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"Ah Lai's Crossing" – Malaysia's first artificial road canopy bridge to facilitate safer arboreal wildlife crossings

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Abstract – Roads negatively affect wildlife populations globally, causing habitat fragmentation that can facilitate mortality by access to forest for poaching and wildlife collisions with vehicles. Primate habitats are vulnerable to fragmentation exposing them to anthropogenic threats. Endangered dusky langurs (*Trachypithecus obscurus*) in Malaysia are often found in urban areas and have been frequent victims of vehicle collisions. To mitigate the hazardous impact of a busy asphalt road on wild dusky langurs in Teluk Bahang, Penang, we built the first artificial road canopy bridge in Malaysia in February 2019 to assist arboreal wildlife to move between habitat fragments more safely. Four days after the bridge construction, the first long-tailed macaque (*Macaca fascicularis*) was recorded via a camera trap crossing the bridge, and plantain squirrels (*Callosciurus notatus*) and dusky langurs first crossed one and eight months later, respectively. The bridge was upgraded from a single-firehose rope to a double-rope in August 2020 to assess the effectiveness of the two designs. In total, 2128 animal crossings comprising three mammal species were recorded between March 2019 and May 2021. Plantain squirrels crossed the bridge most frequently with 2075 crossings, long-tailed macaques crossed 32 times, and dusky langurs 21 times. There was a significant difference in bridge use according to species between the two designs (Chi-Square, $p < 0.001$). Since the construction of the bridge, the rate of previously frequently reported primate roadkills near the bridge location has dropped to zero. This successful pilot project has spurred the efforts to implement more canopy bridges country-wide to support primate conservation efforts and better protect arboreal wildlife from the negative impacts of linear infrastructure.

Keywords – canopy bridge, dusky langur, Malaysia, Penang, *Trachypithecus obscurus*.

Introduction

Transport corridors, like railways, roads and highways, ease transport of goods and people, and make commuting from one place to another comfortable for the public. However, transport corridors threaten natural ecosystems worldwide (Balbuena et al., 2019) negatively affecting natural habitats, wildlife populations and communities (van der Ree et al., 2011). Direct and indirect effects of roads on ecosystems have been described for over 60 years, including the alteration of habitat, interruption of ecological flows, increased erosion and pollution (Balkenhol and Waits, 2009), and disruption of gene flow and metapopulation dynamics due to barrier effects and habitat fragmentation (Lee and Pradhan, 2006). Roads influence wildlife in various ways, including the alteration of their movement patterns, increase of negative edge effects, and facilitation of easier access to remote wildlife habitats, leading to poaching and negative interfaces with humans (Switalski et al., 2004). From a biodiversity perspective, transport corridors are inevitably damaging as

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habitat quality and size are positively correlated to core ecological processes and indicators like species richness and abundance (Karlson et al., 2014).

Road ecology studies the effects of linear infrastructure on ecosystem components, processes, and structures related to engineering, land use planning, and transportation policies (Coffin, 2007). Road ecology aims to investigate the impacts of roads on individuals, populations, and communities of wildlife to avoid, minimise, and compensate for the negative impact of roads (van der Ree et al., 2011). The impact of road development on wildlife has been explored for several decades now (Clauzel et al., 2015), and road ecology has described many negative effects of roads on biodiversity but it is still to understand their evolutionary consequences (Brady and Richardson, 2017). For example, populations adapted to living in highly fragmented landscapes may lose their viability when habitat availability becomes too fragmented (Hanski, 2015), leading to local extinctions. A more immediate and direct anthropogenic impact for terrestrial wildlife is animal-vehicle collisions (Lee and Pradhan, 2006), risking animal and human lives. Especially populations of slow-moving animals and those that cross roads more regularly suffer negative effects of increased road accidents due to vehicle collisions (Coffin, 2007). In combination, road-induced habitat loss, barrier effects, mortality and landscape fragmentation can lead to extinction threats for wildlife populations (Balkenhol and Waits, 2009).

In Southeast Asia, the impacts of roads on mammals have not been well-documented. The rapid development of Malaysia has contributed to progress and economic growth (Kasmuri et al., 2020). Although roads have helped to alleviate rural poverty, they have also caused environmental damage (Clements et al., 2018). It is essential to assess where and how roads contribute to endangering wildlife before evidence-based conservation strategies can be developed to minimise the threats of roads to animals (Clements et al., 2014). A key mammal conservation strategy is to establish wildlife corridors or linkages to reduce roadkill risk and restore ecological connectivity between the fragmented habitat patches (Hedges et al., 2013). While there are wildlife-crossing overpasses and viaducts built as ecological corridors for terrestrial wildlife in the Central Forest Spine (CFS) area in Pahang, Malaysia (van der Ree et al., 2011; Brodie et al., 2016), there are no wildlife crossings for arboreal animals living high up in the trees near linear infrastructure in the country.

In Teluk Bahang, Penang, Malaysia, a coastal two-lane public asphalt road separates the forest and the coast, and wildlife frequently moves across to the coast in search of food. Although dusky langurs (*Trachypithecus obscurus halonifer*; IUCN Red List: Endangered, Boonratana et al., 2020) here appear to be reasonably tolerant to the habitat fragmentation in the short term, they should be considered as highly vulnerable, as their long-term survival depends on a restricted number of food plant species, which could be threatened by other factors (Li et al., 2009).

The dusky langurs in Teluk Bahang spend much time at the forest edge close to the asphalt road and coastal area (Yap et al., 2019). Langurs here feed on coastal plant species, and the coastal road is part of their core home range. To feed on the food plants across the road, the langurs face the risk of fatal vehicle collisions and negative interactions with humans nearby. We observed the first dusky langur roadkill at the site in August 2016 (Yap et al., 2019), where a juvenile of the study troop was hit by a moving vehicle when crossing from the coastal area to the forest. Since then, we recorded seven more roadkill incidents involving dusky langurs and an electrocution case involving a Sunda slow loris on the exposed electrical power cable above the road that is commonly used by primates to cross along a 1 km road stretch at the Teluk Bahang study site. Additionally, we observed three cases of dusky langur road accident-related injuries in the same area.

To assist the dusky langurs and other arboreal wildlife at the study site to cross the road safely, we installed an artificial canopy bridge made of firehose with a twisted liana design connecting the forested and coastal area. Besides targeting dusky langurs as the focal study species, other arboreal wildlife, including long-tailed macaques (*Macaca fascicularis fascicularis*) and plantain squirrels (*Callosciurus notatus*), are also habitat edge dwellers that can often be observed at the study site.

The objective of this road canopy bridge study was to 1) assess the canopy bridge usage of wildlife, and to 2) compare two designs of the canopy bridge in terms of crossing frequencies. This study presents the bridge construction process and wildlife crossing results collected during the initial phase of the project using a first (i.e., single twisted liana design) and second (i.e., double twisted liana) bridge prototype, and helps to determine whether this pilot project contributes to safer road crossings of arboreal wildlife at the study site and should therefore be implemented in other parts of Malaysia.

Materials and methods

Identification of wildlife crossing hotspots

This project has been conducted within the Langur Project Penang (LPP), a citizen-science working group aided by volunteer field assistants. We selected the site for the canopy bridge installation (5°27′48.82″N, 100°13′49.37″E) in Teluk Bahang, Penang after following a study group of dusky langurs for one year (Yap et al., 2019) and analysing their travel routes and frequencies of road crossing behaviours. As a result, we identified four crossing hotspots (fig. 1) but could selected only one to install the canopy bridge due to permit conditions.

Bridge materials and cost

The first bridge design was a single twisted liana made of maroon, upcycled firehoses. The firehose was contributed by the Fire and Rescue Department Malaysia (Jabatan Bomba dan Penyelamat Malaysia), who regularly donates them the local social enterprise Animal Project & Environmental Education (APE Malaysia), for animal conservation projects. The firehose type was a combination of nitrile butadiene rubber (NBR) and a woven polyester jacket (cotton). These two materials ensure properties to combat burst and exposure to the elements. In addition, firehose is flexible, lightweight, easily manageable and transportable, and designed for strength and resistance to abrasion and high temperature (Parker and Brown, 2001). Since this road canopy bridge is the first of its kind in Malaysia, the simple and light-weight single hose design acts as a testing prototype and minimises the risk of road accidents for motorists by bridge parts that could fall. The other materials used for the bridge design were a 12 m aluminium pole to anchor the bridge on one road side, wire rope clips, nuts, and bolts. The first prototype (single twisted liana) was installed on 28 February 2019 and reinforced on 19 August 2020 into the second prototype (double twisted liana) to investigate the crossing activities by the animals. The same materials were used, with an additional row of the firehose parallel to the first rope and connecting ladders.

The cost for the prototype installation was MYR 15 695 (ca. USD 3750), with the addition of MYR 9615.50 (ca. USD 2304) for the second prototype upgrade. The cost is inclusive of all bridge materials and service charges for installation, and a public liability insurance in 2019 and 2020, excluding long-term maintenance cost.

Installation process and design

The bridge location did not offer mature tall trees at the coastal side to anchor the bridge. Therefore, a solid 12 m metal pole was constructed to tie the ends of the bridge across the road, (fig. 2a; pole constructed by JKR Pulau Pinang and CSG Chin Soon Trading, THB Maintenance Sdn. Bhd.) at the coastal road side. A certified arborist selected a mature and stable *Syzygium* tree at the forest road site to anchor the bridge. The distance between the pole and the *Syzygium* tree is 12.5 m. An emergency contact signage is installed on the metal pole to indicate to the public the contact details if any bridge-related accident occurs on the site.

We installed the first canopy bridge design on 28 February 2019. It was single twisted

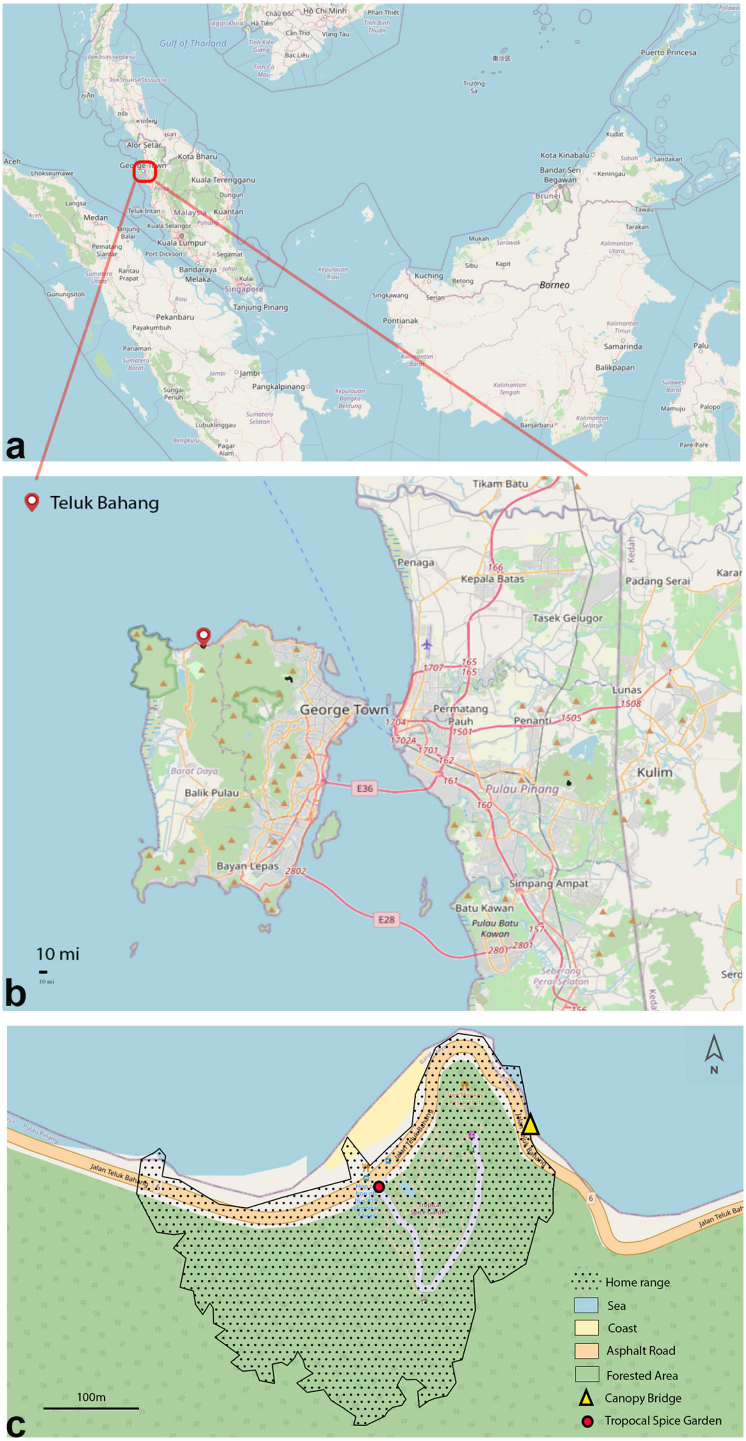

Figure 1. a) Map of Malaysia; b) Map of Penang and location of the study site, Teluk Bahang; c) Home range of the dusky langurs study troop in Teluk Bahang and location of the canopy bridge.

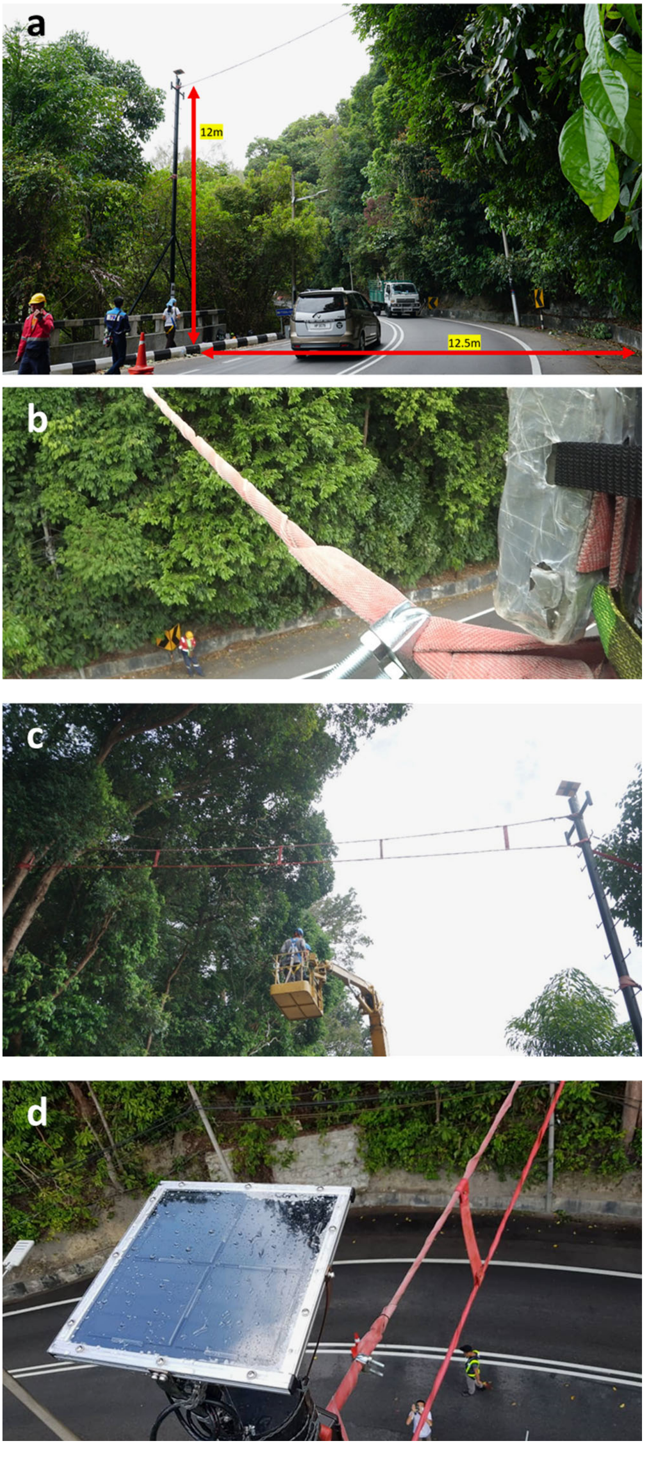

Figure 2. Road canopy bridge – Ah Lai's Crossing: a) Metal pole constructed at the coastal area to anchor the canopy bridge; b) The single-twisted liana canopy bridge (first design); c) A second firehose was used to upgrade the first prototype, the single twisted liana to a double twisted liana; d) Solar panel installed on the top of the pole to charge the batteries of camera trap.

liana where a single fire hose was twisted to mimic the texture and size of liana branches (fig. 2b). The bridge was named “Ah Lai’s Crossing” after the first alpha male of the study troop. We installed a camera trap (Bushnell Model 119537) on the top of the pole to capture the images and videos of wildlife crossing the bridge. The camera captures three images with one-second intervals, followed by 30-second video footage. Between April 2019 to May 2021, we retrieved the camera once per month for battery and memory card renewal and to ensure that the bridge and the camera were in good order.

On certain days, the camera stopped working due to technical issues. After one year and six months (on 19 August 2020), we reinforced the bridge into a second prototype, a double twisted firehose liana, to compare the activities with the single twisted liana design (fig. 2c). We then installed an additional mini solar panel on the top of the metal pole to charge the batteries of the camera trap (fig. 2d). Due to the Movement Control Order (MCO) implemented in Malaysia in March 2020 during the global outbreak of the COVID-19 pandemic, the camera trapping activity was suspended in January, February, March, and April 2020.

Data analysis

We analysed camera footage and photos twice a month from April 2019 to May 2021. We compared the frequencies of crossings for the three mammal species throughout the study period: dusky langurs (*T. obscurus*), long-tailed macaques (*Macaca fascicularis*) and plantain squirrels (*Callosciurus notatus*) by Analysis of Variances (ANOVA), using R. The species and two bridge designs (single vs. double twisted liana) were then compared by Chi-Square Test of Independence in R to test for significant difference between the two variables. We also compared the frequencies of individual species crossing from coast to forest, and forest to coast by dependent t-test in R.

Permit facilitation

As this is a pilot project in Malaysia, there was no formal procedure to apply for a permit to install a road canopy bridge. Thus, we submitted our project proposal with support letters from various governmental and non-governmental agencies to the Ministry of Works (Kementerian Kerja Raya, KKR). The application and subsequent approval (ten months after initial application) were facilitated through the Malaysian Public Works Department, Penang State section (Jabatan Kerja Raya Pulau Pinang, JKR). In addition, we purchased a Public Liability Insurance to cover any potential accidents to the public from falling bridge materials. The bridge was officiated by Dr. Xavier Jayakumar s/o Arulanandam, the acting Minister of the Ministry of Water, Land and Natural Resources at that time, and Dato’ Abdul Kadir bin Abu Hashim, the Director-General of Department of Wildlife and National Parks Peninsular Malaysia (Perhilitan) on 7 July 2019. We obtained a research permit to study dusky langur road ecology by Perhilitan. Ah Lai’s Crossing followed the recommendations for bridge selection and placement guidelines through stakeholder consultation (Gregory et al., 2013).

Results

We recorded 2128 animal crossings in the 21 546 media data obtained during the 27 months study period, with a total of 16 954 photos and 4592 videos taken, equivalent to 2296 minutes of footage. The plantain squirrels were the most frequent bridge users, with 2075 crossings, while the long-tailed macaques crossed 32 times and dusky langurs crossed 21 times. The overall crossing frequencies between April 2019 to May 2021 were significantly different between the three mammal species ($F(2,51) = [12.19]$, $p < 0.001$). There was no bridge-related road accident recorded during the 27 months, and no more wildlife roadkill in this area (fig. 3).

First bridge prototype

The first animal (an adult female long-tailed macaque) crossed the bridge on 4 March 2019 at 9:23 am (here and hereafter UTC+08:00), less than four days after installation. The first plantain squirrel crossed two months later, on 23

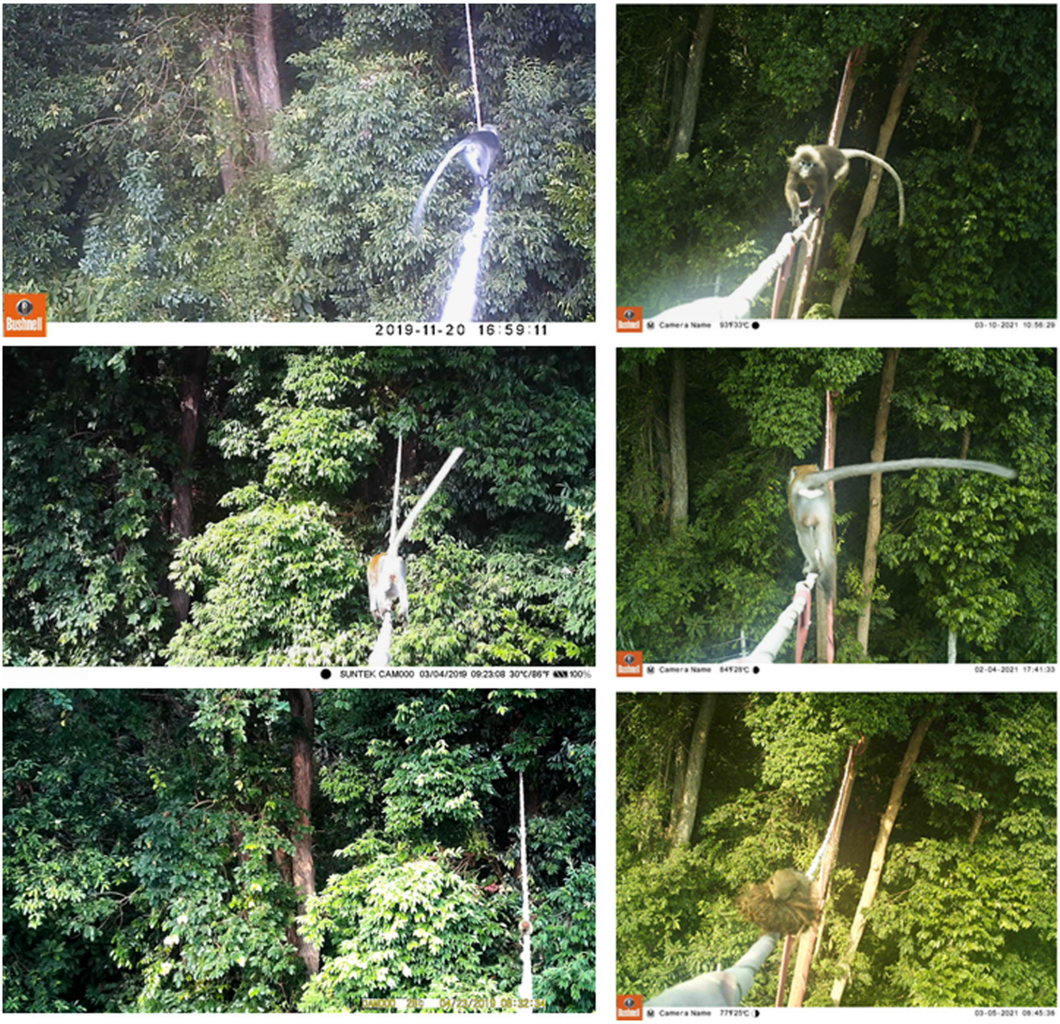

Figure 3. Wildlife crossings on road canopy bridge 'Ah Lai's Crossing'. Left: The: A dusky langur (top), long-tailed macaque (middle), and a plantain squirrel (bottom) crossing the first bridge prototype (single twisted liana); Right: A dusky langur (top), long-tailed macaque (middle), and a plantain squirrel (bottom) crossing on the second bridge prototype (double twisted liana).

April 2019 at 8:32 am, and squirrels are now frequently observed crossing multiple times per day. The first dusky langur crossing was recorded on 20 November 2019, almost nine months after installation. The adult male langur made the first crossing at 4:59 pm, and another individual sat in front of the camera trap, inspecting the bridge not long after the first male crossed, which was at 5:04 pm. We recorded 729 wildlife crossings for the first bridge prototype from 1 March 2019 to 19 August 2020, with 703 plantain squirrels, 20 long-tailed macaques and six dusky langurs.

The first bridge prototype's highest frequency of crossings for squirrels was in July 2020, when 201 crossings were recorded in one month. There was an increase in crossings for the long-tailed macaques every other month, with more macaques crossing in October 2019, December 2019, March 2020, and June 2020. For the dusky langurs, we only observed crossings in November 2019, December 2019, July 2020, and August 2020.

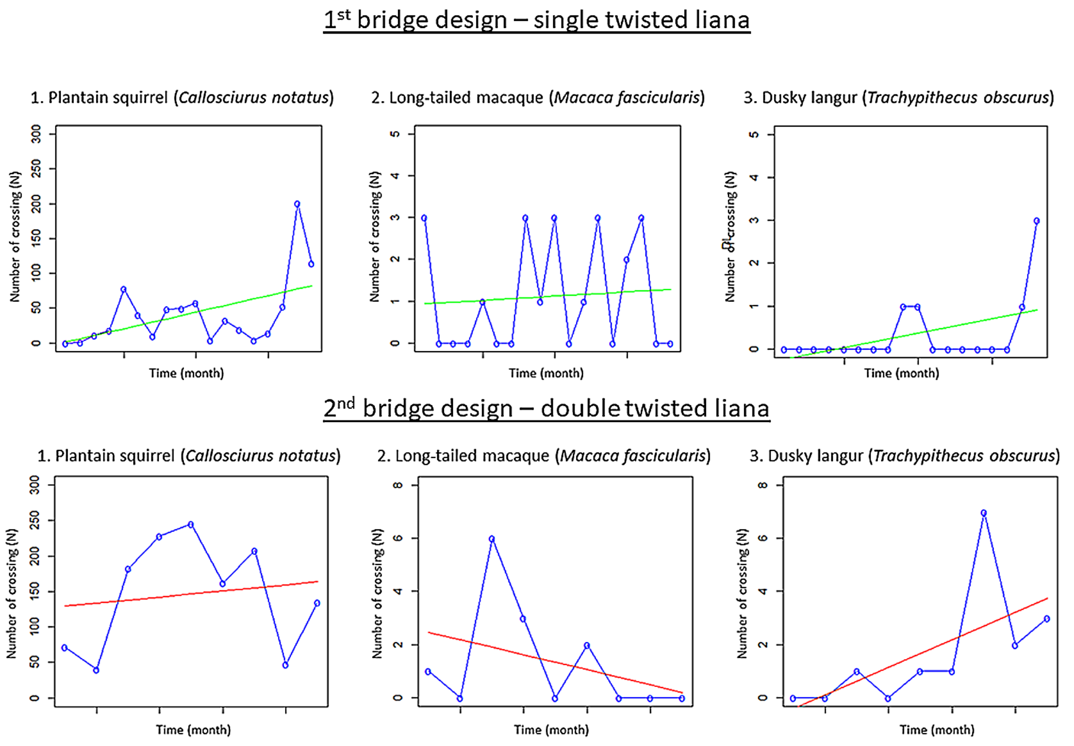

Figure 4. Number of animal crossings of the canopy bridge for plantain squirrel, long-tailed macaque, and dusky langur on the 1st canopy bridge design, 1 March 2019 to 19 August 2020 (top) and 2nd bridge design, 19 August 2020 to 30 May 2021 (bottom).

Second bridge prototype

We reinforced the bridge into the second prototype, the double twisted liana, on 19 August 2020. In total, we recorded 1399 animal crossings between 19 August 2020 to 30 May 2021, with 1372 plantain squirrels crossing, 12 long-tailed macaques, and 15 dusky langurs. The highest frequency of crossings for squirrels for the second bridge prototype was in January 2021, when we recorded 245 crossings. There was an increase in crossing frequency for the long-tailed macaques, with highest monthly number of six crossings recorded in November 2020 compared to maximum 3 monthly crossings in previous months. We observed the highest number of crossings for dusky langurs in March 2021, with seven observations.

Comparison between the two bridge designs

A significantly higher number of animals crossed on the second bridge design (X^2 (2, 84) = [27.85], $p < 0.001$). All three species showed a positively increasing trend line in the species crossing activities for the first bridge design (fig. 4), with plantain squirrels showing the highest increase, a moderate increase for dusky langurs, and a weak increase for long-tailed macaques. For the second bridge design, there was an increasing trend in crossing frequencies for plantain squirrels and dusky langurs, but a decreasing trend for long-tailed macaques.

Crossing directions and times

There are two possible directions to cross this road canopy bridge, 1) from the coast to the forest or 2) from the forest to the coast. There was an increasing trend of wildlife crossing frequencies over time for both directions. However, crossing frequency from coast to forest was significantly higher (M = 51, SD = 46; dependent t-test: $t = 5.16$, $p = 2.2e^{-05}$) than the other way (M = 26, SD = 33) and all species crossed more frequently from the coast to the forest (plantain squirrels N = 1364; long-tailed macaques N = 30; dusky langurs N = 13).

All three diurnal mammal species crossed the bridge similarly often in the mornings and afternoons with no significant time of preference (plantain squirrel, $N_{morning} = 1042$ vs. $N_{afternoon} = 1033$, long-tailed macaques N = 13 vs. 19; dusky langurs N = 13 vs. 8; dependent t-test: $t = 0.16$, $p = 0.87$;).

Discussion

Artificial canopy bridges have been used in many countries to facilitate local wildlife conservation efforts. For instance, rope bridges are regularly used by the arboreal Lemuroid ringtail possum (*Hemibelideus lemuroides*) in Australia (Goosem et al., 2005), a liana bridge in the Peruvian Amazon is utilised by black-headed night monkeys (*Aotus nigriceps*) (Balbuena et al., 2019), and bamboo bridges were installed for Hoolock gibbons (*Hoolock hoolock*) to travel efficiently across forest fragments in Borajan, Asam, India (Das et al., 2004). A rope bridge was also constructed for Hainan gibbons (*Nomascus hainanus*) to facilitate passage at a natural landslide area in the gibbon forest of Bawangling (Chan et al., 2020). The recent update on a canopy bridge study in West Java, Indonesia showed the positive results of five artificial waterline bridges utilized by Javan palm civets (*Paradoxurus musanga javanicus*) and Javan slow lorises (*Nycticebus javanicus*) (Nekaris et al., 2021).

These canopy bridges made from various materials help to reconnect separated forest patches or habitat fragments to allow safe passage for small mammals. In this study, we chose firehose as it is cost-effective, durable, and able to endure the tropical climate and high UV intensity. The firehoses selected for this study were decommissioned from the Fire and Rescue Department of Malaysia, donated to APE Malaysia. Decommissioned firehoses are upcycled for a good cause, such as producing hammocks and fire hose treat pockets for captive sun bears at the Bornean Sun Bear Conservation Center (Corner, 2015), enrichment tools for zoo animals (Clark, 2013), and this urban canopy bridge project. Firehose consists of waterproof liners made of rubber and synthetic fibre, where heat and chemical additives are added to make the rubber stronger and durable (Eccher et al., 2016). The high durability of firehoses allows it to withstand weather and require minimum maintenance when used outdoors. Firehoses have been used to protect cables and minimise mechanical damage for forest research, as firehose is flexible and lightweight (Parker and Brown, 2001).

Arboreal camera trapping is an effective tool in collecting digital data of rainforest mammal communities in the canopy, particularly useful in detecting wildlife with high conservation concerns (Whitworth, et al., 2016). Camera trapping has proven to successfully collect information about arboreal mammals with minimal human effort in the field (Bezerra, et al., 2014). In this study, besides the mentioned advantages, camera trapping also presented some disadvantages, e.g., the excessive triggering by non-target stimuli (Gregory et al., 2014), generating more empty images than real data. For 2128 wildlife crossings, most digital data files (i.e., 21 546 photos and videos) contained media triggered by wind, moving foliage, and other wildlife visitors such as invertebrates and birds; this took months to categorise data to identify crossing species manually. Therefore, we plan to improve the arboreal camera trapping technique in near future by using automated AI technology to recognise false triggers.

A significant challenge of this pilot project in Malaysia was the initial bridge permit application. Applying to the authorities in January 2018 to receive final approval took approximately one year due to the lack of a standard operating procedure for such a proposal. In addition, there is no designated department in Malaysia to focus on mitigating fragmented landscapes. We plan to further expand this project to other potential sites in Peninsular Malaysia to mitigate the impact of linear infrastructure, especially in urban areas. Canopy bridges can be an essential conservation tool to connect forest fragments and promote safe passage of arboreal urban wildlife in human housing areas, plantations, and orchards. Unfortunately, due to the COVID-19 pandemic, Malaysia has been under a strict Movement Control Order from March 2020 until the present (October 2021), impeding the fieldwork to identify new sites.

Before we built the bridge, we recorded six dusky langur roadkills and one Sunda slow loris electrocution incident near the coordinates from August 2016 to January 2018. Since the installation of the bridge until May 2021, there we recorded no more wildlife roadkills and observed an overall increase in crossing frequencies for all three focal species (plantain squirrel, long-tailed macaque, and dusky langur). The species that first used Ah Lai's Crossing shortly after the installation was a long-tailed macaque. The long-tailed macaques around the study area spend time by the road, feeding on human food provided by tourists and residents. As the access of anthropogenic food sources in human-altered habitats creates a situation that significantly influences primate behaviour and ecology (Sha and Hanya, 2013), they are maybe bolder than the langurs and dare to explore new objects around their home range. The long-tailed macaques there often moved toward the area near the bridge from afternoon onwards, as their main sleeping tree is a *Ficus* located around 150 m away from the bridge coordinates.

Dusky langurs did not use Ah Lai's Crossings for the first seven months, but the langurs fed and rested near the bridge site. This was expected due to the shy nature of the langurs, and the new obstacle/structure (Aggimarangsee, 2013), the canopy bridge. The dusky langurs were observed investigating the bridge more often in November 2019 by sitting in front of the camera trap, inspecting the rope, before making their first crossing on 20 November 2019. Accordingly, they crossed more often after the second prototype was introduced. Thus, we assume that dusky langurs took longer to be habituated to the canopy bridge as certain species may need more time to become accustomed to a novel structure in their habitat. It took Hainan gibbons 176 days to start using a canopy bridge to cross the forest gap in Bawangling, China, gradually increasing the number of crossings (Chan et al., 2020). In West Java, the Javan slow lorises used the waterlines and rubber bridges on an average of 12.9 days after installation (Birot et al., 2020). In the Lower Kinabatangan, Sabah, the orangutans took four years to cross a canopy bridge that connects two forest patches across the Kinabatangan River. The bridges have now become a tourist attraction for people on boat cruises to observe wildlife moving across the river (Lombardi, 2017). Hence, habituation time towards the usage of canopy bridges is a process that seems to be significantly different in different primate species.

Other probable reasons why the dusky langurs did not cross the bridge until November 2019 could be found in the design itself: The single firehose twisted liana is less stable for the langurs to balance as their bodies are larger and heavier than long-tailed macaques, who are also more assertive in defending their resources and home range (Ang et al., 2020). It is unclear if there could have been differences in crossing counts if the two prototype designs were constructed in a reversed order. One issue with the first bridge prototype was that the rope slightly loosened and began to wobble six months after installation, which could be one of the factors discouraging certain animal species from crossing the bridge. The second prototype design may have felt more secure and comfortable to cross for the langurs.

Further, there was a change in the social composition of the dusky langur study troop in that area in March 2019 (YJL, pers. obs.). Hence the daily travel routes of the langurs slightly changed with the new leading alpha male, and they crossed the road further away from the bridge site than with the previous alpha male.

It is uncertain why the long-tailed macaques increased their crossing frequency during the first bridge prototype but decreased their crossing frequency during the second bridge prototype. Long-tailed macaques living in an anthropogenic environment spend less time resting and more time moving, indicating that the macaques' foraging strategies and ecological responses may be influenced by anthropogenic influences (Sha and Hanya, 2013) that were not assessed in this study. As a result, additional bridge crossing data is required to investigate the possible causes of the second bridge prototype's lower crossing trend for macaques.

Plantain squirrels showed the highest crossing frequency of all species. This small diurnal rodent frequently uses forest gaps but is distributed in a wide range of forest habitats (Saiful et al., 2001). It can be frequently found feeding on coastal plants, sharing similar food plants with the long-tailed macaques and dusky langurs, such as sea fig (*Ficus superba*), ketapang (*Terminalia catappa*), and cenderai (*Microcos tomentosa*). In addition, the squirrels may cross the bridge to move from the coastal area from their sleeping nest using the bridge as their main crossing passage. We could observe up to 15 plantain squirrel crossings per day, with more than one individual crossing the bridge at the same time. Plantain squirrels crossed the first bridge prototype 201 times in July 2020 due to the flowering and fruiting of food plant Ketapang, Sea Milettia (*Millettia pinnata*), and Acacia (*Acacia auriculiformis*) near the canopy bridge. The dusky langurs used another route to access the food plants in the habitat. Although plantain squirrels, unlike primates, are not of conservation concern in Malaysia (IUCN status: Least Concern), more research needs to be done on the habitat use and feeding ecology of the plantain squirrel population at the study site to obtain a more comprehensive picture on the bridge crossing preference of the species.

Both plantain squirrels and dusky langurs have crossed the bridge more frequently since the installation of the second bridge prototype, but we are still determining whether the increase in crossing activities is due to the species' increasing familiarity with the bridge structure, its stability or to varying seasonal or ecological factors, such as food availability or inter-species competition.

It is essential to protect species with a high degree of flexibility living near areas inhabited by humans, for example, primates, birds, and rodents (Sharma et al., 2010). Urban monkeys are active, manipulative, and contact objects readily and frequently, efficient in learning to solve various problems (Singh, 1966). However, anthropogenic noise can be stressful, affecting the vocal communication of species, like marmosets (*Callithrix penicillata*) in Brazil (Duarte et al., 2011) similar to the dusky langurs in Penang. The species may be easier adapting to artificial structures, such as the canopy bridge, but are also vulnerable to vehicle, electrocution due to exposed power cables, and road accidents. Deforestation and human modification of forest habitats can negatively impact wildlife (Kobayashi et al., 2020). More studies need to be done especially on the comparison between species bridge crossings and cable wire crossings, as the wildlife is still using the nearby cable wires to cross the road. A high usage of cables by arboreal wildlife leads to wildlife electrocutions (Laidlaw et al., 2021), therefore it is crucial to investigate a better and cost-effective strategy to mitigate arboreal wildlife electrocutions.

Overall, this first urban canopy bridge project in Peninsular Malaysia serves to address the impact of habitat fragmentation on urban wildlife, representing a relatively low-cost method to mitigate road accidents involving humans and nature. Our results provide vital data in images, videos, and statistical presentations for environmental education and environmental planning purposes. However, more investigations are to be done especially on the long-term effectiveness of canopy bridges, compared to cable wire crossing and road running crossing behaviour by wildlife. Using the data, we have organised public education programmes to highlight the importance of habitat connectivity and contribute to the bridge installation protocol with other Malaysian conservationists and researchers working on developing canopy bridge projects for their respective species and sites.

Conclusion

Ah Lai's Crossing can be regarded as a stepping stone for local wildlife conservation efforts to mitigate roadkills. This study was also the first observation of dusky langurs crossing an artificial canopy bridge worldwide. This project has established a long-term collaboration among various stakeholders. The study started as a citizen science project with community members of multiple backgrounds who assisted in fieldwork to collect baseline data regarding the activity and behaviour of the dusky langur troop near the bridge coordinates. Then, we presented the data to the government authorities for reviewing and approval. This step was crucial for the canopy bridge site identification and final selection. It is important that researchers work alongside multiple stakeholders, including topographers for location selection and engineers who recommended bridge selection and placement (Gregory et al., 2013). In addition, this project showcases a potential nature-based tourism prospect. We collaborate with the local nature-based tourism site Tropical Spice Garden for a long-term environmental education effort by showcasing Ah Lai's Crossing as an educational tool to highlight the importance of habitat connectivity for wildlife and plants. Since the installation of the bridge, the dusky langurs and our citizen science project, Langur Project Penang, received some national and international media coverage that provided us with the opportunity to call for action among the public community, especially in learning how to coexist with our wildlife residents in this human-impacted world.

To conclude, it is crucial to have urban areas designed to be wildlife-friendly and to protect and maintain natural corridors for the movement of animals, including connected tree canopy along roads. Implementing mitigation solutions, such as artificial canopy bridges, should only come after protecting natural habitat has already failed. Road and urban canopy bridges could be included as part of the town and state planning proposals to mitigate habitat fragmentation and raise more public awareness on the impact of roadkill and the expanding human-wildlife interface. The future of this work is to progress with citizen scientist participation and the data from the local wildlife department to identify more wildlife road crossing hotspots in Malaysia and to propose more canopy bridges and wildlife road crossing signage and educational materials for the public to mitigate the negative impacts of habitat fragmentation caused by development. The outcome of this study creates better understanding about the necessity to conduct long-term road ecology studies on threatened primate species in Malaysia, where hopefully, this canopy bridge initiative can serve as an example for conservation efforts to various states in Malaysia and other countries combating habitat fragmentation.

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Statement of ethics

This project adhered to the laws and regulations of Malaysia pertaining to road works and animal research. This non-invasive study followed USM's animal ethic committee's guidelines with permission from the local wildlife authority.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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Author contributions

YJL: Field research, data collection, project logistics, manuscript writing; NR: Study design and conceptualization, project supervision and logistics, manuscript writing; NFNR: Project supervision, technical assistance, manuscript writing; MM: Project logistics, bridge design and installation; MLB: Project logistics, bridge design and installation; VM: Project logistics, technical assistance, bridge upgrade. All authors contributed to drafting the manuscript and approved its submission.

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