Recommendations for the establishment of a trans-island canopy bridge network to support primate movement across Langkawi Island, Malaysia

BENJAMIN GALEA[1,2], IRSHAD MOBARAK[3], NUR AFIQAH IZZATI[4], MAY YIN FONG[4]
MUHAMMAD FIRDAUS DEV ABDULLAH[4], AZMIL MUNIF MOHD BUKHARI[5]
CHEN KIM LIM[6] and NADINE RUPPERT*[1,2]

Abstract The expansion of transportation and service corridors has numerous, well-documented adverse effects on wildlife. However, little research on this topic has been translated into mitigating the effects of habitat fragmentation caused by road development on primates. The establishment of canopy bridges has proven to be an effective conservation intervention. Of the completed primate canopy bridge projects reported in the literature, to our knowledge, all attempt to mitigate the impacts caused by singular, linear infrastructure routes. Here we provide recommendations for the establishment of a network of natural and artificial canopy bridges over roads throughout Langkawi Island, Malaysia, to reduce rates of roadkill and support the movement of primates and other arboreal animals across the island by identifying suitable sites and appropriate tree species to be planted (including *Ficus racemosa* and *Ficus fistulosa*), bridge materials and post-installation monitoring. The establishment of this pioneering trans-island canopy bridge network could function as a model to enhance connectivity for arboreal animals in other important wildlife habitat sites in Malaysia and beyond that are affected by fragmentation from linear infrastructure. We have begun discussions with relevant authorities, partners and other pertinent parties, focusing on the initiation of construction of the canopy bridge network in 2024.

Keywords Canopy bridges, connectivity, *Ficus*, Langkawi Island, Malaysia, primates, roadkill, wildlife corridors

The expansion of transportation and service networks and their threats to wildlife are relatively well documented (Fahrig & Rytwinski, 2009; Barrientos et al., 2021). The consequences of this for arboreal animals, particularly primates, have been increasingly explored but little of this research has been translated into effective and sustainable mitigation measures (Ascensão et al., 2021; Galea & Humle, 2022). Of the measures implemented to mitigate the effects of transportation-related habitat fragmentation on primates, canopy bridges (both natural and artificial) have so far been the most widely utilized, and they have proven to be effective (Galea & Humle, 2022). Existing literature on primate canopy bridges primarily focuses on mitigating the impacts of linear infrastructure routes. Numerous initiatives have successfully utilized canopy bridges as a means of facilitating primate movement and dispersal by maintaining canopy connectivity or reconnecting fragmented habitats (Gregory et al., 2017; Cunneyworth et al., 2022). Similarly, artificial canopy bridges have been established to prevent or reduce primate–vehicle collisions and powerline electrocutions (Teixeira et al., 2013; Linden et al., 2020; Yap et al., 2022).

The science of artificial crossing structures is faced with knowledge gaps and implementation challenges that require attention. Despite being a promising conservation intervention, the impacts of these structures on mortality and survival rates of most primate populations remain poorly known because of the difficulty of measuring these rates both before and after bridge implementation. Furthermore, some species, such as spider monkeys *Ateles* spp. (Aureli et al., 2022), exhibit avoidance behaviour towards certain artificial crossing structures. Further research is necessary to address these gaps, overcome implementation challenges and improve knowledge of the effectiveness of artificial crossing structures for primate conservation. Here we propose establishing a network of canopy bridges over roads in Langkawi Island, Malaysia, to facilitate primate and arboreal animal movement across an increasingly fragmented landscape and to reduce roadkill and negative human–primate interactions (e.g. food provisioning) along roadsides. Our approach aligns closely with the concept of corridor networks, which involves assessing the spatial arrangements of habitat patches and connecting them to facilitate wildlife movements across fragmented landscapes (Rayfield et al., 2016). In this case we propose the development of the first trans-island canopy bridge network in Malaysia (possibly

*Corresponding author, n.ruppert@usm.my
[1]School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia
[2]Malaysian Primatological Society, Kulim, Malaysia
[3]JungleWalla, Langkawi, Malaysia
[4]The Datai Langkawi, Langkawi, Malaysia
[5]Langkawi Development Authority, Langkawi, Malaysia
[6]Langkawi Research Centre, Tuanku Abdul Halim Mu'adzam Shah Campus, Institute for Environment and Development, Universiti Kebangsaan Malaysia, Langkawi, Malaysia

Received 15 May 2023. Revision requested 14 July 2023.
Accepted 21 August 2023. First published online 20 November 2023.

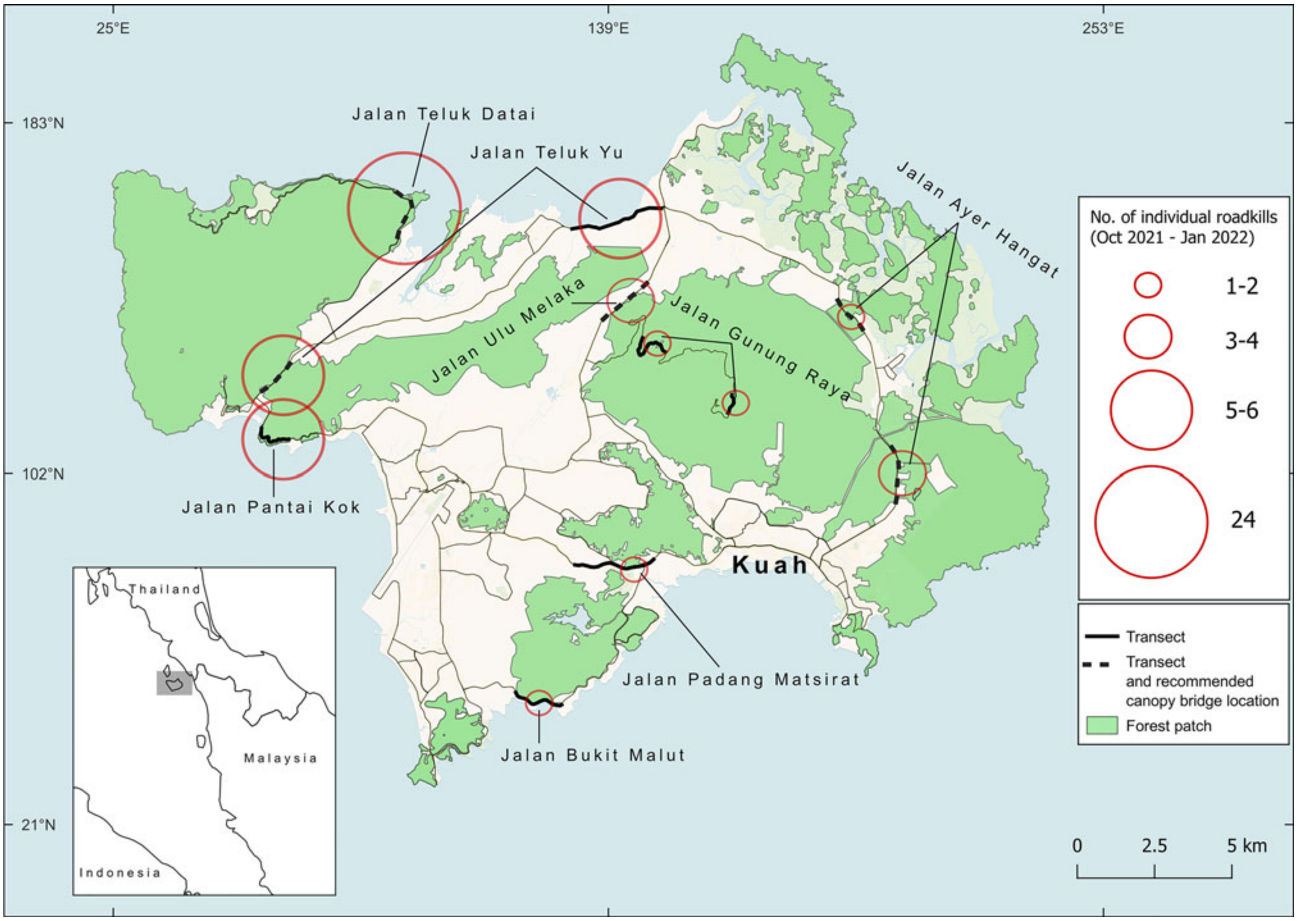

FIG. 1 Langkawi Island (Malay: Pulau Langkawi) on the west coast of Peninsular Malaysia, showing the transect locations along roads where primates frequently occur, with names of the road sections, the concentration of vertebrate roadkill recorded across the island and the recommended sites for the proposed canopy bridge network.

globally), together with a standardized methodology for installation and post-installation monitoring, on Langkawi Island. This trans-island canopy bridge network would encompass a system of elevated structures organized to ensure an uninterrupted connection between the major forest fragments across the whole island, allowing primates and other wildlife to navigate and utilize the landscape more effectively.

Langkawi Island (Malay: Pulau Langkawi; Fig. 1) is the largest and most densely populated of the 99 islands in the Langkawi Archipelago. Located on the west coast of northern Peninsular Malaysia, it has a diverse landscape of flat coastal plains, hilly terrain and rugged mountains. The vegetation primarily comprises semi-evergreen rainforest, along with mangroves, shrubs, limestone structures, agricultural land and sandy beaches (Hussin et al., 2005). Mount Machinchang (Malay: Gunung Machinchang) is the oldest rock formation in Peninsular Malaysia, dating back to the Upper Cambrian period (Lee, 1983). Three primate species occur on Langkawi Island, all categorized as Endangered on the IUCN Red List: the Tarutao Island dusky langur *Trachypithecus obscurus carbo* (Boonratana et al., 2021), common long-tailed macaque *Macaca fascicularis fascicularis* (Hansen et al., 2022) and greater slow loris *Nycticebus coucang* (Nekaris et al., 2020). The island experiences a climate pattern similar to the northern mainland, with a dry season during November–March and two wet seasons, during April–May and August–October (Kohira et al., 2001). Its natural assets have made Langkawi Island a leading holiday destination in Malaysia (Wahid et al., 2016). Tourism is the main economic activity and has transformed Langkawi Island from a rural island inhabited by farmers and fishers to an international tourist hotspot undergoing increasing development (Irwana Omar et al., 2014). To accommodate the growing human population on the island, road development began during the 1980s and intensified from 2001, with most parts of the island now being connected by roads (Marzuki, 2015; Jamil & Badaruddin, 2006). Although Langkawi Island was recognized as a Global Geopark by UNESCO in 2007, it has received multiple warnings about losing its status if the sustainability and conservation requirements of UNESCO cease to be met (Hashim & Abd Latif, 2015). Little is known about the impacts of roads and habitat fragmentation on the vertebrate wildlife of Langkawi Island other

Table 1 List of individual vertebrate carcasses recorded on roads across Langkawi Island, Malaysia (Fig. 1), during October 2021–January 2022.

Taxon	Order/Class	IUCN Red List status[1]	Number of individuals (% of total)
Common long-tailed macaque *Macaca fascicularis fascicularis*	Primates	EN	25 (38.5)
Southeast Asian water monitor *Varanus salvator macromaculatus*	Reptilia	LC	16 (24.6)
Clouded monitor *Varanus nebulosus*	Reptilia	NT	7 (10.8)
Tarutao Island dusky langur *Trachypithecus obscurus carbo*	Primates	EN	5 (7.7)
Grey-bellied squirrel *Callosciurus caniceps*	Rodentia	LC	5 (7.7)
Malaysian eared nightjar *Lyncornis temminckii*	Aves	LC	2 (3.1)
Masked palm civet *Paguma larvata*	Carnivora	LC	2 (3.1)
Greater slow loris *Nycticebus coucang*	Primates	EN	1 (1.5)
Oriental pied hornbill *Anthracoceros albirostris*	Aves	LC	1 (1.5)
Reticulated python *Malayopython reticulatus*	Reptilia	LC	1 (1.5)
Total			65 (100)

[1]EN, Endangered; NT, Near Threatened; LC, Least Concern.

than data on herpetofauna roadkill collected during 2017–2018, which recorded 131 incidents (Ayob et al., 2020).

During October 2021–January 2022 we assessed vertebrate roadkill, focusing on primates. We scanned selected transects twice per day for 15 days each month. The combined length of all transects scanned (without repetition) was 35.17 km. We selected these transects from across the c. 251 km-long road network of Langkawi Island (excluding roads within urban housing areas; Fig. 1). A transect here refers to a specific section of tarmac road that is part of the main road network. We scanned these transects from a moving vehicle at a speed of c. 35 km/h. The purpose of these scans was to search for animal carcasses on the road or roadside. The selection of transects was informed by personal communication with knowledgeable local people (community naturalists and guides working around the island), who provided insight regarding where primates were known to occur at roadsides. We consulted with eight people prior to and whilst conducting the transect scans. Assuming that a higher density of primates along roadsides could result in a proportionally higher occurrence of road crossings and subsequent roadkill, this information guided the identification and prioritization of road sections where we conducted transect scans. We did not add further transects to the study after the initiation of our roadkill assessment once we ascertained there were no other road sections where primates frequently crossed or occurred at roadsides. We identified and recorded the locations of vertebrate carcasses found on these transects and also opportunistically elsewhere on the island.

During the same period, we assessed and documented the activity of diurnal primates (*M. fascicularis fascicularis* and *T. obscurus carbo*) at roadsides along the study transects. We used a group scan sampling method (Altmann, 1974) of 2-min intervals during periods when groups were present at roadsides at any time between 8.30 and 17.30 on observation days. The behavioural categories of scanned individuals recorded were feeding (on vegetation, provisions and roadside waste), social activities (grooming and playing) and resting (sitting and observing). We also noted any instances of road crossing (fully or partially), road vigilance (hesitancy/observance) and interspecies activity (tolerance of other primate species). We collected 160 h of behavioural observations.

We recorded 65 individual animal carcasses across Langkawi Island during the 4 months, with 38% belonging to *M. fascicularis fascicularis* (Table 1). We also recorded individual roadkills of *T. obscurus carbo* (8%) and *N. coucang* (2%). The highest concentrations of roadkill were at road sections Jalan Teluk Datai, Jalan Teluk Yu, Jalan Pantai Kok and Jalan Ayer Hangat (Fig. 1). At each of these sites, primates forage regularly along the roadside at ground level or in the canopy.

Along these four roads, *M. fascicularis fascicularis* spent a mean of 4.25 h per day at ground level. Most of this time (43%) they spent feeding on roadside verge grass (21%), waste disposed at roadsides (13%) and food provided by local people and tourists (9%). The remainder of their time they spent resting (36%) and engaging in social activities (21%). They frequently crossed from one roadside to the other, either to join other group members or whilst playing. *Trachypithecus obscurus carbo* spent a mean of 55 min per day observing road activity from the treetops before retreating into the forest. Their presence at roadsides was limited and inconsistent, and we could not derive comprehensive information about their roadside behaviour through scan sampling. During the study period we recorded eight langur crossing events, six of which were at Jalan Teluk Datai. Individuals descended to the ground and quickly crossed the road without checking for vehicles. We did not observe feeding behaviour by *T. obscurus carbo* at roadsides, but we recorded occasional grooming between group members.

We observed individuals of *M. fascicularis fascicularis* and *T. obscurus carbo* groups in close proximity at roadsides on nine occasions but observed interaction between the species only once, when three *M. fascicularis fascicularis* individuals from the same group and one *T. obscurus carbo* crossed together at Jalan Teluk Datai.

Based on the roadkill and observational data recorded, we recommend both natural and artificial canopy bridges are installed to reduce roadkill rates of arboreal wildlife, especially primates, and to improve habitat connectivity at multiple locations along sections of Jalan Teluk Datai, Jalan Teluk Yu and Jalan Ulu Melaka, and two sections of Jalan Ayer Hangat (Fig. 1). The final selection of proposed canopy bridge sites was based on two factors. Firstly, we considered the rate of roadkill observed. Secondly, we assessed the potential of each site to facilitate the reconnection of major forest fragments and to support the movement of arboreal animals between these areas. In cases where a site had a high rate of roadkill but lacked the capacity to reconnect significant forest fragments (e.g. Jalan Pantai Kok), it was excluded from the proposed canopy bridge network. However, these locations remain under consideration for future inclusion in the network pending the successful piloting of the selected canopy bridge sites. Although there was not a significant forest gap at Jalan Teluk Datai, we included it in the proposed network as the roadkill rate was markedly higher than in other areas. The prioritization of sites that met both the roadkill rate and forest connectivity criteria will ensure that the canopy bridge network maximizes its potential for reducing wildlife–vehicle collisions whilst supporting the long-term conservation of arboreal species. *Macaca fascicularis fascicularis* and *T. obscurus carbo* have both shown a propensity to use artificial canopy bridges (Yap et al., 2022). Slow lorises have also been recorded successfully crossing such structures (Birot et al., 2020).

Appropriate tree species to plant along roadsides as natural canopy bridges include figs such as the cluster fig (Malay: *tangkol*) *Ficus racemosa* or common yellow-stem fig (*pokok buah ara*) *Ficus fistulosa*, pacific lychee (*kasai daun besar*) *Pometia pinnata*, monkey-pod tree (*pokok pukul lima*) *Albizia saman*, Alexandrian laurel (*penaga laut*) *Calophyllum inophyllum* and *pokok buak-buak Teijsmanniodendron pteropodum*, as they are fast-growing and have far-extending crowns and small, light fruits that will not damage vehicles when they fall. The approximate number of saplings required along the roadsides where we recommend wildlife corridors are as follows, based on a recommended 1.8-m distance between the planted saplings (Kerr & Mackintosh, 2012): Jalan Teluk Datai: 422 saplings (760 m of total roadside); Jalan Teluk Yu: 111 (200 m of total roadside); Jalan Ulu Melaka: 88 (160 m); Jalan Ayer Hangat (1): 255 (230 m); and Jalan Ayer Hangat (2): 444 (800 m).

Artificial canopy bridges can be tied to trees where feasible (in consultation with a certified arborist) or to 10–15 m tall galvanized steel poles. A ladder or lattice canopy bridge design using low-cost, lightweight and robust materials, such as repurposed firehose (Yap et al., 2022), might prove sufficient for langurs, macaques and slow lorises. For a more permanent bridge, engineered overpasses could be constructed, although this would significantly increase costs. Engaging local people in a participatory approach to contribute to canopy bridge design, construction and monitoring could foster environmental stewardship amongst community members, and build public trust regarding wildlife conservation interventions (Fan & Lindshield, 2022). The artificial canopy bridges would serve as short- to mid-term measures to facilitate canopy connectivity whilst planted tree saplings grow. Following establishment of artificial canopy bridges, we recommend utilizing camera traps to record crossing details (species, age, sex, number of individuals) and to collect behavioural and environmental data during crossing events. Relevant parameters to record include mode of locomotion (e.g. walking, running) and vigilance behaviour on the bridge, time and weather (van der Grift et al., 2015). To ensure the safety of pedestrians and primates, it will be essential to collaborate with experts in bridge design and construction, install clear signage, consider human–primate separation measures, conduct regular inspections and maintenance, engage with the local community to raise awareness, and coordinate with relevant authorities and conservation organizations to achieve compliance with safety regulations and best practices. We also recommend the installation of speed limits, humps and signs along the road sections, to slow down vehicles and inform drivers of the potential threat they pose to wildlife by speeding, to help further reduce roadkill and to increase public awareness regarding the harm that food provisioning causes to primates, especially along roadsides. We will continue working closely with local authorities, including the Kedah State Forestry Department, the Langkawi Development Authority, the Langkawi Public Works Department, the Langkawi Research Centre and community groups to implement our recommendations. We have begun discussions with the relevant authorities, partners and other pertinent parties, focusing on the initiation of construction of the canopy bridge network in 2024. This project could be an exemplar for multi-partner collaboration to restore and maintain habitat connectivity for arboreal wildlife in other locations.

Author contributions Study design, fieldwork: all authors; data analysis, writing: BG, NR.

Acknowledgements We thank the Kedah State Forestry Department for technical advice and support; the Datai Langkawi for initiating the project and for support; Devakumaran Devanesan and Intan Aasyeerin Hasim for their contributions during the initial stages of this study; and Universiti Sains Malaysia Research University Grant (grant 1001/PBIOLOGI /8011063) and Re:wild (SMA-CCO-G0000000028 through the Malaysian Primatological Society) for funding.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

Data availability All the data supporting the findings of this study are available within the article.

References

ALTMANN, J. (1974) Observational study of behavior: sampling methods. *Behaviour*, 49, 227–267.

ASCENSÃO, F., YOGUI, D., ALVES, M., ALVES, A., ABRA, F. & DESBIEZ, A. (2021) Preventing wildlife roadkill can offset mitigation investments in short–medium term. *Biological Conservation*, 253, 108902.

AURELI, F., HUTSCHENREITER, A., GAMBOA, D.A., ARÉVALO-HUEZO, E., ATAGUA, T.A., BOILEDIEU, C. et al. (2022) Do spider monkeys use artificial canopy bridges to cross linear infrastructure? *Folia Primatologica*, 93, 361–370.

AYOB, N., MUSTAPHA, M., SENAWI, J. & AHMAD, N. (2020) Herpetofauna roadkills on Langkawi Island, Peninsular Malaysia: the influence of landscape and season on mortality distribution. *Sains Malaysiana*, 49, 2373–2382.

BARRIENTOS, R., ASCENSÃO, F., D'AMICO, M., GRILO, C. & PEREIRA, H.M. (2021) The lost road: do transportation networks imperil wildlife population persistence? *Perspectives in Ecology and Conservation*, 19, 411–416.

BIROT, H., CAMPERA, M., IMRON, M. & NEKARIS, K. (2020) Artificial canopy bridges improve connectivity in fragmented landscapes: the case of Javan slow lorises in an agroforest environment. *American Journal of Primatology*, 82, e23076.

BOONRATANA, R., ANG, A. & TRAEHOLT, C. (2021) *Trachypithecus obscurus* ssp. *carbo*. In *The IUCN Red List of Threatened Species* 2021. dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T39857A17988653.en.

CUNNEYWORTH, P.M.K., DONALDSON, A. & ONYANCHA, F. (2022) Canopy bridges are an economical mitigation reducing the road barrier effect for three of four species of monkeys in Diani, Kenya. *Folia Primatologica*, 93, 217–234.

FAHRIG, L. & RYTWINSKI, T. (2009) Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society*, 14, 21.

FAN, Y., & LINDSHIELD, S. (2022) Exploring human factors of wildlife conservation along a forest gap using a participatory design-build canopy bridge. *Folia Primatologica*, 93, 437–452.

GALEA, B. & HUMLE, T. (2022) Identifying and mitigating the impacts on primates of transportation and service corridors. *Conservation Biology*, 36, e13836.

GREGORY, T., CARRASCO-RUEDA, F., ALONSO, A., KOLOWSKI, J. & DEICHMANN, J.L. (2017) Natural canopy bridges effectively mitigate tropical forest fragmentation for arboreal mammals. *Scientific Reports*, 7, 3892.

HANSEN, M.F., ANG, A., TRINH, T., SY, E., PARAMASIWAM, S., DIMALIBOT, J. et al. (2022) *Macaca fascicularis* ssp. *fascicularis*. In *The IUCN Red List of Threatened Species* 2022. dx.doi.org/10.2305/IUCN.UK.2022-2.RLTS.T195351957A221668305.en.

HASHIM, G. & ABD LATIF, Z. (2015) Langkawi's sustainable regeneration strategy and natural heritage preservation. *Environment Asia*, 8, 1–8.

HUSSIN, A., DORALL, R., MEOR, H.H. & GOLIKAN, S. (2005) The physical geography and geology of northeast Langkawi. *Malaysian Journal of Science*, 24, 1–8.

IRWANA OMAR, S., GHAPAR OTHMAN, A. & MOHAMED, B. (2014) The tourism life cycle: an overview of Langkawi Island, Malaysia. *International Journal of Culture, Tourism and Hospitality Research*, 8, 272–289.

JAMIL, J. & BADARUDDIN, M. (2006) Tourist infrastructure provision versus successful destinations case study: Langkawi Island. *Paper presented at the 12th Asia Pacific Tourism Association & 4th Asia Pacific CHRIE Joint Conference, 26–29 June 2006, Hualien, Taiwan*.

KERR, G. & MACKINTOSH, H. (2012) Long-term survival of saplings during the transformation to continuous cover. *Forests*, 3, 787–798.

KOHIRA, M., NINOMIYA, I., IBRAHIM, A.Z. & LATIFF, A. (2001) Diversity, diameter structure and spatial pattern of trees in a semi-evergreen rain forest on Langkawi Island, Malaysia. *Journal of Tropical Forest Science*, 13, 460–476.

LEE, C.P. (1983) Stratigraphy of Tarutao and Machinchang formations. In *Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia*. Volume 1 Technical Papers (eds P. Nutalaya, T. Thanasuthipitak, N. Thiramongkol, C. Chonglakmani, S. Sodsri, N. Muangnoicharoen et al.), pp. 20–38. Geological Society of Thailand, Bangkok, Thailand, and Geological Society of Malaysia, Kuala Lumpur, Malaysia.

LINDEN, B., FOORD, S., HORTA-LACUEVA, Q.J.B. & TAYLOR, P.J. (2020) Bridging the gap: how to design canopy bridges for arboreal guenons to mitigate road collisions. *Biological Conservation*, 246, 108560.

MARZUKI, A. (2015) Impacts From Tourism Development in Langkawi Island, Malaysia. In *International Tourism and Hospitality in the Digital Age* (ed. S. Kumar), pp. 21–33. IGI Global, Hershey, USA.

NEKARIS, K.A.I., POINDEXTER, S. & STREICHER, U. (2020) *Nycticebus coucang*. In *The IUCN Red List of Threatened Species* 2020. dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T163017685A17970966.en.

RAYFIELD, B., PELLETIER, D., DUMITRU, M., CARDILLE, J.A. & GONZALEZ, A. (2016) Multipurpose habitat networks for short-range and long-range connectivity: a new method combining graph and circuit connectivity. *Methods in Ecology and Evolution*, 7, 222–231.

TEIXEIRA, F.Z., PRINTES, R.C., FAGUNDES, J.C.G., ALONSO, A.C. & KINDEL, A. (2013) Canopy bridges as road overpasses for wildlife in urban fragmented landscapes. *Biota Neotropica*, 13, 117–123.

VAN DER GRIFT, E.A., VAN DER REE, R. & JAEGER, J.A.G. (2015) Guidelines for evaluating the effectiveness of road mitigation measures. In *Handbook of Road Ecology* (eds R. van der Ree, D.J. Smith & C. Grilo). John Wiley & Sons, Chichester, UK.

WAHID, S.D.M., ALIMAN, N.K., HASHIM, S.M. & HARUDIN, S. (2016) First-time and repeat visitors to Langkawi Island, Malaysia. *7th International Economics & Business Management Conference (IEBMC 2015)*, 35, 622–631.

YAP, J.L., ROSELY, N.F.N., MAHADZIR, M., BENEDICT, M.L., MUNIANDY, V. & RUPPERT, N. (2022) 'Ah Lai's Crossing' – Malaysia's first artificial road canopy bridge to facilitate safer arboreal wildlife crossings. *Folia Primatologica*, 93, 255–269.