx.doi.org/10.1098/rstb.2012.0303>
- Ahmad, A., Gary, D., Rodiansyah, R., Sinta, S., Srifitria, S., Putra, W., Sagita, N., Adirahmanta, S. N., & Miller, A. E. (2021). Leveraging local knowledge to estimate wildlife densities in bornean tropical rainforests. *Wildlife Biology*, 2021(1). <https://doi.org/10.2981/wlb.00771>.
- Alamgir, M., Campbell, M.J., Sloan, S., Engert, J., Word, J., & Laurance, W.F. (2020). Emerging challenges for sustainable development and forest conservation in Sarawak Borneo. *PLOS ONE*, 15(3). <https://doi.org/10.1371/journal.pone.0229614>

- Andersen, J., Nilsson, C., Richelieu, T.d., Fridriksdottir, H., Gobilick, J., Mertz, O., & Gausset, Q. (2003). Local Use of Forest Products in Kuyongon, Sabah, Malaysia. *ASEAN Review of Biodiversity and Environmental Conservation (ARBEC)*, 1-18. <http://www.arbec.com.my/pdf/art2janmar03.pdf>
- Aziz, A.F., & Justin Mergie Laman, C. (2018). Population Estimation of Proboscis Monkeys in Mangroves at Kuching Wetland National Park, Sarawak. *Borneo Journal of Resource Science and Technology*, 8 (2).
- Balme, G.A., Hunter, L.T.B., & Slotow, R. (2009). Evaluating methods for counting cryptic carnivores. *Journal of Wildlife Management*, 73(3), 433-441. <https://doi.org/10.2193/2007-368>
- Barker, G., Lloyd-Smith, L., Barton, H., Cole, F., Hunt, C., Piper, P.J., Rabett, R., Paz, V., & Szabó. (2011). Foraging-farming Transitions at the Niah Caves, Sarawak, Borneo. *Antiquity*, 85(2011), 492-509. <http://antiquity.ac.uk/ant/085/ant0850492.htm>
- Benítez-López, A., Alkemade, R., Schipper, A. M., Ingram, D. J., Verweij, P. A., Eikelboom, J. A. J., & Huijbregts, M. A. J. (2017). The impact of hunting on tropical mammal and bird populations. *Science*, 356(6334), 180–183. <https://doi.org/10.1126/science.aaj1891>
- Benítez-López, A., Santini, L., Schipper, A. M., Busana, M., & Huijbregts, M. A. J. (2019). Intact but empty forests? Patterns of hunting-induced mammal defaunation in the tropics. *PLOS Biology*, 17(5). <https://doi.org/10.1371/journal.pbio.3000247>
- Bennett, E.L. (1992). A wildlife survey of Sarawak. Report for Wildlife Conservation International, New York Zoological Society and World Wildlife Fund for Nature Malaysia. Retrieved from http://repository.wwf.org.my/Technical_Reports/A/A_WildlifeSurvey_Of_Sarawak.pdf.

- Bennett, E.L., Nyaoi, A.J., & Sompud, J. (2000). Savings Borneo's bacon: the sustainability of hunting in Sarawak and Sabah. In E.L. Bennett and J.G. Robinson (Ed.), *Hunting for sustainability in tropical forests*. Columbia University Press, New York, NY.
- Bennett, E.L., & Robinson, J.G. (2000). *Hunting of wildlife in tropical forests: Implications for biodiversity and forest peoples* [The World Bank Environment Department working paper No. 76]. <http://documents.worldbank.org/curated/en/101611468780290485/Hunting-of-wildlife-in-tropical-forests-implications-for-biodiversity-and-forest-peoples>.
- Bennett, E.L., & Gumal, M. (2001). The interrelationships of commercial timber, hunting and wildlife in Sarawak: Recommendations for forest management: Conserving wildlife in logged tropical forests. In Fimbel, R.A., Grajal, A. & Robinson, J.G. (Ed.), *The Cutting Edge*. New York, USA: Columbia University Press.
- Bennett, E.L. (2007). Hunting, wildlife trade and wildlife consumption patterns in Asia. In Davies, G. & Brown, D. (Eds.), *Bushmeat and Livelihoods: Wildlife Management and Poverty Reduction*. Oxford, UK: Blackwell Publishing Ltd.
- Bernard, H., Ahmad, A.H., Brodie, J., Giordano, A.J., Lakim, M., Amat, R., Hue, S.K.P., Khee, L.S., Tuuga, A., Malim, P.T., Lim-Hasegawa, D., Wai, Y.S., & Waidi, S. (2013). Camera-trapping survey of mammals in and around Imbak Canyon Conservation Area in Sabah, Malaysian Borneo. *The Raffles Bulletin of Zoology* 2013, 61(2), 861-870.
- Bernard, H., Baking E.L., Giordano, A.J., Wearn, O.R., & Ahmad, A.H. (2014). Terrestrial mammal species richness and composition in three small forest patches within an oil palm landscape in Sabah, Malaysian Borneo. *Mammal Study* 39, 141-154.
- Bersacola, E., Smith, D. A. E., Sastramidjaja, W.J., Rayadin, Y., & Cheyne, S. (2014).

- Population density of *Presbytis rubicunda* in a small primary dipterocarp forest in East Kalimantan, Indonesian Borneo. *Asian Primates Journal*, 4(2). <https://www.researchgate.net/publication/266030177>.
- Bersacola, E., Cheyne, S., & Macdonald, D. (2019). Occupancy patterns of ungulates and pig-tailed macaques across regenerating and anthropogenic forests. *The Italian Journal of Mammalogy*, 30(2), 126-133. <https://doi.org/10.4404/hystrix-00177-2019>
- Borneo Post Online (November 21, 2019). Sarawak targets 1 million hectares of totally protected land areas by 2020. Retrieved in 28 March 2020 from <https://www.theborneopost.com/2019/11/21/sarawak-targets-1-million-hectares-of-totally-protected-land-areas-by-2020/>
- Brodie, J.F., Giordano, A.J., Zipkin, E.F., Bernard, H., Mohd-Azlan, J., & Ambu, L. (2015). Correlation and persistence of hunting and logging impacts on tropical rainforest mammals. *Conservation Biology*, 29(1), 110-121.
- Bruchac, M.M. (2014). Indigenous Knowledge and Traditional Knowledge. In C. Smith (Ed.), *Encyclopedia of Global Archaeology*. Springer Science and Business Media.
- Brum, F. T., Graham, C. H., Costa, G. C., Hedges, S. B., Penone, C., Radeloff, V. C., Rondinini, C., Loyola, R., & Davidson, A. D. (2017). Global priorities for conservation across multiple dimensions of mammalian diversity. *Proceedings of the National Academy of Sciences of the United States of America*, 114(29), 7641–7646. <https://doi.org/10.1073/pnas.1706461114>
- Buckland, S.T., Anderson, D.R., Burnham, K.P., & Laake, J.L. (1993). Distance Sampling: Estimating Abundance of Biological Populations. Chapman and Hall, London, UK.
- Buckland, S.T., Rexstad, E.A., Marques, T.A., & Oedekoven, C.S. (2015). *Distance Sampling: Methods and Applications*. Springer International Publishing Switzerland.

- Bunya, K., Adrus, M., & Abdullah, M.T. (2012). Review and validation of selected materials on illicit hunting in Malaysia. In M. Mokhtar and Sharina A.H (Ed.), *Regional Sustainable Development in Malaysia and Australia*. Lestari Publisher.
- Caldecott, J.O. (1986). *Hunting and wildlife management in Sarawak*. World Wildlife Fund Malaysia and Sarawak Forest Department: Kuching, Sarawak.
- Cheyne, S. M., Sastramidjaja, W. J., Muhalir, Rayadin, Y., & Macdonald, D. W. (2016). Mammalian communities as indicators of disturbance across Indonesian Borneo. *Global Ecology and Conservation*, 7(206), 157-173. <https://doi.org/10.1016/j.gecco.2016.06.002>
- Choy, Y.K. (2004). Sustainable development and the social and cultural impact of a dam-induced development strategy—the Bakun experience. *Pacific Affairs* 77(1), 50-68. 10.2307/40022274.
- Connor, E.F., & McCoy, E.D. (2017). Species-Area relationships. *Reference Module in Life Science*, Elsevier 2017. Cambridge, UK: Academic Press. <http://dx.doi.org/10.1016/B978-0-12-809633-8.02354-2>
- Corlett, R.T. (2007). The impact of hunting on the mammalian fauna of tropical asian forests. *Biotropica*, 39(3), 292-303.
- Curran, L.M., & Leighton, M.(2000). Vertebrate responses to spatiotemporal variation in seed production of mast-fruited dipterocarpaceae. *Ecological Monographs*, 70(1), 101-128.
- Davison, C.W., Chapman, P.M., Wearn, O.R., Bernard, H., & Ewers, R.M. (2019). Shifts in demographics and behavior of Bearded pigs (*Sus barbatus*) across a land-use gradient. *Biotropica* 2019. wileyonlinelibrary.com/journal/btp
- Deith, M.C.M., & Brodie, J.F. (2020). Predicting defaunation: accurately mapping bushmeat

- hunting pressure over large areas. *Proceedings of the Royal Society B*, 287(1922).
<http://dx.doi.org/10.1098/rspb.2019.2677>
- Department of Statistics Malaysia. (2018). *Statistics yearbook Sarawak*. (Publication No. ISSN 0128-7613). Retrieved from <https://newss.statistics.gov.my/newss-portalx/ep/epFreeDownloadContentSearch.seam?cid=60237>.
- Department of Statistics Malaysia. (2019). *Malaysia statistical handbook*. (Publication No. ISSN 0127-4643). Retrieved from https://www.dosm.gov.my/v1/uploads/files/1_Articles_By_Themes/Others/MSHB/Buku_Maklumat_Perangkaan_Malaysia_2019.pdf.
- Dique, D.S., Villiers, D.L.D., & Preece, H.J. (2003). Evaluation of line-transect sampling for estimating koala abundance in the Pine Rivers Shire, south-east Queensland. *Wildlife Research*, 30, 127-133.
- Duckworth, J.W., & Nettelbeck, A.R. (2007). Observations of Small-toothed palm civets *Arctogalidia trivirgata* in Khao Yai national park Thailand, with notes on feeding techniques. *Natural History Bulletin of the Siam Society*, 55(1), 187-192.
- Ekhuemelo, D.O., Amonum, J.I., & Usman, I.A. (2016). Importance of Forest and Trees in Sustaining Water Supply and Rainfall. *Nigeria Journal of Education, Health and Technology Research*, 8(2016), 273-280.
- Elith, J., Leathwick, J. R., & Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology*, 77(4), 802–813. <https://doi.org/10.1111/j.1365-2656.2008.01390.x>.
- Fa, J.E., Funk, S.M., & Nasi, R. (2022). *Hunting willife in the tropics and subtropics*. Cambridge, UK: Cambridge University Press.
- Fragoso, J.M.V., Levi, T., Oliveira, L.F.B., Luzar, J.B., Overman, H., Read, J.M., & Silvius,

- K.M.(2016). Line transect surveys underdetect terrestrial mammals:implications for the sustainability of subsistence hunting. *PLOS One*, 11(4). 10.1371/journal.pone.0152659
- Forest Department Sarawak. (2020). Heart of Borneo (HoB) initiative. Retrieved from <https://forestry.sarawak.gov.my/page-0-146-993-Heart-of-Borneo-HoB-Initiative.html>.
- Forest Department Sarawak. (March 30, 2020). Totally Protected Area (TPA). Retrieved in 30 March 2020 from <https://forestry.sarawak.gov.my/modulesweb/pages.php?mod=webpage&sub =page&id=661>.
- Foo, J. (2019). Managing the Environment of Development in Malaysia - The Tagal System from the Perspective of the Local Community. *International Journal of Society, Development and Environment in the Developing World*, 3(3), 52-59.
- Gallego-Zamorano, J., Benítez-López, A., Santini, L., Hilbers, J. P., Huijbregts, M. A. J., & Schipper, A. M. (2020). Combined effects of land use and hunting on distributions of tropical mammals. *Conservation Biology*, 34(5), 1271–1280. <https://doi.org/10.1111/cobi.13459>
- Gaveau, D.L.A., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N.K., Acrenaz, M., Nasi, R., Quinones, M.m Wielaard, N., & Meijaard, E. (2014). Four decades of forest persistence, clearance and logging on Borneo. *PLOS One*, 9(7). 10.1371/journal.pone.0101654
- Gaveau, D.L.A., Sheil, D., Husnayaen, Salim, M.A., Arjasakusuma, S., Acrenaz, M., Pacheco, P., & Meijaard, E. (2017). Rapid conversions and avoided deforestation:examining four decades of industrial plantation expansion in Borneo. *Scientific Reports*, 3(6).10.1038/srep32017

- Gaveau, D.L.A., Locatelli, B., Salim, M.A., Yaen, H., Pacheco, P., & Sheil, D. (2018). Rise and fall of forest loss and industrial plantations in Borneo (2000-2017). *Conservation Letters* 2019, 12. <https://doi.org/10.1111/conl.12622>
- Gay, K. (2001). *Rainforests of the world* (2nd ed.). California, US: ABC-CLIO Inc.
- Gestich, C. C., Caselli, C. B., Nagy-Reis, M. B., Setz, E. Z. F., & Da Cunha, R. G. T. (2017). Estimating primate population densities: the systematic use of playbacks along transects in population surveys. *American Journal of Primatology*, 79(2), 1–9. <https://doi.org/10.1002/ajp.22586>
- Gomez. L., Shepherd, C.R., & Khoo. M.S. (2020). Illegal trade of Sun Bear parts in the Malaysian states of Sabah and Sarawak. *Endangered Species Research*, 41, 279-287. <https://doi.org/10.3354/esr01028>
- Gonzalez, R.P., Thomas, L., & Marques, T. A. (2017). Estimation bias under model selection for distance sampling detection functions. *Environmental and Ecological Statistics*, 24(3), 399–414. <https://doi.org/10.1007/s10651-017-0376-0>
- Greene, T., & Efford, M.(2012). Bird:estimates of absolute density and abundance-distance sampling. *Report for Department of Conservation inventory and monitoring toolbox:birds*, New Zealand.
- Gumal, M.T., Bennett, E.L., Robinson, J.G., & Tisen, O.B. (2008). A master plan for wildlife in Sarawak: preparation, implementation and implication for conservation. In Sodhi, N.S., Acciaoli, G., Erb, M. & Tan, A.K. (Ed.), *Biodiversity and human livelihoods in protected areas: case studies from Malay archipelago*. England, UK : Cambridge University Press.
- Halim, A.A., Jawan, J.A., Ismail, S.R. Othman, N., & Masnin, M.H.(2013).Traditional knowledge and environmental conservation among indigenous people in Ranau,

- Sabah. *Global Journal of Human Social Science Geography, Geo-sciences, Environmental & Disaster Management*, 13 (3).
- Hansen, T.S., & Mertz, A.O. (2006). Extinction or adaptation?three decades of change in shifting cultivation in Sarawak, Malaysia.*Land Degradation & Development*, 17, 135- 148. 10.1002/ldr.720
- Hansen, A. J. (2011). Contribution of source-sink theory to protected area science. Pg 339-360 in J. Liu, V., Hull, A. Morzillo, and J. Wiens, (Eds.), *Sources, Sinks, and Sustainability across Landscapes*. Cambridge University Press.
- Hearn, A.J., Ross, J., Pamin, D., Bernard, H., Hunter, L., & Macdonald, D.W. (2013). Insights into the spatial and temporal ecology of the Sunda Clouded Leopard *Neofelis diardi*. *The Raffles Bulletin of Zoology* 2013, 61(2), 871-875.
- Hearn, A.J., Ross, J., Macdonald, D.W., Bolongon, G., Cheyne, S.M., Mohamed, A., Samejima, H., Brodie, J.F., Giordano, A., Alfred, R., Boonratana, R., Marshall, J., Pilgrim, J.D., Hall, J., Breitenmoser-Wursten, C., Kramer-Schadt, S., & Wilting, A. (2016). Predicted distribution of the Sunda Clouded Leopard *Neofelis diardi* (Mammalia: Carnivora: Felidae) on Borneo. *Raffles Bulletin of Zoology*, 33, 149-156.
- Hoeven, C.A.V.D, Willem, F.D.B., & Prins, H.H.T. (2004). Pooling local experts opinions for estimating mammal densities in tropical rainforests. *Journal For Nature Conservation*, 12, 193-204.
- Hon, J., & Samejima, H. (2020). Land-use types along the Kemena river Tubau-Lower Jelalong region, Sarawak. In Ishikawa, N. & Soda, R. (Ed.), *Anthropogenic Tropical Forests Human-Nature interfaces on the plantation frontier* (pp. 41-84). Gateway East, SG: Springer Nature Singapore Pte Ltd.

- Horowitz, L.S. (1998). Integrating indigenous resource management with wildlife conservation: a case study of Batang Ai National Park, Sarawak, Malaysia. *Human Ecology* 1998, 26(3), 371-403.
- Inoue, Y., Sinun, W., & Okanoya, K. (2016). Activity budget, travel distance, sleeping time, height of activity and travel order of wild East Bornean Grey gibbons (*Hylobates funereus*) in Danum Valley Conservation Area. *Raffles Bulletin Of Zoology*. <http://zoobank.org/urn:lsid:zoobank.org:pub:BF830118-CE0A-4D4E-8180-BFE9545F56CF>.
- International Tropical Timber Organization and Forest Department Sarawak. (2017). *Pulong Tau Buffer Zone: Ecosystem, Biodiversity and People*. International Tropical Timber Organization, Yokohama, Japan and Forest Department Sarawak, Malaysia.
- Ioki, K., Din, N.M., Ludwig, R., James, D., Hue, S.W., Johari, S.A., Awang, R.A., Anthony, R., & Phua, M. (2019). Supporting forest conservation through community-based land use planning and participatory GIS— lessons from Crocker range Park, Malaysian Borneo. *Journal for Nature Conservation*, 52(2019). <https://doi.org/10.1016/j.jnc.2019.125740>
- IUCN.(2022). The IUCN Red List of Threatened Species. Version 2022-2. <https://www.iucnredlist.org>. Accessed on [10 October 2022].
- Janowski, M. (2016). The Dynamics of the Cosmic Conversation. Beliefs about Spirits among the Kelabit and Penan of the Upper Baram River, Sarawak. In K. Arhem & G. Sprenger (Ed.), *Animism in Southeast Asia* (pp. 181-204). Routledge Taylor and Francis Group. 10.4324/9781315660288
- Jedediah, B., & Giordano, A.J. (2012). Density of the vulnerable Sunda Clouded Leopard *Neofelis Diardii* in a protected area in Sabah, Malaysian Borneo. *Oryx*, 46(03).

10.1017/S0030605312000087

- Kato, Y., & Samejima, H. (2020). The effects of landscape and livelihood transitions on hunting in Sarawak. In Ishikawa, N. & Soda, R. (Eds.), *Anthropogenic Tropical Forest Human- Nature Interfaces on the Plantation Frontier*, (pp. 277-313). Gateway East, SG: Springer Nature Singapore Pte Ltd.
- Kato, Y., & Soda, R. (2020). The impact of RSPO certification on oil palm smallholdings in Sarawak. In Ishikawa, N. & Soda, R. (Eds.), *Anthropogenic Tropical Forest Human- Nature Interfaces on the Plantation Frontier*, (pp. 277-313). Gateway East, SG: Springer Nature Singapore Pte Ltd.
- Keeping, D., Burger, J.H., Keitsile, A.O., Marie-charlotte, G., Mudongo, E., Wallgren, M., Skarpe, C., & Foote, A.L. (2018). Can trackers count free-ranging wildlife as effectively and efficiently as conventional aerial survey and distance sampling? Implications for citizen science in the Kalahari, Botswana. *Biological Conservation*, 223(2018), 56-169. <https://doi.org/10.1016/j.biocon.2018.04.027>
- Kirupaliny, S.B., & Mohd-Azlan, J.(2012). Wildlife utilization in selected areas of Sarawak, presented at 4th Regional Conference on Natural Resources in the Tropics, 2012 (NTrop4): Sustaining Tropical Natural Resources Through Innovations, Technologies and Practices.
- Kümpel, N.F., East, T., Keylock, N., Rowcliffe, J.M., Cowlishaw, G., & Milner-Gulland, E.J.(2008). Determinants of Bushmeat Consumption and Trade in Continental EquatorialGuinea: An Urban-Rural Comparison. In G. Davies & D. Brown (Ed.), *Conservation Science and Practice Series Bushmeat and Livelihoods: Wildlife Management and Poverty Reduction* (pp. 73-91).
- Kulip, J. (2003). An Ethnobotanical Survey of Medicinal and Other Useful Plants of Muruts

- in Sabah, Malaysia. *Telopea*, 10(1), 81-98.
- Kurten, E.L. (2013). Cascading effects of contemporaneous defaunation on tropical forest communities. *Biological Conservation*, 163(2013), 22-32.
- Kurz, D. J., Hanisdah Saikim, F., Terrence Justine, V., Bloem, J., Libassi, M., Scott Luskin, M., Withey, L. S., Goossens, B., Brashares, J. S., & Potts, M. D. (2021). Transformation and endurance of indigenous hunting: Kadazandusun-Murut bearded pig hunting practices amidst oil palm expansion and urbanization in Sabah, Malaysia. *People and Nature* 2021, 3(5), 1078-1092. <https://doi.org/10.1002/pan3.10250>
- Kurz, D.J., Connor, T., Brodie, J.F., Baking, E.L., Szeto, S.H., Hearn, A.J., Gardner, P.C., Wearn, O.R., Deith, M.C.M., Deere, N.J., Ampeng, A., Bernard, H., Goon, J., Granados, A., Helmy, O., Lim, H., Luskin, M.S., Macdonald, D.W., Ross, J., Simpson, B.K., Struebig, M.J., Mohd-Azlan, J., Potts, M.D., Goosens, B., & Brashares, J.S. (2023). Socio-ecological factors shape the distribution of a cultural keystone species in Malaysian Borneo. *Npj Biodiversity* 2023, 2(1).
- Langner, A., Miettinen, J., & Siegert, F. (2007). Land cover change 2002-2005 in Borneo and the role of fire derived from MODIS imagery. *Global Change Biology* , 13(11), 2329- 2340.10.1111/j.1365-2486.2007.01442.x
- Liebenberg, L., & Stevenson, J. (1997). Cybertracker Software Version 3.514. [Computer Software]. <https://www.cybertracker.org/>
- Loke, V. P. W., Lim, T., & Campos-Arceiz, A. (2020). Hunting practices of the Jahai indigenous community in northern peninsular Malaysia. *Global Ecology and Conservation*, 21. <https://doi.org/10.1016/j.gecco.2019.e00815>
- Mackenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L.L., & Hines, J.E. (2006). Occupancy estimation and modelling inferring patterns and dynamics of

species occurrence. California, USA: Elsevier Inc.

- Maiwald, M. J., Mohd-Azlan, J., & Brodie, J. F. (2021). Resilience of terrestrial mammals to logging in an active concession in Sarawak, Borneo. *Mammalia*, 85(2), 115–122. <https://doi.org/10.1515/mammalia-2020-0011>
- Mahidin, H.B., & Sofwan, N.B.M. (2012). Tourist's perception on conservation of natural resources at Bako National Park, Sarawak, Malaysia. *Paper presented at 4th Regional Conference on Natural Resources in the Tropics (NTrop4), 2012*. Retrieved from https://www.researchgate.net/publication/309768585_TOURIST'S_PERCEPTION_ON_CONSERVATION_OF_NATURAL_RESOURCES_AT_BAKO_NATIONAL_PARK_SARAWAK_MALAYSIA
- Mathai, J., Hon, J., Juat, N., Peter, A., & Gumal, M. (2010) . Small carnivores in a logging concession in the Upper Baram, Sarawak, Borneo. *Small carnivore Conservation*, 42,1- 9.
- Mathai, J., Jathanna, D., & Duckworth, J.W.(2013). How useful are transect surveys for studying carnivores in the tropical rainforests of Borneo?. *The Raffles Bulletin of Zoology*, 28, 9-20. <https://www.researchgate.net/publication/264011428>.
- Mathai, J., Buckingham, L., & Ong, N. (2014). Borneo bay cat and other felids in a logging concession in Sarawak, Malaysia. *Catnews* 60.
- Mathai, J., Duckworth, J.W., Meijaard, E., Fredriksson, G., Hon, J., Sebastian, A., Acrenaz, M., Hearn, A.J., Ross, J., Cheyne, S., Borneo Carnivore Consortium, & Wilting, A.(2016).Carnivore conservation planning on Borneo: identifying key carnivore landscapes, research priorities and conservation interventions. *Raffles Bulletin of Zoology*, 33, 186-217.

- Malaysia Palm Oil Board.(2019). Oil palm planted area 2019. Retrieved from http://bepi.mpob.gov.my/images/area/2019/Area_summary.pdf.
- Malaysia Palm Oil Council. (n.d.). One of the world's largest palm oil exporter. *Malaysia Oil Palm Industry*. Retrieved from <http://mpoc.org.my/malaysian-palm-oil-industry/>.
- McAlpine, C. A., Johnson, A., Salazar, A., Syktus, J., Wilson, K., Meijaard, E., Seabrook, L., Dargusch, P., Nordin, H., & Sheil, D. (2018). Forest loss and Borneo's climate. *Environmental Research Letters*, 13(4). <https://doi.org/10.1088/1748-9326/aaa4ff>
- Meijaard, E., & Sheil, D. (2007). The persistence and conservation of Borneo's mammals in lowland rainforests managed for timber: observations, overviews and opportunities. *The Ecological Society of Japan* 2007. 10.1007/s11284-007-0342-7
- Meijaard, E., Abram, N.K., Wells, J.A., Pellier, A., Acrenaz, M., Gaveau, D.L.A., Runting, R.K., & Mengersen, K. (2013). People's Perceptions about the Importance of Forests on Borneo. *PLOS ONE*, 8(9), 1-14. 10.1371/journal.pone.0073008
- Meijaard, E., Garcia-Ulloa, J., Sheil, D., Wich, S. A., Carlson, K. M., Juffe-Bignoli, D., & Brooks, T.M. (2018). *Oil Palm and Biodiversity. A Situation Analysis by the IUCN Oil Palm Task Force*. Gland, Switzerland: IUCN.
- Ministry of Primary Industries. (2018). Malaysia: Distribution of oil palm planted area by state and sector in 2018. Retrieved from http://www.data.gov.my/data/en_US/dataset/malaysia-distribution-of-oil-palm-planted-area-by-state-and-sector-in-2017-v2/resource/7e162d8e-babd-4626-933f-b2c41113544a.
- Ministry of Natural Resources and Environment. (2016). *National Policy on Biological Diversity 2016-2025*. (Publication No. ISBN 978-967-0250-24-3). Retrieved from

<https://www.cbd.int/doc/world/my/my-nbsap-v2-en.pdf>.

- Miller, D.L., Burt, M.L., Rexstad, E.A., Thomas, L., Marshall, L., & Laake, J.L. (2019). Distance sampling in R. *Journal of Statistical Software* 2019, 89(1). 10.18637/jss.v089.i01.
- Miller, D.L., Burt, M.L., Rexstad, E.A., & Thomas, L. (2013). Spatial models for distance sampling data: recent developments and future directions. *Methods in Ecology and Evolution*, 4(2013), 1001-1010. 10.1111/2041-210X.12105
- Mohamed, A., Sollmann, R., Bernard, H., Ambu, L.N., Lagan, P., Mannan, S., Hofer, H., & Wilting, A. (2013). Density and habitat use of the leopard cat (*Prionailurus bengalensis*) in three commercial forest reserves in Sabah, Malaysian Borneo. *Journal of Mammalogy*, 94(1). 10.1644/11-MAMM-A-394.1
- Mohd-Azlan, J., & Fauzi, M.F. (2006). Ethnozoological survey in selected areas in Sarawak. *The Sarawak Museum Journal*, 83, 185–200.
- Mohd-Azlan, J., & Lawes, M. (2011). The Efficacy of Protected Areas and Future Challenges for Wildlife Conservation in Sarawak. In M. Mokhtar, & S. A. Halim (Eds.), *RIMBA2 Regional Sustainable Development in Malaysia and Australia* (pp. 136-148).
- Mohd-Azlan, J. (2014). Wildlife conservation legislations in Malaysia: evolution and future needs. In Tuen, A.A., Mohd-Azlan, J. & Grinang, J. (Eds.), *RIMBA 3 Sustainable livelihood through prudent utilization and management of natural resources*. Kuching, MY: Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak.
- Mohd-Azlan, J., Yi, M.C.K., Jailan, T.S., & Pui, Y.M. (2016). River crossing and migration

- of the Bearded pig (*Sus barbatus*) in Central Sarawak, Borneo. *Suiform Surroundings*, 15(1).
- Mohd-Azlan, J., Yi, M.C.K., Engkamat, L., & Tisen, O.B. (2017). Incidental killing of sunda clouded-leopard in Sarawak, Malaysia. *Cat News* 65, 42-46.
- Nicholas, C., & Lasimbang, J. 2004. Deliberations at the National Roundtable on biodiversity and indigenous knowledge systems in Malaysia. Vinlin Press Sdn Bhd, Kuala Lumpur, Malaysia.
- Nelson, J., Muhammed, N., & Rashid, R.A. (2015). Community's Forest Dependency and Its Effects towards the Forest Resources and Wildlife Abundances in Sarawak, Malaysia. *International Journal of Sustainable Development & World Ecology*, 22(5), 401-412. <http://dx.doi.org/10.1080/13504509.2015.1072117>
- Newey, S., Davidson, P., Nazir, S., Fairhurst, G., Verdicchio, F., Irvine, R.J., & Wal, R.V.D. (2015). Limitations of recreational camera traps for wildlife management and conservation research: A practitioner's perspective. *Ambio* 2015, 44(4), S624-S635.
- Nuttall, M. N., Griffin, O., Fewster, R. M., McGowan, P. J. K., Abernethy, K., O'Kelly, H., Nut, M., Sot, V., & Bunnefeld, N. (2022). Long-term monitoring of wildlife populations for protected area management in Southeast Asia. *Conservation Science and Practice*, 4(2). <https://doi.org/10.1111/csp2.614>
- Ocampo-Peñuela, N., Garcia-Uolla, J., Kornecki, I., Philipson, C.D., & Ghazoul, J. (2020). Impacts of Four Decades of Forest Loss on Vertebrate Functional Habitat on Borneo. *Frontiers in Forests and Global Change*, 3(53). 10.3389/ffgc.2020.00053
- Okuno, K., & Ichikawa, T. (2020). Oil palm plantations and bezoar stones: an ethnographic sketch of human-nature interactions in Sarawak. In Ishikawa, N. & Soda, R. (Ed.), *Anthropogenic Tropical Forests Human-Nature interfaces on the plantation frontier*

- (pp. 479-496). Gateway East, SG: Springer Nature Singapore Pte Ltd.
- Pacheco, P., & Meijaard, E. (2016). Rapid conversions and avoided deforestation: examining four decades of industrial plantation expansion in Borneo. *Scientific Reports* 6, 32017(2017). 10.1038/srep32017
- Phillips, H.R.P., Newbold, T., & Purvis, A.(2017). Land-use effects on local biodiversity in tropical forests vary between continents. *Biodiversity Conservation*, 26, 2251–2270.
- Phillipps, Q., & Phillipps, K., (2014). Phillipps' Field Guide to the Birds of Borneo and Their Ecology: Sabah, Sarawak, Brunei, and Kalimantan (3rd ed). New Jersey, US: Princeton University Press.
- Phillipps, Q., & Phillipps, K., (2018). Phillipps' Field Guide to the Mammals of Borneo and Their Ecology: Sabah, Sarawak, Brunei, and Kalimantan (2nd ed). Oxford, UK: John Beaufoy Publishing Ltd.
- Philoveny, P., & Mohd-Azlan, J. (2021). How do people in the "land of hornbills" perceive hornbills?. *Bird Conservation International*, 33, 1-15. 10.1017/S0959270921000381
- Piper, P.J., & Rabett, R.J. (2009). Hunting in a tropical rainforest: Evidence from the terminal Pleistocene at Lobang Hangus, Niah Caves, Sarawak. *International Journal of Osteoarcheology*, 19, 551-565.
- Puertas, P.E., & Bodmer, R.E. (2004). Hunting Effort as a Tool for Community-Based Wildlife Management in Amazonia. In Silvius, K.M., Bodmer, R.E. & Fragoso, J.M.V (Ed.), *People in Nature: Wildlife Conservation in South and Central America*. New York, USA: Columbia University Press.
- Puri, R.K. (1999). Teknik-teknik perburuan pada masyarakat Penan dan Kenyah di kawasan Sungai Lurah. Pp. 73-96, in *Kebudayaan dan Pelestarian Alam: Penelitian*

- interdisipliner di pedalaman Kalimantan, eds., C. Eghenter and B. Sellato. Jakarta: WWF Indonesia.
- QGIS Development Team, (2021). QGIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>
- R Development Core Team. (2020). R Software Version 4.0.2. [Computer Software]. <https://www.r-project.org/>
- Radhi, N.A.M., & Landau, E. (2019, November 4). Tackle illegal online wildlife trade too, corps urged. *New Straits Times*. Retrieved from <https://www.nst.com.my/news/nation/2019/11/535670/tackle-illegal-online-wildlife-trade-too-cops-urged>
- Ramlee, H. (2009). *Distribution, ecology and systematics of Presbytis hosei and other leaf monkey species in North Borneo*. [Doctoral Dissertation, The Australian National University].
- Rider, I.J., Donnelly, M.A., & Watling, J.I.(2018). The influence of matrix quality on species richness in remnant forest. *Landscape Ecology* (2018), 33, 1147-1157.
- Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M. P., Schmitz, O. J., Smith, D. W., Wallach, A. D., & Wirsing, A. J. (2014). Status and ecological effects of the world's largest carnivores. In *Science*, 343(6167). American Association for the Advancement of Science. <https://doi.org/10.1126/science.1241484>
- Ripple, W. J., Abernethy, K., Betts, M. G., Chapron, G., Dirzo, R., Galetti, M., Levi, T., Lindsey, P. A., Macdonald, D. W., Machovina, B., Newsome, T. M., Peres, C. A., Wallach, A. D., & Wolf, C. (2016). Bushmeat hunting and extinction risk to the world's mammals. *Royal Society Open Science*, 3(10).

<https://doi.org/10.1098/rsos.160498>

- Ripen, J.E., & Noweg, G.T. (2017). Documenting ethnobotanical knowledge of rural community for sustainable benefits. *International Journal of Service Management and Sustainability*, 2(1).
- Ritter, E., & Dauksta, D. (2013). Human-forest relationships: Ancient values in Modern Perspectives. *Environement, Development and Sustainability*, 15(2013), 645-662. 10.1007/s10668-012-9398-9
- Robinson, J.G., & Redford, K.H. (1994). Measuring the sustainability of hunting in tropical forests. *Oryx*, 28(4), 249-256.
- Rogan, J.E., & Jr, T.E.L. (2018). Impacts of habitat loss and fragmentation on terrestrial biodiversity. In *Reference Module in Earth Systems and Environmental Sciences*, Elsevier 2018. Cambridge, UK: Academic Press.
- Sahari, F. (2012, August). *Sustainability of Orang Ulu Crafts*. [Paper Presentation]. RIMBA 3 Conference, Permai Rainforest Resort, Santubong, Kuching, Sarawak, SWK, Malaysia.
- Sahmat, N.S., & Mohd-Azlan, J. (2022). The utilisation, perceptions and awareness of Melanau communities on wildlife in Rajang area, Sarawak, Malaysia. *Malayan Nature Journal* 2022, 74(2), 189-204.
- Sait, E.K.L., Mersat, N.I., & Wong, S.K. (2018). Preliminary Observations on Indigenous Knowledge and the Uses of Natural Resources in Banting and Padawan. *Akademika*, 88(3), 33-42. <https://doi.org/10.17576/akad-2018-8803-03>
- Samejima, H., & Hon, J. (2020). Diversity of medium- to large-sized ground-dwelling mammals and terrestrial birds in Sarawak. In Ishikawa, N. & Soda, R. (Ed.), *Anthropogenic Tropical Forests Human-Nature interfaces on the plantation frontier*

- (pp. 149-170). Gateway East, SG: Springer Nature Singapore Pte Ltd.
- Samejima, H. (2020). Tropical timber trading from Southeast Asia to Japan. In Ishikawa, N. & Soda, R. (Ed.), *Anthropogenic Tropical Forests Human-Nature interfaces on the plantation frontier* (pp. 517-541). Gateway East, SG: Springer Nature Singapore Pte Ltd.
- Santini, L., Isaac, N. J. B., & Ficetola, G. F. (2018). TetraDENSITY: A database of population density estimates in terrestrial vertebrates. *Global Ecology and Biogeography*, 27(7), 787–791. <https://doi.org/10.1111/geb.12756>
- Scriven, S. A., Hodgson, J. A., McClean, C. J., & Hill, J. K. (2015). Protected areas in Borneo may fail to conserve tropical forest biodiversity under climate change. *Biological Conservation*, 184, 414–423. <https://doi.org/10.1016/j.biocon.2015.02.018>
- Seaman, D. J. I., Bernard, H., Ancrenaz, M., Coomes, D., Swinfield, T., Milodowski, D. T., Humle, T., & Struebig, M. J. (2019). Densities of Bornean orang-utans (*Pongo pygmaeus morio*) in heavily degraded forest and oil palm plantations in Sabah, Borneo. *American Journal of Primatology*, 81(8). <https://doi.org/10.1002/ajp.23030>
- Silvius, K.M. (2004). Bridging the Gap Between Western Scientific and Traditional Indigenous Wild- life Management: The Xavante of Rio Das Mortes Indigenous Reserve, Mato Grosso, Brazil. In Silvius, K.M., Bodmer, R.E. & Fragoso, J.M.V (Ed.), *People in Nature: Wildlife Conservation in South and Central America*. New York, USA: Columbia University Press.
- Simcharoen, A., Savini, T., Gale, G.A., Roche, E., Chimcome, V., & Smith, J.L.D. (2014). Ecological factors that influence Sambar (*rusa unicolor*) distribution and abundance in western Thailand: implications for tiger conservation. *Raffles Bulletin of Zoology*

- 62, 100-106. <http://zoobank.org/urn:lsid:zoobank.org:pub:3528409A-62CE-4F2D-8713-06D47FF98585>
- Sinclair, A.R.E., Fryxell, J.M., & Caughley, G. (2006). Wildlife ecology, conservation and Management. (2nd Edition). Blackwell Publishing.
- Sodhi, N.S., Koh, L.P., Brook, B.W., & Ng, P.K.L.(2004). Southeast asian biodiversity:an impending disaster.*TRENDS in Ecology and Evolution*, 19(12), 654- 660. 10.1016/j.tree.2004.09.006
- Sodhi, N.S., Posa, M.R.C., Lee, T.M., Bickford, D., Koh, L.P., & Brook, B.W.(2010). The state and conservation of southeast asian biodiversity. *Biodiversity Conservation* 2010, 19, 317-328. 10.1007/s10531-009-9607-5
- Sodhi, N.S., Butler, R., & Raven, P.H. (2011). Bottom-up conservation. *Biotropica* 43(5): 521-523. 10.1111/j.1744-7429.2011.00793.x
- Soepadmo, E., & Wong, K.M. (Ed.). (1995). *Tree flora of Sabah and Sarawak* (Vol.1). Kuala Lumpur, MY: Ampang Press Sdn. Bhd.
- Sovacool, B.K., & Bulan, L.C. (2013). They'll be dammed: the sustainability implications of the Sarawak Corridor of Renewable Energy (SCORE) in Malaysia. *Sustainable Science* 2013, 8, 121-133.10.1007/s11625-012-0159-3
- Steinmetz, R., Chutipong, W., Seuaturien, N., Chirngsaard, E., & Khaengkhetkarn, M. (2010). Population recover patterns of Southeast Asian ungulates after poaching. *Biological Conservation*, 143(1), 42-51.
- Strindberg, S., Kumar, N.S., Thomas, L., & Goswami, V.R. (2017). Concepts:estimating abundance of prey species using line transect sampling. In *Methods for monitoring tiger and prey populations*, edited by Karanth, K.U. and Nichols, J.D., pp. 89-120. Springer Nature, Singapore. 10.1007/978-981-10-5436-5_6

- Symes, W.S., Edwards, D.P., Miettinen, J., Rheindt, F.E., & Carrasco, L.R.(2018). Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nature Communications* 2018, 9, 4052. 10.1038/s41467-018-06579-2
- Thomas, L., Buckland, S.T., Burnham, K.P., Anderson, D.R., Laake, J.L., Borchers, D.L., & Strindberg, S. (2002). Distance sampling. *Encyclopedia of Environmetrics* 1, 544-552.
- Tilker, A., Abrams, J. F., Mohamed, A., Nguyen, A., Wong, S. T., Sollmann, R., Niedballa, J., Bhagwat, T., Gray, T. N. E., Rawson, B. M., Guegan, F., Kissing, J., Wegmann, M., & Wilting, A. (2019). Habitat degradation and indiscriminate hunting differentially impact faunal communities in the Southeast Asian tropical biodiversity hotspot. *Communications Biology*, 2(1). <https://doi.org/10.1038/s42003-019-0640-y>
- Tucker, M.A., Santini, L., Carbone, C., & Mueller, T. (2020). Mammal population densities at a global scale are higher in human modified areas. *Ecography*, 43, 1-13. 10.1111/ecog.05126
- Ubaidillah, N.Z., Saib, R., Ab-Rahim, R., & Ismail, F. (2018). Tagang System Development: The Impacts and Perception of Local Communities in Terbat Mawang Village, Sarawak, Malaysia. *International Journal of Academic Research in Business & Social Sciences*, 8(12), 1203-1222. 10.6007/IJARBS/v8-i12/5192
- Udevitz, M. S., & Gould, W. R. (2012). Abundance: Population Size and Density Estimation. *Encyclopedia of Environmetrics*. Wiley. <https://doi.org/10.1002/9780470057339.vaa002.pub2>
- United Nations, Educational, Scientific and Cultural Organization. (2018). UNESCO'S Commitment to Biodiversity - Connecting People and Nature for an Inspiring Future.

<https://unesdoc.unesco.org/ark:/48223/pf0000265200>

- Uolla, A., Rubio-Torgler, H., & Campos-Rozo, C. (2004). Conceptual Basis for the Selection of Wildlife Management Strategies by the Embera People in Utría National Park, Chocó, Colombia. In Silvius, K.M., Bodmer, R.E. & Fragoso, J.M.V (Ed.), *People in Nature: Wildlife Conservation in South and Central America*. New York, USA: Columbia University Press.
- Vijith, H., & Dodge-Wan, D. (2021). Statistical Trend Characteristics of Rainfall in the Baram River Basin (Malaysian Borneo). *Applied Geography*, 7(2), 131-160. 10.1080/23754931.2020.1847728
- Wadley, R.L., Carol, J.P.C., & Hood, I.G. (1997). Hunting primates and Managing Forests: The case of Iban forest farmers in Indonesian Borneo. *Human Ecology* 25(2): 243-271.
- Wearn, O.R., Rowcliffe, J.M., Carbone, C., Bernard, H., & Ewres, R.M. (2013). Assessing the status of wild felids in a highly- disturbed commercial forest reserve in Borneo and the implications for camera trap survey design. *Plos One*, 8(11). 10.1371/journal.pone.0077598
- Wearn, O.R., Rowcliffe, J.M., Carbone, C., Pfeifer, M., Bernard, H., & Ewers, R.M. (2017). Mammalian species abundance across a gradient of tropical land-use intensity: a hierarchical multi-species modelling approach. *Biological Conservation* 212, 162-171.
- Wildlife Conservation Society & Sarawak Forest Department. (1996). A master plan for wildlife in Sarawak.
- Wilson, G.J., & Delahay, R.J. (2001). A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. *Wildlife Research* 2001, 28,

- Wilting, A., Mohamed, A., Ambu, L.N., Mannan, P.L.S., Hofer, H., & Sollman, R. (2012). Density of the vulnerable Sunda Clouded leopard in two commercial forest reserves in Sabah, Malaysian Borneo. (2012). *Oryx*, 46(3). 10.1017/S0030605311001694
- Wintle, B.A., Kujala, H., Whitehead, A., Cameron, A., Veloz, S., Kukkala, A., Moilanen, A., Gordon, A., Lentini, P.E., Cadenhead, N.C.R., & Bekessy, S.A.(2019).Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity. *PNAS*, 116(3), 909-914. www.pnas.org/cgi/doi/10.1073/pnas.1813051115
- Wong, A., Huaimei, Y., Wong, C., & Shukor, J.A. (2012). A study on hunting activity of Sambar Deer and Bearded Pig in Paitan forest reserve, Pitas, Sabah, Malaysia. *Journal of Tropical Biology and Conservation*, 9(1), 35-47.
- Workman, D. (October 22, 2019). Palm oil exports by country. *World's Top Exports*. Retrieved from <http://www.worldstopexports.com/palm-oil-exports-by-country/>.
- World Wildlife Fund. (2010). *Borneo's new world: newly discovered species in Heart of Borneo*. Retrieved from https://wwf.panda.org/wwf_news/?195396/Borneos-New-World-Newly-Discovered-Species-in-the-Heart-of-Borneo.
- Yi, M.C.K., & Mohd-Azlan, J. .2018. Preliminary analysis on the hunting activities in selected areas in interior Sarawak. *Malaysia Applied Biology*, 47, 37–43.

APPENDICES

Appendix A: Hunting Return Survey Questions

Soalan Hasil Buruan

- 1) Background Questions /*Latar Belakang*
 - a. Name of interviewer/*Nama penemu duga:*
 - b. Date of interview/*Tarikh temu duga:*
 - c. Name of household head/*Nama Ketua isi rumah:*
 - d. Name of hunter/*Nama Pemburu:*
 - e. Date of hunt/*Tarikh Berburu:*
 - f. What was the weather?/*Cuaca semasa memburu:*

Hot/Panas

Wet/Lembap

Cool/Sejuk
 - g. Was it a planned hunting trip?/*Adakah perjalanan untuk memburu dirancang?*

Yes/Ya

No/Tidak
- 2) Was the hunting trip overnight?/*Bermalam untuk memburu?*

Yes/Ya

No/Tidak
- 3) Was the hunting trip for multiple days?/*Adakah perjalanan memburu mengambil masa beberapa hari?*

If so, how many?/Jika ya, nyatakan berapa hari?
- 4) If yes, where did you start the trip?/*Jika ya, nyatakan bila aktiviti pemburuan bermula?*

5) Where did you hunt?/*Dimanakah anda berburu?*

Rubber estate/*Ladang Getah*

Paddy hill/*Kawasan tanaman padi bukit*

Paddy field/*Ladang padi*

Salt lick/*Jenut Garam*

Stream or river/*Sungai*

Pond/*Kolam*

On the banks of a stream/river/*Tebing sungai*

Road/*Jalan*

Bulldozer trail/*Laluan jentolak*

Wild fruit land/ *Ladang Buah liar*

Farmed fruit land/*Ladang Tanaman Buah*

Animal trail/ *Laluan haiwan*

Human trail/*Laluan manusia*

Primary forest/ *Hutan primer*

Secondary forest/ *Hutan sekunder*

Degraded land/ *Hutan tergradasi*

Other/*Lain-lain*

6) How did you get there?/*Bagaimanakah anda pergi ke sana?*

Driving/Memandu kereta

Walk/berjalan kaki

Motorcycle/Motosikal

Boat/Perahu

7) What animals were you trying to hunt?/*Apakah haiwan yang anda ingin buru?*

8) Were you hunting in group?/*Adakah anda memburu secara berkumpulan?*

Yes/*Ya*

No/*Tidak*

9) If yes, how many? Who were the other people with you?/*Jika ya, nyatakan berapa orang?*

10) Why were you hunting?/*Mengapakah anda pergi memburu?*

Food for your household/*Makanan untuk isi rumah*

Food to share outside your household/*Makanan untuk dikongsikan selain dengan isi rumah*

Food to sell or trade as meat/*Makanan untuk jual beli*

For a festival or celebration or visit of guests/*Untuk perayaan atau hidangan sempena menyambut tetamu*

Wildlife trade (live animals)/ *Jual beli haiwan liar hidup*

11) What methods did you use?/*Apakah kaedah yang anda gunakan?*

Hunting from car/ *Memburu menggunakan kereta*

Hunting from boat/ *Memburu menggunakan perahu*

Sit and wait/ *Duduk dan tunggu*

Trapping/*Perangkap*

Walking a hunting trail/*Bejalan di laluan berburu*

Flushing dogs/*Anjing Pemburu*

Spotlighting/*Lampu suluh*

Tracking/*Menjejak*

12) What weapons did you use?/*Senjata yang digunakan ketika memburu?*

Blowpipe/*Sumpit*

Spear/*Lembing*

Shotgun/*Senapang Patah*

Parang/*Parang*

Trap/*Perangkap*

Other, please state/*Nyatakan lain-lain:*

13) Did you consult a person before hunting?/*Adakah anda merujuk sesiapa sebelum memburu?*

Yes/*Ya*

No/*Tidak*

a) If so, whom? /*Jika ya, siapa?*

b) If so, when?/*Jika ya, nyatakan bila?*

14) Did you pray before or during hunting?/*Adakah anda berdoa sebelum memburu?*

Yes/*Ya*

No/*Tidak*

15) Did you catch/kill an animal?/*Adakah anda berhasil menangkap/ membunuh haiwan hasil buruan?*

Yes/*Ya*

No/*Tidak*

16) Were there any wounded animals that escaped?/*Adakah terdapat haiwan cedera yang melarikan diri ketika diburu?*

a) If yes, how many?/*Jika ya, nyatakan berapa bilangan?*

b) If yes, what species?/*Apakah spesis/jenis haiwan tersebut?*

Continue to Successful Hunt Survey if there's animal caught from hunting

17) Date of kill/*Tarikh diburu*:

Animal name/*Jenis haiwan*:

Sex/*Jantina*:

Old/young/*Muda/Tua*:

Male/female/*Jantan/Betina*:

Was the animal pregnant/*Adakah haiwan tersebut bunting?*: Yes/No/*Ya/Tidak*

Was the animal nursing/*Adakah haiwan tersebut sedang menyusu?*: Yes/No/*Ya/Tidak*

18) Where was the animal caught/*Dimanakah haiwan tersebut ditangkap?*:

Rubber estate/*Ladang Getah*

Paddy hill/*Kawasan tanaman padi bukit*

Paddy field/*Ladang padi*

Salt lick/*Jenut Garam*

Stream or river/*Sungai*

Pond/*Kolam*

On the banks of a stream/river/*Tebing sungai*

Road/*Jalan*

Bulldozer trail/*Laluan jentolak*

Wild fruit land/ *Ladang Buah liar*

Farmed fruit land/*Ladang Tanaman Buah*

Animal trail/ *Laluan haiwan*

Human trail/*Laluan manusia*

Primary forest/ *Hutan primer*

Secondary forest/ *Hutan sekunder*

Degraded land/ *Hutan tergradasi*

Other/*Lain-lain*

19) What weapon was used to kill the animal?/ *Senjata digunakan untuk membunuh haiwan tersebut?*

Shotgun/*Senapang Patah*

Trap/*Perangkap*

Spear/*Lembing*

Parang/*Parang*

Blow pipe/*Sumpit*

Other (please state)/*Lain-lain nyatakan*

20) Can you show us where on the map the animal was captured?/ *Tandakan tempat haiwan buruan ditangkap/dibunuh?*

Photo of map/*Tandakan di atas peta gambar*

Mark XY coordinate/*Tandakan dan nyatakan koordinat XY*