BEHAVIOURAL ECOLOGY AND CONSERVATION MANAGEMENT OF DUSKY LANGURS (*Trachypithecus obscurus*) IN PENANG, MALAYSIA

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ABSTRAK

Lotong cengkong (*Trachypithecus obscurus*) merupakan sejenis primat terancam di Semenanjung Malaysia yang mempunyai informasi yang terhad mengenai ekologi serta perilakunya. Dalam kajian ini, peruntukan aktiviti, penggunaan habitat, dan diet empat kumpulan kajian terhabituat dalam jenis habitat yang berbeza telah dinilai untuk lebih memahami perilaku lotong dalam persekitaran antropogenik. Kajian ini telah dikendalikan dari Januari 2016 hingga Disember 2019 dengan menggunakan teknik perilaku persampelan seperti imbasan, persampelan fokus, plot tumbuh-tumbuhan, penilaian julat rumah, dan perangkap kamera. Julat kawasan tempat tinggal kumpulan yang dikaji serta kebanyakan parameter habitat di kawasan kajian memiliki perbezaan ketara dengan jenis habitat (Kruskal-Wallis, $p \leq 0.05$). Aktiviti utama lotong adalah membetulkan kedudukan mereka (46.2%) melalui aktiviti duduk (70.8%) yang menjadikan jenis membetulkan posisi yang paling utama dengan perbezaan ketara dari segi aktiviti dengan semua kumpulan kajian (Kruskall-Wallis, $p \leq 0.05$) (N= 21,050). Lotong kerap memakan daun-daun muda (60.3%) dan menjadikan 135 spesies yang telah dikenal pasti daripada 49 keluarga tumbuhan liar serta tumbuhan yang ditanam sebagai sumber makanan. Untuk mengurangkan kesan jalan raya berturap yang kian sibuk terhadap lotong liar di Teluk Bahang, Pulau Pinang, sebuah jambatan kanopi yang pertama di Malaysia telah dibina pada Februari 2019 bagi memudahkan haiwan arboreal untuk bergerak dengan selamat merentasi pecahan habitat. Secara keseluruhan, sebanyak 2,128 lintasan haiwan terdiri daripada tiga spesies mamalia telah direkodkan

dari Mac 2019 hingga Mei 2021. Tupai kampung merupakan spesies yang kerap menggunakan jambatan tersebut dengan lintasan sebanyak 2,075 kali, diikuti kera, dengan lintasan sebanyak 32 kali, dan lotong cengkong sebanyak 21 kali, sekaligus menunjukkan perbezaan ketara dalam penggunaan jambatan berdasarkan spesies (Chi-Square, $p \leq 0.001$). Kajian ini telah diperluaskan kepada projek pemuliharaan berasaskan sains untuk masyarakat sejak 2016, yang dikenali sebagai Langur Project Penang (LPP), bagi menggalakkan manusia dan hidupan liar untuk hidup bersama secara damai dalam habitat yang dikongsi, melalui penyelidikan lapangan, tindakan pemuliharaan dan pendidikan alam sekitar. Kajian tesis ini menyediakan data asas bagi membangunkan dokumen kerja pelbagai bahasa iaitu "Pelan Pemuliharaan Lotong Cengkong" untuk dibentangkan kepada pihak berkepentingan utama yang merujuk tindakan pemuliharaan penting dan rasional yang digariskan dalam tesis ini bagi melindungi spesies terancam ini di Malaysia dan serata dunia.

BEHAVIOURAL ECOLOGY AND CONSERVATION MANAGEMENT OF DUSKY LANGURS (*Trachypithecus obscurus*) IN PENANG, MALAYSIA

ABSTRACT

The dusky langur (*Trachypithecus obscurus*) is an endangered primate species in Peninsular Malaysia with little information about their ecology and behavior. In this study, the activity budget, habitat use, and diet of four habituated study groups in different habitat types in Penang were assessed to better understand how langurs behave in anthropogenic environments. This study was conducted between January 2016 and December 2019 using behavioural sampling techniques such as scan, focal sampling, vegetation plotting, home range assessment, and camera trapping. The home range areas of the study groups and most habitat parameters in the study sites were significantly different between habitat types (Kruskal-Wallis, $p \leq 0.05$). The main activity of langurs was positioning (46.2%) with sitting (70.8%) as main positioning type with significant differences of activities between all study groups (Kruskall-Wallis, $p \leq 0.05$) (N= 21,050). Langurs mainly fed on young leaves (60.3%) and consumed 135 identified species from 49 families of wild and cultivated plants (N= 5,039). To mitigate the impact of a busy asphalt road on wild langurs in Teluk Bahang, Penang, I constructed the first artificial road canopy bridge in Malaysia in February 2019 to assist arboreal wildlife to move more safely between habitat fragments. In total, 2,128 animal crossings comprising three mammal species were recorded between March 2019 and May 2021. Plantain squirrels crossed the bridge most frequently with 2,075 crossings, long-tailed macaques crossed 32 times, and dusky langurs 21 times indicating a significant difference in bridge use according to species (Chi-Square,

$p \leq 0.001$). This study has been expanded into a citizen science-driven conservation project since 2016, entitled Langur Project Penang (LPP), to promote the coexistence between humans and wildlife in our shared habitat through field research, conservation actions and environmental education. This thesis provides the baseline data to develop a multilingual working document as "Dusky Langur Conservation Plan ‘’ to be presented to key stakeholders that references important conservation actions and the rationales outlined in this thesis to protect this endangered species in Malaysia and beyond.

CHAPTER ONE

INTRODUCTION

Malaysia is home to 26 species of primates (Roos et al., 2014; Ang et al., 2020). The dusky langurs (*Trachypithecus obscurus)* are a species of leaf-eating primates that can be found in Myanmar, Thailand, and Peninsular Malaysia (Boonratana et al., 2020). Dusky langurs range in forested areas and human-influenced sites around Penang (Karimullah & Bakhsh, 2014), where they search for food and shelter. Dusky langurs are currently classified as 'Endangered' under the IUCN Red List, while more research is needed in terms of life history, ecology, population size and distribution (IUCN, 2019). Though the species can be easily spotted in several sites in Penang, for example, in Penang Botanical Gardens, Penang Hill, Bukit Mertajam and more, not many Penang residents know about their existence due to their predominantly arboreal lifestyle and a general lack of environmental awareness in the community.

Figure 1.1 An adult and an infant dusky langur in Penang, Malaysia (photo by Yap Jo Leen)

Deforestation and urbanization can increase environmental pollution and affect sustainable development in long run (Arshad et al., 2020), which has led to major losses of wildlife's natural habitat. This also applies to the second smallest state in Malaysia, Penang. The 1.77 million human population in the 1,032 km^2 Penang state has an average annual population growth rate of 1.3% (Department of Statistics Malaysia, 2010) and the population of Penang Island itself is projected to rise exponentially over the next 15 years (Chee et al., 2017). Penang Island has the third-highest regional population density in Malaysia, and since the 1960s there were increases in the extent of urbanized areas that led to losses of natural habitats on the island (Chee et al., 2017; Elmahdy et al., 2016). The growth of urban areas is irreversible and can potentially lead to the reduction of local wildlife populations or local extinction (Hong & Chan, 2010). The island's hills are important water catchment areas as they are covered with dense forest habitat, and the central hill region in Penang Island is one of the few remaining forest areas left in the state that acts as a green lung for the island (Chan, 1998). In mainland Penang, there are important water catchment in Bukit Mertajam and Bukit Seraya as well, where pristine water resources like clean stream and waterfall can be easily found in these hills in mainland, as well as wildlife like dusky langurs (pers. obs). Thus, it is essential to understand how wildlife in general, and especially highly arboreal primates with a specialized leaf-eating diet, can cope in Penang's anthropogenic environments to facilitate feasible conservation actions, if needed.

Primates play a vital role in the ecosystem as many of these species rely heavily on fruits and primates constitute a large component of frugivore biomass in tropical forests (Chapman, 1995). Although dusky langurs are mainly folivorous but *Trachypithecus* spp. also consume a fair amount of fruits, depending on fruiting season

and availability (Solanki et al., 2008a). The seeds in fruits consumed by primates may be chewed and digested, then defecated or separated from the flesh while feeding and spat out (Corlett & Lucas, 1990). This process facilitates the growth of new seedlings on the forest floor, hence assists in forest regeneration. Large-seeded plant species are more threatened than others as they depend on a restricted number of larger seed dispersers (Chapman et al., 2010). In Penang, there are only four species of non-human primates, *i.e.*, long-tailed macaques (*Macaca fascicularis*), Sunda slow lorises (*Nycticebus coucang*), silver langurs (*T. selangoensis*) and the dusky langurs (*T. obscurus*). While on the Penang Island, there are three species (long-tailed macaques, Sunda slow lorises and the dusky langurs). Therefore, the disappearance of potential seed dispersers could bring large-seeded plant species to extinction because of the low probability of finding seed dispersers with a similar role (Albert et al., 2013). The conservation of primates is thus critical to maintain effective seed dispersal of large-seeded or hard-husked fruit species (Chapman & Russo, 2007) and overall forest health.

Not many studies of ecology and behaviour on this species are available from Malaysia or other countries. Some baseline studies conducted on dusky langurs were conducted in Penang, such as a study on the species' activity pattern in Penang Botanical Gardens (Md-Zain & Ch'ng, 2011), population structure in Penang Botanical Gardens (Karim et al., 2014), the feeding behaviour on *Acacia auriculiformis* in Bukit Mutiara (Baker & Graeme, 2017), and the social behaviours in Bukit Juru (Karimullah & Bakhsh, 2014). There are also studies about dusky langurs in other states of Peninsula Malaysia, such as the discovery of a leucistic adult dusky langurs (Najmuddin et al., 2020), monitoring of two non-native male dusky langur individuals in Singapore (Ang et al., 2020), the feeding ecology of dusky langurs in a mixed landscape of urban and

agro-forested areas (Ruslin et al., 2019), and the preliminary study on the activity budget of dusky langurs in Batu Pahat, Johor (Siti-Kauthar et al., 2019).

This long-term study, started in year 2016, later named as Langur Project Penang (LPP) and further developed into a citizen science and community outreach project is still (as of 2022) being carried out and its progress is documented in this thesis. One of LPP's missions besides research on dusky langurs in Penang is to mitigate threats to the species, especially by habitat degradation.

One of the methods to mitigate the impact of habitat loss and fragmentation to arboreal wildlife is to provide natural arboreal routes via canopy bridges to preserve canopy connectivity (Gregory et al.,2017). Canopy bridges are important to keep connectivity between fragments and they can mitigate the impact of cable wires which often lead to electrocution. The exact impact and importance of these movements for gene flow and population persistence is yet to be evaluated (Teixeira et al.,2013). During the study period of this research, six fatal incidents of dusky langurs related to road crossing have been recorded in Teluk Bahang, Penang (Yap et al., 2019), and to facilitate safer road crossings, an urban canopy bridge was installed at the study site to assist these primates and other arboreal wildlife to cross the road more safely.

It is not yet understood to what extent langurs that live in the remaining forests of this island can cope with human development and resulting habitat decimation and fragmentation. Dusky langurs in Penang are still found in the primary lowland and hill forests and inhabit disturbed habitats, such as secondary forests and human settlements. Habitat fragmentation may put pressure on their population, which is shown through the increased frequencies of human-primate encounters in Penang (pers. obs.). Penang residents have been complaining about nuisance behaviour of dusky langurs in Penang

(e.g., Md-Zain & Ch'ng, 2011; Karimullah & Bakhsh, 2014; Department of Wildlife and National Parks – personal communication) or the langurs enter gardens and orchards, and road kills are common on the island (pers. obs.).

To assess whether there is a need for active conservation management of this species on the island and to identify targeted management actions, I need to better understand how the langurs behave in anthropogenic environments. This behavioural baseline study aimed at better comprehending the ecology of dusky langurs on Penang Island by assessing the activities, habitat use, diet composition, and habitat structure of several habituated groups in different study sites in Penang state. I aimed to further understand how the primates behave and cope in a fragmented landscape, and is canopy bridge a feasible strategy to mitigate the impact of habitat fragmentation?

The objectives of this study were:

1. To determine the habitat use and habitat quality of dusky langur groups in three study sites in Penang.
2. To measure the activity budget, locomotion, and positioning behaviour of dusky langur groups in three study sites in Penang.
3. To examine the diet composition of dusky langur groups in three study sites in Penang.
4. To establish the first road canopy bridge in Malaysia to assist the dusky langurs and other arboreal wildlife to cross roads more safely.
5. To produce a 'Langur Conservation Plan' blueprint for the proposal to stakeholders in Penang, Malaysia.

The study sites comprised secondary forest, two public nature eco-tourism parks, a recreation forest, and an open-canopy beach site divided from the forest and

one of the parks by an asphalt road. As the habitat types and their respective vegetation were substantially different from one another, I prepared several hypotheses to be evaluated and determined for this study:

1. The forest stratum use by each dusky langur study group is significant different from each other.
2. The various parameters of the habitat structure are significantly different between the three study sites and different habitat types.
3. It was expected that the activity budgets, positioning, and locomotion behaviour, of the four dusky langur study groups are significant different from each other.
4. The behaviours of the focal study group's individuals of sex-age classes are significantly different.
5. The dusky langurs consume a fair number of flowers, fruits, and other food plant parts, in addition to leaves.
6. The diet of each dusky langur study group is significant different from each other, due to food plant choices and habitat types.
7. Road canopy bridge can be successful conservation management tool to assist dusky langurs and other arboreal wildlife to crossroad safely.

Understanding ecological factors that influence behaviours is especially crucial in fragmented and human-impacted landscapes where seasonal food scarcity may also lead to road crossings or foraging in parks and orchards, which may result in road accidents and unwanted human-primate interactions. As this research is the first long-term study on the ecology of wild, habituated dusky langurs its results are essential to understand the ecological flexibility of this species to design applicable conservation scenarios (Estrada & Coates-Estrada, 1996). As wildlife conservation can

become a significant contributor to the socio-economic development of Penang (Kaffashi et al., 2015), data-driven communication with the public and government stakeholders is vital to create awareness and influence local decision-makers (Chivers, 2013). It is vital to continue long-term monitoring on various aspects of ecology and behaviour of dusky langurs and their habitat to gain better understanding of the relationship of these primates with the anthropogenic environment alongside their natural rainforest habitat.

This knowledge can be used to effectively work towards a "Langur Conservation Plan", which considers the primate ecology, anthropogenic influences, and the use of scientific date and ecotourism to create awareness for primate conservation and environmental education in Malaysia.

CHAPTER TWO

LITERATURE REVIEW

2.1 Colobines

2.1.1 General background of Asian Colobines

Colobines (subfamily Colobinae) are folivorous primates that can be categorized as old-world monkeys (family Cercopithecidae). Colobines have a sacculated stomach, which ferments foods, allowing better access to nutrients and thus they have relatively low food competition both within and between groups (Kirkpatrick, 2016). Asian colobines are split into the odd-nosed monkeys (genera Pygathrix, Rhinopithecus, Nasalis, and Simias) and langurs (genera *Presbytis*, *Trachypithecus*, and *Semnopithecus*) (Osterholz et. al., 2008).

Only a few Asian colobine species have been used for morphological or behavioural analyses of their life histories (Borries et al., 2011). Some of the West Malaysian species have been the subject of detailed studies about their social behaviour (McClure, 1964), ecology (Southwick & Cadigan, 1972) and genetics (Zhang & Ryder, 1998). Osterholz et al. (2008) assessed the phylogenetic position of the genera *Semnopithecus* and *Trachypithecus* through mitochondrial DNA data analysis. The post-conflict behaviour of captive T. obscurus was studied by Arnold & Barton (2001). In the wild, an interesting interspecific interaction was observed, namely that *T. obscurus* and Siamangs were seen playing together in the dipterocarp forest near Kuala Lumpur (McClure, 1964).

More studies were conducted on the ecology of this species. It was found that food availability and predation risk were the major factors influencing habitat use in langurs (Zhou et al., 2013). The habitat use of *Trachypithecus* spp. also depends on the tolerance of humans with whom they coexist. Moore et al. (2010) showed that groups of *T. vetulus* at urban areas had home ranges of 3.06 and 2.86 ha in Talangama Wetlands, Sri Lanka. Meanwhile, the White-headed langurs (*T. leucocephalus*) in Fusui Precious Animal Reserve, Guangxi, China had home range sizes ranging from 28 to 48 ha, whereby group size and food plant species diversity increased significantly with habitat quality (Li & Rogers, 2005). The seasonal proportion of food items in the langurs' diet was determined by food plant availability, phenological stages of the plants and the types of habitats in Arunachal Pradesh, India (Solanki et al., 2008b). Yang et al. (2007) indicated that natural habitats provided adult Francois' langurs (*T. francoisi francoisi*) in Mayanghe National Nature Reserve of Guizhou Province, China with different main food resources during different seasons, which changed the foraging time budget of this species, and led to changes in the time budget of other behaviours. There are several field studies on gray langurs (*P. antellus*) in Sri Lanka that address the langurs' activity pattern change during different seasons that showed the amount of time spent in each behavioural activity varies with the season (Wolfheim, 1979).

Not only seasons influence the behaviour of langurs, but also habitat disturbances. Langurs and other arboreal primates have a fundamental relationship with the upper dipterocarp rainforest as they exploit the most abundant food-leaves and occur there at the highest biomasses (Chivers, 1989). In addition, seed dispersal by tropical frugivores plays a critical role in the maintenance and regeneration of tropical forests (Poulsen et al., 2002) as studies showed that even though colobines are

largely folivorous, fruits and other items were actively sought out when available, depending on seasonal variation (Rahman et al., 2015).

The disturbance of natural forests is causing populations of various primate species to decline. This consequently alters the ecological balance of the forest communities in Malaysia (Zakaria & Topani, 1999). Despite the implementation of awareness programmes and vigorous campaigns on primate conservation, many populations have become increasingly fragmented and threatened with extinction (Chivers, 2013). Intact forests are more valuable economically in the long-term if left intact rather than harvested for the sale of timber or devastated by mining for coal and gold (Chivers, 2013). Previous studies found that many arboreal primates including silver langurs (*Trachypithecus cristatus*) (Kool, 1993) and banded langurs (*Presbytis femoralis*) (Ang et al., 2010) depend on the higher canopy of the rainforest for activities and food. In Malaysia's tropical rainforests, these arboreal primates tend to use regular highways through the canopy when travelling during their daily foraging tours (McClure, 1964). There are several recent studies focusing on the genus *Trachypithecus* and *Presbytis*. Leucistic *T. obscurus* and first discovery of two adult male *P.femoralis* were observed in Malaysia and the individuals showed no indication of albinism and no distinct behaviour among individuals within the group as per the researchers' observation (Najmuddin et al., 2020). The three subspecies of *Presbytis femoralis* were resurrected from their current subspecific status, where *P. femoralis*, *P. percura* and *P. robinsoni* are now separate species (Agar, 2019), which this add *P. robinsoni* as the 26th species of primates in Malaysia, and the fifth langur species in Peninsular Malaysia.

2.1.2 The Dusky Langur *(Trachypithecus obscurus)*

Trachypithecus obscurus ranges from Burma, Thailand to Peninsular Malaysia, including small islands, and is considered one of the most common primate species in Peninsular Malaysia (Roos et al., 2014). It consists of seven subspecies (Roos et al., 2014), i.e. *T. o. obscurus, T. o. flavicauda, T. o. halonifer, T. o. carbo, T. o. styx, T. o. seimundi, T. o. sanctorum*, with five subspecies distributed in Peninsular Malaysia. The recent research showed that the categorization of *T. obscurus* populations in Peninsular Malaysia revealed that the north-eastern and southern populations are different, and that the subspecies may not support classification based on morphology (Aifat et al., 2020).

It is frequently called by its common names, such as dusky langur or the local Malay name ’lutung’ or ‘lotong’. These langurs are also called spectacled langurs due to the characteristic white circled patch around their eyes, which look like a pair of spectacles. Their head, body and tail are covered with dark grey (often blackish) hair while the abdomen is lighter in colour. Infants have yellow fur, but the colour will gradually turn slate greyish black by the end of the fourth month or early fifth month (Furuya, 1961). *Trachypithecus obscurus* practices a multilevel social system (harem) and social units can contain one or two adult males and multiple females and their subadult offspring (Grueter et al., 2012). The group size ranges from 14 to 17 individuals, and frequently forms smaller groups (Rowe, 2016).

Dusky langurs are arboreal and occupy primarily the upper strata of the forests of South-East Asia, meaning that they spend most of their time in the trees, above the ground and around the canopy layer of the rainforest. The variety of positional behaviours of langurs are unequalled to other mammals; thus, it is interesting to study

this species (Eakins, 2010). Dusky langurs are adapted to a diet primarily consisting of leaves, considered a folivorous primate (Ruslin et al., 2019). However, the species also feed on figs, flowers, and fruits, which indicates a varied diet with many species of plants (McClure, 1964). Having a three-chambered stomach, longer digestive tract and slow metabolisms, these primates are well adapted to the folivorous diet. Dusky langurs prefer large, tall Ficus and rain trees as their sleeping sites, and prefer the middle and canopy strata of the forest (Rowe, 2016).

This species is understudied and being considered a nuisance in certain local communities. There is still no population estimation being done on the distribution of dusky langurs, as well as the life history, seed dispersal and predation role of the species. Hence, more research and conservation efforts need to be done to gather baseline data of dusky langurs, so that I can understand the impact of anthropogenic environment(s) on the primate species.

2.1.3 The Dusky Langur *(Trachypithecus obscurus)* In Penang

There are two sub-species of dusky langurs in Penang, *T. o. halonifer* (island) and *T. o. obscurus* (mainland). Past studies of dusky langurs in Penang assessed their activity patterns, social behaviours, and population structure in protected and non-protected areas around Penang, including Botanical Gardens Penang and Bukit Juru, Penang. Behavioural studies on Dusky langurs are rare due to their shyness, great caution, and the ability to disperse when followed by observers (Chivers, 2013).

A study on the activity budget of a group was conducted by Md-Zain & Ch'ng (2011) in Botanical Gardens Penang (PBG). The results showed that the groups spent most of their time on feeding, which contradicted previous studies showing that many

colobines spend most of their time on resting rather than feeding (Zhou et al., 2017; Yang et al., 2017). However, there is a lack of information on the diet and feeding behaviour especially on the types of food plants the langurs fed on, and the canopy height during foraging on different trees, as well as their preferred stratum for other activities.

A study by Karimullah & Bakhsh (2014) on the feeding behaviour and nuisance activities of dusky langurs in Bukit Juru, Penang also reported that the feeding behaviour was higher than other activities. It concluded that human disturbances encouraged the langurs to enter the villages for foraging (Karimullah & Bakhsh, 2014). Social behaviours of dusky langurs were compared with previous research. Here, vocalization in dusky langurs had a positive correlation with playing, nuisance activities and sexual behaviours.

The population structure of langurs in protected and non-protected areas of Peninsular Malaysia was assessed in selected areas in Northern Peninsular Malaysia. Dusky langurs were only observed in Botanical Gardens Penang, where a group of 18 langurs were observed for their activity patterns (Md-Zain & Ch'ng, 2011), Taiping Zoo Perak, where 24 free ranging individuals were counted (Karimullah & Anuar, 2012), and Bukit Juru Penang with observations on two groups (16 and 13 individuals, respectively) (Karimullah & Bakhsh, 2014), however no conclusive information about their population density was given in any of these reports.

The first long-term study of dusky langurs on the ecology and behaviour study on a wild, habituated group of dusky langurs was conducted from 2016 to 2019 (Yap et al., 2019). The home range of the study group was 12.9 hectares, including secondary forest, a nature park and beach. The langurs spent significantly more time

resting and foraging in the secondary forest and consumed 56 identified plant species from 32 families of wild and cultivated plants. The group had to cross a busy motorway to reach the beach, hence multiple road crossing behaviour.

The dusky langurs are seemingly adapted well to disturbed habitats. However, more comparative studies of langurs in Penang are needed to predict the impact of habitat degradation on the population of the species and to develop feasible conservation plans (Yap et al., 2019).

2.2 Threats and Challenges for Dusky Langurs and All Primates

2.2.1 Habitat Fragmentation

Conversion, degradation, and fragmentation of natural habitats threaten the integrity of forest ecosystems worldwide (Curran et al., 2004). Deforestation not only causes habitat loss but also habitat fragmentation, i.e. the breaking apart of formerly contiguous habitat (Fahrig, 2003). Arboreal mammals show differential sensitivity to landscape processes where a species may be able to persist in a sub-divided landscape if these are connected (Mortelliti et al., 2011). Forest-dwelling mammals such as primates could be particularly vulnerable to habitat fragmentation (Arroyo-Rodríguez et al., 2013), resulting in smaller and more isolated, fragmented populations (Fahrig et al., 2019). Inbreeding, lack of gene flow, and genetic drift are the main concerns arising from habitat fragmentation (Marsh, 2003) and these dynamics will often significantly affect birth weight, survival, reproduction and resistance to diseases, predation risk, and environmental stress. Habitat fragmentation may compound the threat of climate change, where the building of roads prevents the migration of species

to adapt to a warming climate, and the fragmented habitat serves additional negative consequences for biodiversity (Kroner, 2016).

To document the ecology and behaviour of primates and how species response to habitat fragmentation is important, as such information is necessary to understand the ecological flexibility of the species involved, and its relevant to design long-term conservation actions (Estrada & Coates-Estrada, 1996). Various studies were carried out to investigate the impact of habitat fragmentation on primates. The immediate effect of fragment isolation is the loss of large frugivores, such as black spider monkeys (*Ateles paniscus*), bearded sakis (*Chiropotes* sp), and brown capuchins (*Cebus apella*) (Gilbert, 2003). Frugivorous diet may force certain primate species to live in fragments as the fruit is patchily distributed, both spatially and temporally (Bicca-Marques, 2003). Mekonnen et al., (2016) suggested that Bale monkeys (*Chlorocebus djamdjamensis*) can cope with a certain threshold of habitat destruction but the species in fragments remain unclear if there are negative fitness consequences on the species. Bicca-Marques (2003) found that black-and-gold howler monkeys (*Alouatta caraya*) living in small and degraded fragments showed a high diversity and prevalence of parasites. Goldberg et al. (2008) provide evidence that forest fragmentation increases transmission as genetic similarity between human/ livestock and primate bacteria increased as anthropogenic disturbance within forest fragments increased from moderate to high. In Mexico, small areas and greater isolation from other forest fragments may result in extensive changes in ecological conditions of the isolated habitat, which may result in a high mortality of trees, hence the disappearance of arboreal primates (Bicca-Marques, 2003).

The Penang state, especially Penang Island, consists of hills and has been undergoing rapid development in the recent decades. Industrialisation efforts and economy development have been intensified, leading to greater urbanisation, and creating more pressures on the island (Pradhan et al., 2012). The efforts to industrialize and develop the island led to greater pressure on wildlife (Chan, 1998). Such developments have brought about high environmental costs in terms of loss of natural habitats (Chan, 2009). During the period of 1999 to 2007, the forest area of Penang Island deceased by 77.69% due to urbanisation impact (Tan et al., 2010). Several areas in the hills of Tanjung Bungah and Paya Terubung has been identified as high risk for development (Ahmad et al., 2010), and yet paired roads are being planned and built for these two sensitive areas. Anthropogenic activities have proven to alter global climate as human activities, rather than natural forces, are the major causes of global environmental change (Ackermann & Bishop, 2010). An overview of hazards to the environment associated with hill development in Penang was carried out by Basith et al. (2010).

Langurs that live in the coastal forests from Tanjung Tokong to Teluk Bahang (Penang Island) face high risks by habitat fragmentation, and due to the asphalt roads dividing the inland forest and coastal area. Although linear infrastructure like roads is important for our society to connect people and places, roads also impose significant negative effects on adjacent habitats, wildlife populations, communities, and ecosystems (van der Ree et al., 2011). The increasing human population in Penang facilitates more development of linear infrastructure and the number of moving vehicles is increasing. Roads expose animals to the hazards of traffic and many animals are killed on roads daily (Weston, 2003). Roads are a source of mortality for

wildlife, especially mammal and bird populations (Benítez-López et al., 2010) that are regularly brought into contact with busy roads. This also impacts the conservation status of affected wildlife species (Bennett, 1991). Unfortunately, despite of all the road kills that are happening daily, it is a huge challenge to convince the local stakeholders to make the road more wildlife friendly. The impact of traffic on wildlife is still not a major issue that would attract the attention of local authorities (Sharma, 2013).

The vast improvement to infrastructure today has greatly facilitates the wildlife trade in Asia, made forests more accessible and allowing the possibility of trade for wildlife products (Lee et al., 2020). In Malaysia, primates are being widely promoted as exotic pets on Facebook and Instagram, where protected species like orangutan, dusky langurs, pig-tailed macaques and slow lorises are sold openly on the internet. The growth of the internet provide accessibility for exotic pet trade with virtual internet marketplace (Siriwat and Nijman, 2018), and the trade brings wildlife inti proximity with humans and domestic animals, which provides an interface for pathogen transmission (Greatorex et al., 2016). Therefore it is crucial to combat illegal wildlife trade collectively through 1) increased health awareness in community and public; 2) increased efforts in surveillance and reporting of wildlife disease outbreaks; ad 3) increased research to alleviate critical knowledge gap (Gómez and Aguirre, 2008).

Deforestation and environmental degradation cause the primate hosts to move closer to the forest edges getting in closer contact with humans (Vythilingam, 2010), hence increasing chances of zoonoses. Cost-effective prevention and control of zoonoses in humans is needed, including risk communication and holistic approach that acknowledges the importance of wildlife as a reservoir (Kruse et al., 2004).

Human-altered landscape has caused increased interface between humans and monkeys for space and resources in urban and rural areas. This interface exposes humans to zoonotic pathogens found in monkeys, especially long-tailed macaques (*Macaca fascicularis*) such as CHIKV, dengue virus, and *Plasmodium knowlesi* (Sam et al., 2015). Today, zoonoses with a wildlife reservoir constitute a major public health problem, affecting all continents (Kruse, Kirkemo, & Handeland, 2004). Many zoonoses with wildlife origin are spread through insect vectors (Kruse et al., 2004). Vector-borne diseases are illness cause by pathogens, which are transmitted to humans or animals by the bites of infected vectors such as mosquitoes (Gao et al., 2019). The long-tailed macaques (*Macaca fascicularis*), pig-tailed macaques (*Macaca nemestrina*) and langurs (*Presbytis melalophos*) of Southeast Asia are the principal natural hosts for the malaria parasite *Plasmodium knowlesi* (Galinski & Barnwell, 2009; Collins, 2012), a major cause of malaria in Malaysia, particularly in the island of Borneo (White, 2008), which is transmitted by mosquito bites from monkey to monkey, monkey to human, human to human, and even from humans back to monkeys (Vythilingam et al., 2008).

Experimentally, almost all primates, including humans, are susceptible to infection. Distribution of the parasite from the monkey host to humans appear to be restricted to mosquito vectors of *Anopheles lencosphyrus* group, which is confined to Southeast Asia (Collins, 2012). It is apparent that one of the human malaria parasite *P. knowlesi* is present in most states of peninsular Malaysia, where humans can get infected with monkey malaria if both humans and monkeys share the same habitat (Vythilingam et al., 2008). Research also shows that *Macacine* herpesvirus 1 (MaHV-1; B virus), a zoonotic pathogen that is enzootic among macaque species in Asia, and the virus can be transmitted to humans handling the macaques without any proper

protection (PPE) (Lee et al., 2015). Though no human deaths have been reported from contracting McHV-1 from free-ranging macaques, this pathogen should be considered a low-incidence, high-consequence risk, and proper public health measures should be taken (Wisely et al, 2018). For the recent outbreak of SARS-CoV-2 (Covid-19), the International Union for Conservation of Nature (IUCN) released a statement emphasizing the risk that Covid-19 poses for great apes and stressing the importance of risk mitigation where the virus considered a potential threat to all wild primates, as they are susceptible to human pathogens (Lappan et al., 2020).

2.2.2 Human-Primate Interface

One of the greatest challenges faced by primate conservation is the increasing level of interaction between humans and non-human primates, and the resulting conflicts that emerge (Hockings, 2016). Human-wildlife interfaces have existed for centuries, mainly due to increase in human population, expansion of human activities hence the increase of resource use by humans (Zaffar Rais et al., 2015). Disappearance of forests and primate food sources inevitably leads to an increased competition between humans and wild animals for space and resources, creating conflicts such as crop raiding, predation on domestic livestock, or aggression to humans by wild animals (Rocha & Fortes, 2015). Most people in tropical countries perceive primates as pest species due to their adaptive behaviour, especially to agricultural landscapes (Else, 1991).

Many primates become habituated due to feeding and positive interactions with people, or they are regarded as pests to agriculture. Almost all non-human primate families have agricultural conflicts with local farmers about food plants (Lee

and Priston, 2005) and the crop-raiding, conservation and sustainable community projects all point to increasing conflict for space and food as a critical component (Fuentes, 2012). In Peninsular Malaysia, the long-tailed macaques (*Macaca facicularis*) have become a major problem and the habituation of the macaques to humans have led to urban macaques that live around neighbourhoods (Hambali et al., 2012). Members of the genera *Macaca, Papio* and *Cercopithecus* are amongst the most frequently cited primate pest species with their highly social nature, intelligence, and behaviour flexibility (Hill, 2005).

Humans who feed monkeys, such as the long-tailed macaques, alter their behaviours and condition them to be dependent on humans for food, which encourages them to move towards the forest fringe to forage (Yeo & Neo, 2010). Monkeys that live in anthropogenic environments experience tend to have decreased interbirth intervals, lower infant mortality, as well as increased group sizes and population densities (Marty et al., 2020) Primate populations that inhabit human-influenced landscapes have access to anthropogenic food, where for some species, human foods can become an integral part of their diet (Arroyo-Rodríguez et al., 2013). Artificial feeding influences many aspects of behaviour and ecology, as feeding not only determines their diet, home range and primary habitat, but it also influences virtually all patterns of spatial distribution and social behaviour (Southwick et al., 1976).

Human-primate conflicts also happen in Penang, where residents complain that monkeys are often found too close to human settlements and in orchards and have learned to associate humans with food (Karimullah & Anuar, 2012). Human-primate conflicts are a threat to primate species in Penang and have led to people misunderstanding these animals, and difficulties in accepting and appreciating them. In various parts of Penang, long-tailed macaques are being fed frequently by the public.

In Penang National Park, tourists can be observed feeding the macaques as one of the highlights of the park, and locals and tourists can be spotted feeding the macaques in Penang Botanical Gardens and Youth Park (pers. obs.) There is a lack of awareness among Malaysians on the consequences of feeding monkeys, thus more enforcement and educational campaigns need to be conducted to raise awareness about why feeding monkeys is harmful and prohibited to mitigate further human-monkey conflict.

2.3 Primate Conservation

2.3.1 Means for Primate Conservation

Primates are our closest living biological relatives, offering insights into human evolution, biology, behaviour, and play important roles in livelihoods, cultures, and religions of many societies (Estrada et al., 2017). The primate fauna of Malaysia is diverse and valuable. Primates play an important role in forest regeneration and habitat fragmentation impacts the livelihood of both, wildlife and humans negatively (Boyle, 2008). With the on-going human population growth, there is a need to a better management for urban wildlife and natural resources (Morzillo et al., 2014). Therefore, a proper detailed study on these aspects will help to reduce the conflict and improve the conservation status of primate species, also in Penang. Finding solutions for conservation can be challenging, as identifying and documenting risks takes time, money, effort, and the appropriate scientific methods (Wallis & Lonsdorf, 2010). Primatologists have the responsibility to inform the public and encourage government to conserve these species by implementing critical conservation measures (Pebsworth & LaFleur, 2014).

Education plays an important role in conveying the message about the importance of primate conservation to the public. This also includes addressing forest health, human welfare, socio-economy, and others, as conservation education goals include influencing people's conservation awareness, attitudes, and behaviours toward primate conservation issues (Jacobson, 2010). However, only a few people understand and appreciate the above, while urban development is increasing throughout the nation. Thus, educational campaigns and workshops need to be conducted with research to target a wide public audience to broaden awareness. Ethical consideration requires that local communities have greater control over natural resources, and that conservation programmes contribute to these people's livelihood and food security (Hill, 2002).

Social media has emerged as a popular channel for providing new sources of information and rapid communication (Yin et al., 2015). This channel has been playing an important and useful role in providing information and to raise attention towards environmental issues, which is essential for scientific research nowadays to gain broad coverage and to raise the public's interest. Social media platforms like Facebook, Twitter and Instagram enable socializing and networking online through words, pictures, and videos to initiate two-way discussions where people can share and learn new information instantly (Reuben, 2008). Utilizing social media well to initiate conversations and dialogues is indeed one of the many methods to improve primate conservation efforts.

In a nut shell, the goals of primate conservation are to 1) develop strategies to reduce conflicts between human and non-human primates; 2) promote education programmes to highlight the significance of primates; 3) initiate local community involvement through dialogue and offering positive benefits (Lee and Priston, 2005).

Effective conservation education should be fact-based and science-driven and is essential for improving people's knowledge, promoting pro-conservation behaviours, and involving more people in primate conservation and sustainable development (Jacobson, 2010). In this sub-chapter, I had reviewed two conservation methods that I use for my study: canopy bridge and community conservation efforts.

2.3.2 Canopy Bridges

Habitat loss represents a significant threat to biodiversity and forest-dwelling mammals such as primates could be particularly vulnerable to habitat fragmentation (Arroyo-Rodríguez et al., 2013). Roads can be found everywhere and is the most extensive human footprint on the planet. The interface between roads and wildlife has emerged as a global issue of economic, human safety and conservation significance (S. Lee & Pradhan, 2006). Roads create access for human settlements, logging, hunting, and mining (Balbuena et al., 2019), hence they create small and isolated subpopulations of wildlife, rising extinction probabilities due to demographic, environmental, and genetic factors (Teixeira et al., 2013). Today, road kills and wildlife electrocutions have been documented worldwide with considerable impact towards mortality of animals worldwide (Teixeira et al., 2013). The environmental impacts of roads on wildlife population are numerous, where home ranges are split by roads and individual wildlife suffers mortality and death due to collisions with vehicles (Sharma & Ramesh, 2013). Mitigation measurements in biodiversity hot spots to reduce impact of habitat fragmentation on the movement of wildlife are needed on a large scale.

Primate mortality due to road kills has been recorded worldwide. Monkeys were injured or killed by vehicles on the Diani Beach Road, Kenya, and cause a 3% loss in local primate population annually between 1999 and 2012 (Donaldson & Cunneyworth, 2015). In Peninsular Malaysia, there were 368 roadkill cases in Peninsular Malaysia, with 223 cases of it involved mammals (PERHILITAN, 2018). The latter figure is most likely underestimated as most residents are not aware of the roadkill incidents involving other small treetop or ground dwelling species. Langur Project Penang (LPP) recorded eight fatal accident of dusky langurs related to road crossing and one electrocution case of Sunda slow loris (pers. obs.). In Bangladesh, a total of 27 monkeys of five primate species were recorded of road accidents and electrocution between 2015 to 2017 (Al-Razi et al., 2019). In United States, roadkill has surpassed hunting for vertebrate mortality, where roadkill is the primary factor for mortality of Florida's large and endangered vertebrates, like panther and black bear (Coffin, 2007). Meanwhile in Tasmania, roadkill is perceived as a greater impact compared to other Australian states, where brushtail possums and Tasmanian padmelons are the most common species identified throughout the roadkill survey (Hobday & Minstrell, 2008). The populations of slower moving animals and those animals who cross regularly suffer from the negative effects like vehicle collisions and increased contact with humans and human-land-use activities (Coffin, 2007).

Wildlife corridors such as viaducts or green bridges have been constructed over of bellow roads and has been documented in different places around the world (Teixeira et al., 2013). Artificial canopy bridges have been implemented more often compared to natural canopy bridges, to restore lost forest connectivity (Balbuena et al., 2019). The first canopy bridge was installed in 1963 in the United States, and the idea has been disseminated in countries such as Australia, Belize, and Brazil (Teixeira