

Wildlife Crossings at Felda Aring - Tasik Kenyir Road, Malaysia

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ABSTRACT

The Felda Aring - Tasik Kenyir Road was identified as one of the most threatening roads to wildlife in Malaysia. The present study was conducted to assess the road crossing activities involving the medium- to large-mammal species due to the problem stated. The objectives of this study were to (1) predict the suitability of the road and its surroundings as the roaming areas for the Asian elephant (*Elephas maximus*, n = 104) and Malayan tapir (*Tapirus indicus*, n = 66), (2) identify the mammalian species inhabiting the forest beside the road, (3) compare the forest's common species [photographic capture rate index (PCRI) > 10/ detection probability (P) ≥ 0.05] with the ones utilising the road crossing structures; the viaducts and the bridges, and (4) determine the most impacted species from traffic collisions. The road and its surroundings were classified as moderately suitable to the elephant and tapir (suitability values = 0.4 - 0.8). A total of 16 mammal species were recorded at the forest edges, in which the wild pig (*Sus scrofa*) (PCRI = 118.96, P = 0.3719 ± 0.027), barking deer (*Muntiacus muntjak*)

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(PCRI = 68.89, $P = 0.2219 \pm 0.0232$), sun bear (*Helarctos malayanus*) (PCRI = 11.13, $P = 0.0507 \pm 0.0159$), tapir (PCRI = 11.13, $P = 0.0469 \pm 0.0118$), elephant (PCRI = 10.7, $P = 0.0787 \pm 0.0195$), and Malayan porcupine (*Hystrix brachyura*) (PCRI = 10.7, $P = 0.103 \pm 0.0252$) were the common species utilising the crossing structures. In contrast, the Asian palm civet (*Paradoxurus hermaphroditus*) and leopard cat (*Prionailurus bengalensis*) were the most frequently hit species on the road [$F(7,398) = 28.53, p < 0.0005$]. The present study found that large-mammal species were utilising the crossing structures at a higher frequency, whereas more medium-mammal species were involved in traffic collisions.

Keywords: Camera trapping, fragmentation, GIS mapping, roadkill, viaducts

INTRODUCTION

Southeast Asia is home to many endangered megafauna species, including the Asian elephant (*Elephas maximus*), Malayan tiger (*Panthera tigris*), and Malayan tapir (*Tapirus indicus*). These species' population are declining primarily due to habitat loss (Chwalibog et al., 2018; Fernando & Pastorini, 2011; García et al., 2012). In most Southeast Asian countries, the forest area is decreasing with rapid road development. For example, between 2009 - 2016, the evergreen forest and deciduous forest in Thailand were reduced by 8% and 11%, respectively (Trisurat et al., 2019). In 2011 - 2012, Indonesia, the most forested Southeast

Asian country, experienced the world's highest annual rate of forest loss (2.2 million hectares) and expansion of road network by 42% (Alamgir et al., 2019).

Malaysia has undergone rapid infrastructure growth, with 122% growth in road length in a decade. In 2016, the total road length in Peninsular Malaysia was 177,569 km (CEIC, 2016). Malaysia has progressed and gained tremendous success in economic growth and productivity due to its rapid infrastructure development. However, rapid urbanisation has had a significant impact on the surrounding environment.

Major road expansion, particularly within natural habitats, obstructs wildlife's movement and ability to utilise resources. Roads reduce landscape permeability and connectivity by acting as barriers to animal movement through traffic collisions and habitat fragmentation (Ahmad Zafir & Magintan, 2016). The number of wildlife-vehicle collisions (WVC) will most likely increase with rapid road development (Alamgir et al., 2018). In Peninsular Malaysia, there were 350 mammalian individuals killed between 2006 - 2009, 605 between 2010 - 2014, and 535 between 2012 - 2017 due to WVC (Jamhuri et al., 2020; Kasmuri et al., 2020; Sukami, 2016). From this number, the wild pig (*Sus scrofa*), leopard cat (*Prionailurus bengalensis*), long-tailed macaque (*Macaca fascicularis*), Asian palm civet (*Paradoxurus hermaphroditus*), and Malayan tapir were among the most frequently hit species (Jamhuri et al., 2020). A total of 15 individuals of Malayan tapir

were killed between 2006 - 2010 (Magintan et al., 2012), while another 68 were killed between 2012 - 2017 (Kasmuri et al., 2020). A study also found that some of the Peninsular Malaysia roads acted as a solid barrier to elephant movements, with 80% reduction in permeability (Wadey et al., 2018).

Several initiatives from the Malaysian government have been apprehended to mitigate wildlife issues due to road expansion. The Central Forest Spine (CFS) is an important national land-use master plan for maintaining wildlife habitat connectivity across major forest blocks in Peninsular Malaysia (Department of Town and Country Planning, 2009). A study has identified 16 main roads in Southeast Asia that are threatening mammal habitats in which three of them are located in primary linkage (PL) 1 (Tanum Forest Reserve (FR) - Sungai Yu FR), PL 2 (Temengor FR - Royal Belum State Park), and PL 7 (Taman Negara National Park-Tembat FR) of CFS 1 (Clements et al., 2014). The implementation of the CFS plan involved the construction of several viaducts under those three roads (Kasmuri et al., 2020) to reduce road implications and facilitating the wildlife movement, particularly the large-mammal species such as the sun bear (*Helarctos malayanus*), gaur (*Bos gaurus*), Asian elephant, Malayan tiger, and Malayan tapir (Magintan, 2012).

The PL 7 is an important wildlife corridor aimed to maintain the connection between the Taman Negara National Park with Tembat FR despite being bisected by

the road. This connection is crucial as both areas are identified as wildlife hotspots in Peninsular Malaysia (Ratnayeke et al., 2018). While the road's impact has been somewhat mitigated by constructing three viaducts along the Felda Aring - Tasik Kenyir Road, WVC involving large-mammal were still reported (Clements et al., 2012b). This manuscript highlights the road crossing activities, particularly involving the medium- to large-mammal species using the crossing structures (CS) under the road; the viaducts and the bridges. The road and its surrounding's suitability as the roaming areas for the Asian elephant and Malayan tapir were accessed as both species were recognised among the most impacted large-mammal species from road development. Besides, the viaducts were built primarily to assist the movement of both species.

To assess the crossing activities at the Felda Aring - Tasik Kenyir Road, the objectives of the present study were to (1) predict the suitability of the road and its surrounding as the roaming areas for the Asian elephant and Malayan tapir, (2) identify the mammalian species inhabiting the forest beside the road, (3) compare the forest's common species with the ones utilising the road CS; the viaducts and the bridges, and (4) determine the most impacted mammal species from WVC. In achieving the objectives, camera traps were used to record the mammal species inhabiting the forest edges and utilising the CS. Maximum entropy algorithm (MaxEnt) was applied to predict the road's suitability as a wildlife roaming area, and roadkill events involving

medium- to large-mammal species along the road were recorded continuously during the sampling period.

MATERIALS AND METHODS

Study Area

The present study was conducted along the Felda Aring - Tasik Kenyir Road, situated in Tembat FR (Figure 1), the largest FR in Terengganu, Malaysia (1346.92 km²). Located in eastern Peninsular Malaysia, Tembat FR (5°20' to 4°50'N and 102°20' to 102° 60'E) serves as an important connection between the Titiwangsa-Bintang-Nakawan Ranges Forest Complex and the Taman Negara National Park-Eastern Ranges Forest Complex. The highest peak of Tembat FR is the Tembat Mountain, reaching 965 m from sea level. Located near the equator, this rainforest experiences a hot and humid climate throughout the year, with an average temperature ranging from 28 °C to 30 °C during the daytime and relatively cooler at night. The total rainfall at Tembat FR in 2018 was 2320 mm, and April was the driest month (55 mm), while December was the wettest (552 mm).

All the study sites, the forest edges, viaducts, and standard bridges are located along the Felda Aring - Tasik Kenyir Road (Figure 1). The forest edges were the most extensive study site, which acts as the control site representing the natural habitat for mammal species inhabiting the study area. The forest edges data was used as the baseline data to predict the mammal species using the CS to cross the road. The sampling stations in the forest edges were

located at (mean ± SD) 166.50 ± 174 m from the road. Chen and Koprowski (2016) found that some animals did not avoid entering roadside areas, and the probability of crossing random line transects in the forest edges was not affected by distance to roads. According to a study conducted in Peninsular Malaysia, the closest distance between a roadkill location and forest is 4.2 ± 0.3 km (Jamhuri et al., 2020). With reference to these studies, the mammal species recorded at the forest edges have the potential to cross the road.

The viaducts and bridges are the concrete CS built under the road (Figure 2). The Malaysia Public Works Department created the viaducts in 2008 to assist wildlife movement between forest patches. Shrubs and grasses dominated both CS types with fewer existing trees of (mean ± SD) height = 8.35 ± 5.80 m and diameter at breast height (dbh) = 5.40 ± 5.24 cm. In contrast, the vegetation in the forest edges was dominated mainly by understories of bekak (*Aglaia malaccensis*) [Ivi(%) = 6.75], membuluh (*Pellacalyx saccardianus*) [Ivi(%) = 5.46], and huru (*Beilschmiedia madang*) [Ivi(%) = 5.05].

The three viaducts (located between Felda Aring, Kelantan and Kenyir Reservoir, Terengganu) are situated inside the PL 7 (Figure 1) serve as important linkages between the Taman Negara National Park and Tembat - Lebir FRs. Construction of Viaduct 1 (V1: length = 245 m, width = 11.90 m, height = 14.50 m), Viaduct 2 (V2: length = 140 m, width = 12.95 m, height = 13.93 m), and Viaduct 3 (V3: length = 245 m, width = 10.30 m, height = 15.40 m) were

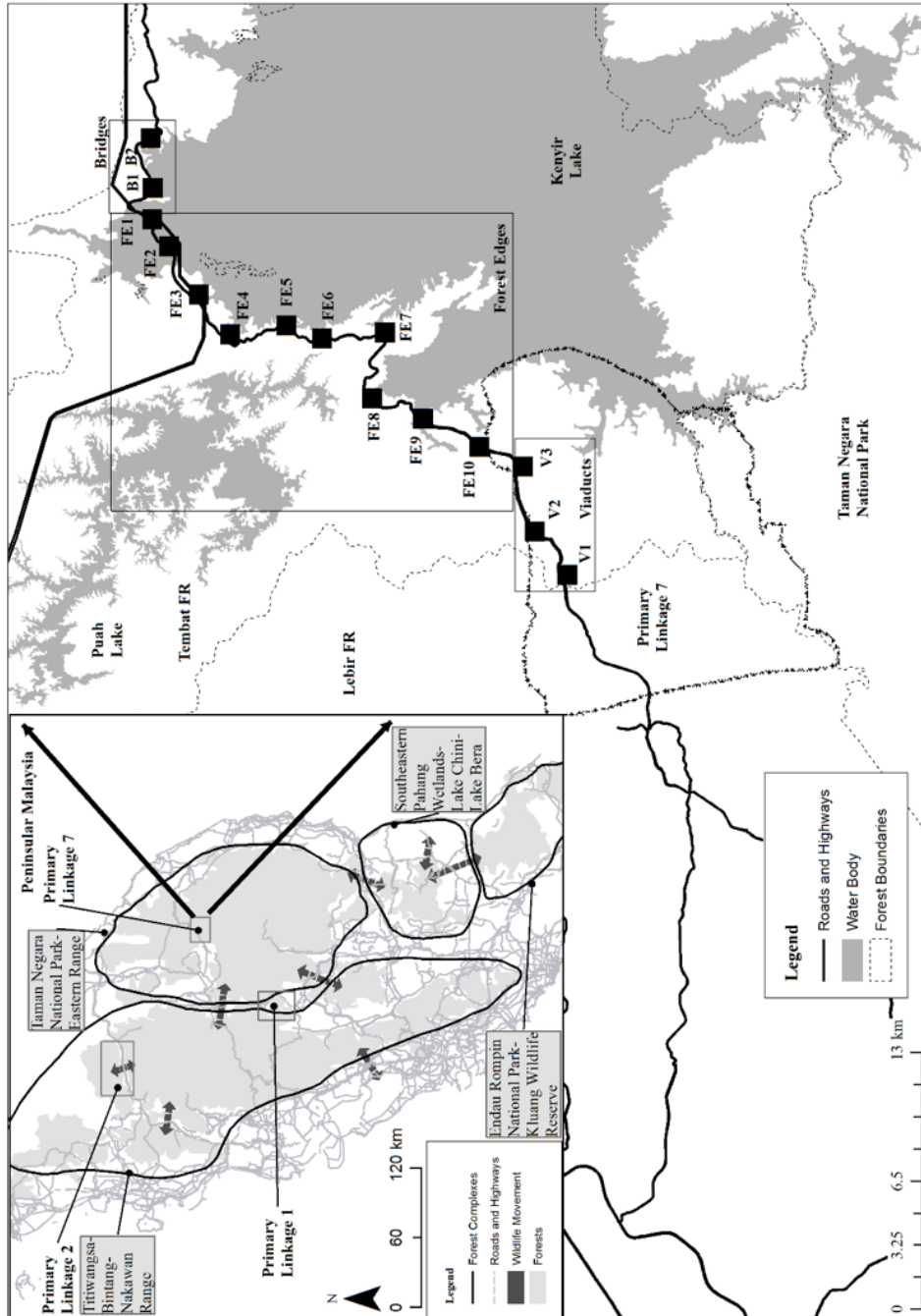


Figure 1. The camera trap stations along the Felda Aring - Tasik Kenyir Road, the road which bisects the primary linkage 7 (PL 7) of Central Forest Spine



(a)



(b)

Figure 2. (a) The viaduct, which was built to assist the wildlife movement; (b) The bridge, which was built to connect the road

Photo credit: Mr. Mohd. Faiz bin Mohd. Yusoff

completed in 2008 (Magintan, 2012) at the cost of RM30 million (Kawanishi, 2014) to mitigate the impact of road development on wildlife movement inside the PL 7 area. The viaducts were built at ± 10 m higher than the average height of adult Asian elephants (240 cm - 300 cm) (Sukumar, 2006) to provide a spacious crossing area to the large-mammal. The animal trails are accessible on both sides of the viaducts.

The CS was built across existing rivers, namely Sg. Kembur at V1, Sg. Kelampai at V2, and Sg. Purun at V3. Pastures of 20,200 m² were planted at V2, and artificial salt licks were introduced at each viaduct by the Department of Wildlife and National Park Peninsular Malaysia (DWNP) (Bakri et al., 2019). In 2018, ten local fruit tree species were planted at the viaducts as part of the present study with the Jabatan Perhutanan Negeri Terengganu's supervision to rehabilitate the area. 'Tampoi' (*Baccaurea kunstleri*), 'santol' (*Sandoricum koetjape*), Malay apple (*Syzygium malaccense*), gandaria (*Bouea macrophylla*), 'jering' (*Archidendron jiringa*), 'asam gelugur' (*Garcinia atroviridis*), 'kerdas' (*Archidendron bubalinum*), bitter bean (*Parkia speciosa*), 'kembang semangkuk' (*Scaphium longiflorum*), and wild almond (*Irvingia malayana*) were the species planted.

Seven other bridges were constructed outside of the PL 7 along the road to meet engineering purposes. However, these bridges were not specifically designed for wildlife crossings (Department of Town and Country Planning, 2009). Most of

the bridges were built to provide passage across the Tasik Kenyir and its tributaries. The bridges were built at the two-way road with guardrails installed on both sides with no divider built in the middle. The forest edges and hillside terraces sandwich the road (Figure 2). Two bridges; Bridge 1 (B1: length = 140.39 m, width = 9.30 m, height = 17.70 m) and Bridge 2 (B2: length = 166.06 m, width = 9.36 m, height = 17.37 m) were selected as the study sites. The selected bridges are the farthest bridges from the nearest village; Kampung Basung, Hulu Terengganu. Bridges were selected based on the level of human disturbance to avoid vandalism of the camera traps. Bridges without wildlife passage and dominated by water bodies were not selected as the study sites.

Data Gathering and Analysis

Prediction of Roaming Areas for *Elephas maximus* and *Tapirus indicus* Near Felda Aring - Tasik Kenyir Road. The distribution of *E. maximus* (n = 104) and *T. indicus* (n = 66) at the road and its surroundings were predicted using the occurrence data (n) collected from the year 2003 - 2008 (Figure 3). The occurrence data was based on sightings, footprints, faecal matter, and feeding signs of both species, collected by the DWNP rangers during their routine patrol in the forests. Factors including slope, elevation, land use types, soil types, and distance to rivers and roads were used to predict the distribution (Table 1). All the variables were converted into a raster format. The correlation between each

parameter was tested using the Pearson correlation in which the variables with a correlation coefficient $r > \pm 0.8$ were excluded from the analysis. This step was taken to reduce errors in the contribution of interrelated variables in the prediction (Yi et al., 2016). Subsequently, the selected variables were converted to ASCII format and analysed by MaxEnt software version 3.3.3a with the default setting (convergence threshold = 10^{-5} , maximum iterations = 500,

regularisation parameter of 1.0). MaxEnt consists of an algorithm that estimates the probability of distribution and produces the most uniform information in the targeted area (Phillips et al., 2006). In this study, the PL 7 and the Felda Aring - Tasik Kenyir Road suitability as wildlife roaming areas were assessed based on the predicted distributions of both *E. maximus* and *T. indicus*.

Table 1

The variables used for assessing suitable roaming areas for Tapirus indicus and Elephas maximus using the maximum entropy algorithm

Variables	Unit/Format	Data source	Type
Land Use	–	JUPEM	Categorical
1 = Non-agriculture			
2 = Forest			
3 = Road and utility			
4 = Mine			
5 = Others			
6 = Urban			
7 = Agriculture			
8 = Water body			
Distance to river	Kilometre (km)	JUPEM	Continuous
Distance to roads and urban	Kilometre (km)	JUPEM	Continuous
Altitude	Metre (m)	SRTM	Continuous
Gradient (derive from altitude)	Degree (°)	SRTM	Continuous
Lithology	–	JMG	Categorical
1 = Intrinsic acid rocks, mud, and clay			
2 = lime stones and alluvium			

Note. JUPEM = Department of Survey and Mapping Malaysia, SRTM = Shuttle Radar Topography Mission, JMG = Mineral and Geoscience Department Malaysia

Wildlife Crossings at Felda Aring - Tasik Kenyir Road

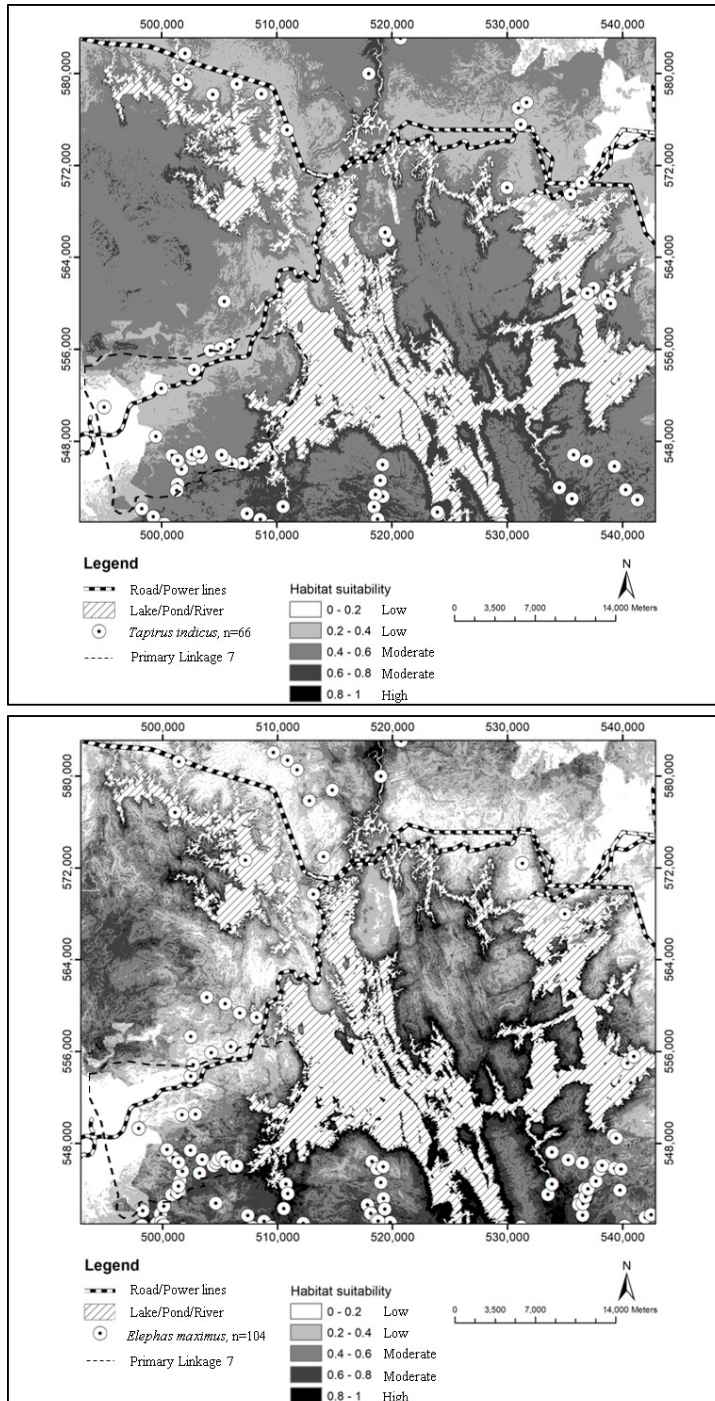


Figure 3. Prediction of the Felda Aring - Tasik Kenyir Road suitability as roaming area for *Tapirus indicus* (n = 66) and *Elephas maximus* (n = 104) based on the GIS: maximum entropy algorithm. The predictive maps were reclassified into five classes with the logistic threshold of 0.2

Camera Trapping. Digital camera traps (16 MP, 20 m infrared night vision, IP65 water resistance, ARTITAN brand) were used to record the presence of wildlife in the study area. The camera traps with 0.6 s trigger speed were powered by four AA-sized alkaline batteries and equipped with an eight GB SD card. A total of 33 camera traps were positioned in all study sites covering a whole area of 75.01 km² in which 20 camera traps were placed at ten stations in the forest edges, nine camera traps at the viaducts, and four camera traps at the bridges.

Camera trapping layouts used for data collection in the forest edges included systematic placement and random allocation following the road as a line transect. In contrast, deliberately-biased placement was applied at both CS types (Meek et al., 2014). The starting point for camera trapping was initiated at a random position in the forest edges while the other stations were located at 2.36 ± 1.2 km intervals. Two camera traps were placed at each station with a distance of 210.79 ± 185 m from each other. Random allocation was added to the systematic placement if needed due to habitat and geographical constraints. The deliberately-biased placement was used at the CS targeting the crossing area located under the road as the focal point. The number of camera trap replicates at each CS depended on the CS's length, column structures distance, and river width, including two to three camera traps at approximately 64 \pm 15 m intervals.

The camera traps were operated for eight months from December 2017 to July 2018.

All wildlife images captured due to motion and heat triggers were defined as events. In contrast, consecutive images of different individuals of different species, consecutive images of individuals of the same species taken more than 60 minutes apart (Meek et al., 2014), and non-consecutive images of individuals of the same species were defined as independent events (N) (O'Brien et al., 2003). The camera traps were set to capture three photos in one trigger with a 60 s delay between each trigger. All camera traps were mounted on trees at least 0.3 m (Meek et al., 2014) above the ground, perpendicular and approximately 3 m to the animal trails in the forest edges. At the CS, the camera traps were mounted on a 1 m steel pole at least 0.3 m above the ground. Habitat clearing was performed at all study sites to avoid false triggers by leaves and clear the view. No bait was used to prevent recapturing images of the same individuals. The changing of batteries, retrieval of images, and camera trap replacement due to theft and damage were performed after at least one month of operation.

All captured images were identified to species level with the aid of Francis (2019) and sorted through the digiKam 7.2.0 photo management application. To avoid sequences of photos of a particular individual, a period of 60 minutes was used to differentiate the individual mammal photographs. The camtrapR package (Niedballa et al., 2016) in R-3.5.0 software (R Core Team, 2019) implements a temporal independence filter between images of the same species at the same station (argument `minDeltaTime`

= 60 minutes). By setting to 60 minutes, the number of independent events of each species at each station was produced from images taken at least 60 minutes after the same species/individual's last record at the same station (Niedballa et al., 2016). All functions for downstream analysis depend on the number of independent events produced.

The most common mammal species in the forest edges that crossed both CS types were identified. Each species' independent events from each camera trap (N) were used to calculate the photographic capture rate index (PCRI) in each study site using the equation: $PCRI = N * 1000 / \sum \text{trap nights}$ (Table 2). Each species' PCRI was assigned to three rank abundance categories, i.e., < 10 = rare species, $10 - 100$ = common species, and > 100 = abundant species (Bartholomew, 2017). PCRI was used to reduce bias in the frequency of detection when sample sizes were unequal for each study site.

Furthermore, the relative abundance index (RAI) for each sampling station was calculated (Table 3), and a map of RAI versus species richness was developed to quantify all 15 stations' effectiveness as wildlife crossings independently (Figure 4). Species richness was defined as the total number of mammal species detected at each station over the entire camera trap duration, and the relative abundance was calculated using the equation: $RAI = 100 * (N / \sum \text{trap nights})$. RAI was used to reduce bias among stations by standardising

each station's independent events into 100 days of sampling efforts (Clements, 2011).

The camtrapR package also computes detection/non-detection data (1, 0) for use in occupancy analysis. One camera trap week (7 days) was compressed to represent each survey. PRESENCE software (Hines, 2006) was used to obtain the occupancy estimates (Ψ) and detection probabilities (P) of each species at each study site (Table 2).

Roadkill. The WVC involving medium- to large-mammal species along the Felda Aring - Tasik Kenyir Road was recorded during the eight-month sampling period. Data were collected by four observers in a moving vehicle [Toyota Hilux Double Cab 2.4G (MT) 4 x 4] at a speed of 50 km/h using a GPS (Garmin GPSMAP 64s) and a digital camera (Olympus TG-870). Surveys were made during early hours every three days, checking both sides of the road. Whenever a road-killed animal was detected, the carcass was identified to the lowest possible taxonomy, pictures were taken, and the geographic coordinate position was recorded with 3 m accuracies. By referring to Santos et al. (2011), three days were selected as the survey's interval in the present study since medium- to large-species had the longest persistence time on the road, which is three to seven days. A graph of roadkill number versus species was plotted to determine the most frequently hit species on the road during the sampling period, and multivariate analysis was conducted to support the findings.

Table 2
The independent events (N) of each mammal species recorded in each study site at 60 minutes intervals. The photographic capture rate index (PCRI) was used to identify the common mammal species in the forest edges using the equation: $N*1000/\sum \text{trap nights}$. Occupancy (Ψ) and detection probability (P) was calculated from detection/non-detection data grouped into camera trap weeks

Order	Species	Common name	Forest edges (FE)					Viaducts (V)					Bridges (B)				
			N	PCRI	Ψ	P	N	PCRI	Ψ	P	N	PCRI	Ψ	P	N	PCRI	Ψ
Artiodactyla	<i>Capricornis sumatraensis</i>	Sumatran serow	3	1.28	1 ± 0	0.0094 ± 0.0054	0	—	—	—	—	—	—	—	—	—	—
	<i>Muntiacus muntjak*</i>	Barking deer	161	68.89	1 ± 0	0.2219 ± 0.0232	228	124.05	1 ± 0	0.7742 ± 0.0434	7	13.57	1 ± 0	0.1714 ± 0.0637			
	<i>Sus scrofa*</i>	Wild pig	278	118.96	1 ± 0	0.3719 ± 0.027	50	27.2	1 ± 0	0.3118 ± 0.048	1	1.94	1 ± 0	0.0256 ± 0.0253			
	<i>Tragulus sp*</i>	Mouse-deer	25	10.7	0.64 ± 0.1683	0.083 ± 0.0215	0	—	—	—	—	—	—	—			
Carnivora	<i>Canis lupus familiaris</i>	Domestic dog	2	0.86	1 ± 0	0.0062 ± 0.0044	0	—	—	—	—	—	—	—	—	—	
	<i>Catopuma temminckii</i>	Asian golden cat	4	1.71	0.6435 ± 0.5405	0.0194 ± 0.0184	0	—	—	—	—	—	—	—	—	—	
	<i>Paguma larvata</i>	Masked palm civet	0	—	—	—	1	0.54	1 ± 0	0.0104 ± 0.0104	0	—	—	—	—	—	
	<i>Panthera pardus</i>	Leopard	5	2.14	1 ± 0	0.0156 ± 0.0069	0	—	—	—	—	—	—	—	—	—	
	<i>Pardofelis marmorata*</i>	Marbled cat	4	1.71	0.2467 ± 0.1679	0.0507 ± 0.0318	0	—	—	—	—	—	—	—	—	—	
	<i>Prionailurus bengalensis</i>	Leoprad cat	0	—	—	—	10	5.44	0.6721 ± 0.2745	0	—	—	—	—	—	—	
	<i>Martes flavigula</i>	Yellow-throated marten	2	0.86	1 ± 0	0.0062 ± 0.0044	0	—	—	—	—	—	—	—	—	—	

Table 2 (Continued)

Order	Species	Common name	Forest edges (FE) 2337				Viaducts (V) 1838				Bridges (B) 516					
			N	PCR	Ψ	P	N	PCR	Ψ	P	N	PCR	Ψ	P		
	<i>Helarctos malayanus*</i>	Sun bear	26	11.13	0.987 ± 0.1994	0.0507 ± 0.0159	0	—	—	—	1	1.94	1 ± 0	—	—	0.0256 ± 0.0253
	<i>Paradoxurus hermaphroditus</i>	Asian palm civet	1	0.43	1 ± 0	0.0031 ± 0.0031	3	1.63	1 ± 0	0.0323 ± 0.0183	0	—	—	—	—	—
	<i>Viverra tangalunga</i>	Malayan civet	2	0.86	1 ± 0	0.0062 ± 0.0044	1	0.54	1 ± 0	0.0108 ± 0.0107	0	—	—	—	—	—
	<i>Viverra zibetha</i>	Large Indian civet	0	—	—	—	5	2.72	0.822 ± 0.3937	0.0523 ± 0.0328	0	—	—	—	—	—
Perissodactyla	<i>Tapirus indicus*</i>	Malayan tapir	26	11.13	1 ± 0	0.0469 ± 0.0118	76	41.35	1 ± 0	0.4194 ± 0.0512	15	29.07	1 ± 0	—	—	0.2564 ± 0.0699
Primates	<i>Macaca nemestrina*</i>	Southern pig-tailed macaque	12	5.13	0.316 ± 0.1537	0.089 ± 0.031	0	—	—	—	0	—	—	—	—	—
	<i>Macaca fascicularis</i>	Long-tailed macaque	0	—	—	—	0	—	—	—	1	1.94	1 ± 0	—	—	0.0208 ± 0.0206
Proboscidea	<i>Elephas maximus*</i>	Asian elephant	25	10.7	0.7549 ± 0.1613	0.0787 ± 0.0195	13	7.07	1 ± 0	0.0968 ± 0.0307	0	—	—	—	—	—
Rodentia	<i>Hystrix brachyura*</i>	Malayan porcupine	25	10.7	0.5159 ± 0.1638	0.103 ± 0.0252	11	5.98	0.3333 ± 0.2722	0.3226 ± 0.084	0	—	—	—	—	—

Note. Species* = Common mammal species recorded in the forest edges with PCR > 10/ P ≥ 0.05; N = Independent events from Camera trapping; PCR = Photographic capture rate index; Ψ = Occupancy estimates; P = Detection probabilities

Table 3

The total number of species and independent events (*N*) in each study site. The relative abundance index (RAI) was calculated to standardise the sampling efforts of each sampling station into 100 days using the equation: $100*(N/\Sigma\text{trap nights})$, where *N* = independent events at 60 minutes intervals

Sampling stations	Total number of species	N	RAI
FE1	7	57	2.44
FE2	4	18	0.77
FE3	8	46	1.97
FE4	9	44	1.88
FE5	10	171	7.32
FE6	7	76	3.25
FE7	6	18	0.77
FE8	8	66	2.82
FE9	6	59	2.52
FE10	12	46	1.97
V1	7	98	5.33
V2	8	160	8.71
V3	6	140	7.62
B1	3	16	3.1
B2	4	9	1.74

Note. N = Independent events from Camera trapping; RAI = Relative abundance index

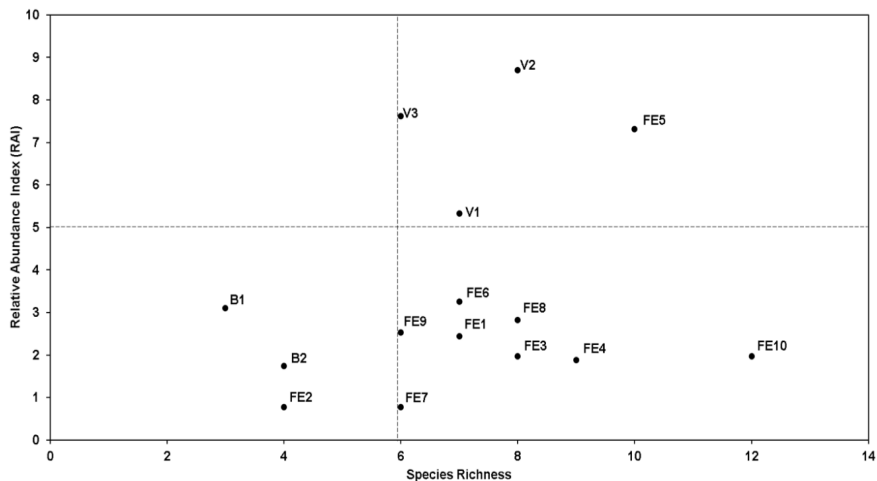


Figure 4. Each camera trap station was plotted based on the relative abundance index (RAI) and species richness. RAI was calculated using the equation: $100*(N/\Sigma\text{trap nights})$, where *N* = independent events at 60 minutes intervals. Each camera trap station is representing a wildlife crossing area

RESULTS

Prediction of Roaming Areas for *Elephas maximus* and *Tapirus indicus* Near Felda Aring - Tasik Kenyir Road

The present study generated a useful MaxEnt prediction with an area under the curve (AUC) > 0.7 in which values close to 1 refer to high prediction model accuracy (Yang et al., 2013; Yi et al., 2016). Based on the selected variables collected before the enrichment activities, the model categorised the study area into five classes with suitability values ranging from 0, the lowest suitability value to 1, the highest suitability value (Figure 3). The maps in Figure 3 show that majority of the study area was moderately suitable as roaming areas for both *T. indicus* (n = 66) and *E. maximus* (n = 104) with suitability values of 0.4 - 0.8. However, this suitability was disconnected at the Felda Aring - Tasik Kenyir Road, indicated with suitability values between 0 and 0.4. Most of the PL 7 area, including the viaducts, was recognised as less to moderately suitable as a wildlife crossing area with suitability values ranging from 0 to 0.8. The viaducts, however, are sandwiched by moderately suitable habitats with suitability values between 0.4 and 0.8.

Camera Trapping

The camera trap sampling efforts include a total of 4,691 trap nights, which exclude the days when the cameras were not functioning due to technical problems, getting stolen, and being damaged. These sampling efforts yield a total of 3,282 events of 33 wildlife

species comprised of six birds, two reptiles, and 25 mammal species, including five small and 20 medium- to large-mammal species. Out of all recorded medium- to large-mammal species, 16 were recorded at the forest edges while ten were recorded at the viaducts, and five were recorded at the bridges (Table 2). Based on the PCRI, the most common large-mammal species in the forest edges (PCRI > 10) were the *S. scrofa* (PCRI = 118.96), barking deer (*M. muntjak*) (PCRI = 68.89), *H. malayanus* (PCRI = 11.13), *T. indicus* (PCRI = 11.13), and *E. maximus* (PCRI = 10.7) while the mouse-deer (*Tragulus* sp.) (PCRI = 10.7) and Malayan porcupine (*H. brachyura*) (PCRI = 10.7) were the most common medium-mammal in the forest edges.

The probability of detecting a species in the forest edges during a survey (P) was higher (≥ 0.05) for the *S. scrofa* (P = 0.3719), *M. muntjak* (P = 0.2219), *E. maximus* (P = 0.0787), *H. malayanus* (P = 0.0507), and *T. indicus* (P = 0.0469). Besides, the probability of detecting a *Tragulus* sp. (P = 0.083), *H. brachyura* (P = 0.103), marbled cat (*Pardofelis marmorata*) (P = 0.0507), and pig-tailed macaque (*Macaca nemestrina*) (P = 0.089) was higher compared to other medium-mammal. Four of the listed common large-mammal species were recorded at both CS types, except for *H. malayanus* at the viaducts and *E. maximus* at the bridges while *H. brachyura* was the only common medium-mammal species recorded at the viaducts. Based on this analysis, the usage of both CS types by the common large-mammal was nearly equal to that observed in the forest edges.

The RAI versus species richness map was generated to compare each camera trap station's effectiveness as a wildlife crossing (Figure 4). The map classifies stations with high species richness and high RAI (indicates a higher frequency of mammals' crossings) at its top-right quadrant and *vice versa*. All viaducts were categorised as effective wildlife crossings since all of them were plotted on the top-right quadrant. In contrast, the bridges were classified as the least effective wildlife crossings since both were plotted on the bottom-left quadrant. The map also indicates V2 as the most effective crossing compared to the other viaducts.

Roadkill

A total of five medium- to large-mammal species were killed along the Felda Aring - Tasik Kenyir Road during the sampling

period due to WVC (Figure 5). From those species, *P. hermaphroditus* and *P. bengalensis* recorded the highest number of cases ($n = 4$), followed by *S. scrofa* ($n = 2$), silvery langur (*Trachypithecus cristatus*), and spectacled langur (*Trachypithecus obscurus*) ($n = 1$), in which *S. scrofa* and *P. hermaphroditus* were the only species recorded at the viaducts. There was a statistically significant difference in road crossing activities (roadkill versus viaduct) based on species from multivariate analysis, $F(7,398) = 28.53$, $p < 0.0005$. Post hoc comparison using the Tukey HSD test indicated that the mean score for road crossing activities was statistically significantly different between *P. hermaphroditus* and *P. bengalensis* with other species ($p < 0.005$), which means that both species are at risk to be involved in WVC compared to other

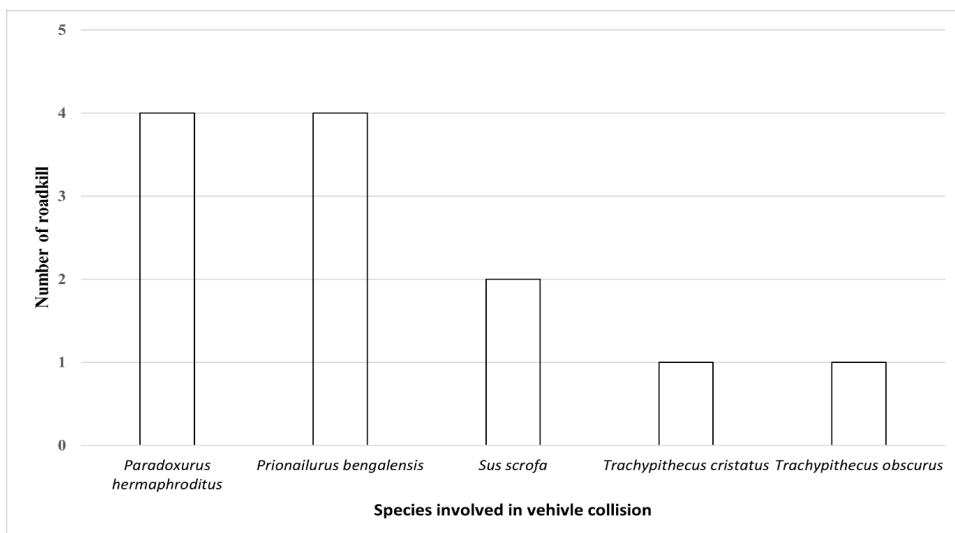


Figure 5. Medium- to large-mammal species involved in wildlife-vehicle collisions along the Felda Aring - Tasik Kenyir Road during the sampling period

mammal species, that are utilising the viaducts. There was no roadkill recorded for the common medium- to large-mammal species utilising the CS, i.e., *E. maximus*, *M. muntjak*, *T. indicus*, *H. malayanus*, and *H. brachyura*, except for *S. scrofa*. Besides, no roadkill recorded for other medium-mammal species utilising the viaducts, i.e., the masked palm civet (*Paguma larvata*), Malayan civet (*Viverra zibetha*), and large Indian civet (*Viverra zibetha*).

DISCUSSION

Prediction of Roaming Areas for *Elephas maximus* and *Tapirus indicus* Near Felda Aring - Tasik Kenyir Road

Prediction of wildlife distribution is one of the analyses that must be performed to identify the forest's connectivity zones to mitigate the road impacts toward wildlife (Poor et al., 2012). MaxEnt algorithm is the widely used landscape analysis that produces good predictions of species distribution (Poor et al., 2012) compared to other species distribution models (SDM) such as analytic hierarchy process (AHP), genetic algorithm for rule-set production (GARP), BIOCLIM, and DOMAIN. MaxEnt is based on a machine learning response designed to make predictions from incomplete input information (Baldwin, 2009), such as previous distribution data with the selected set of environmental, climatic, and spatial variables of the input (Abidin et al., 2019). MaxEnt also has been used to predict suitable habitats for wildlife species (Kabir et al., 2017; Mohd Taher et

al., 2017), which is essential in predicting the habitat connectivity zones (Mohd Taher et al., 2017). A study found that 10 out of 12 published works implementing SDM in Malaysia used MaxEnt as their preferred modelling method (Rahman et al., 2019).

The *H. malayanus* was listed as one of the common large-mammal species in the study area. However, this species was recorded only once at the CS, suggesting road avoidance behaviour. This finding is supported by Nazeri et al. (2012), which found that the sun bear has a strong preference for dense forests and avoids open areas and roads based on the SDM.

The low habitat suitability values at the viaducts were anticipated because roads were recognised as barriers to most of the wildlife species by SDM (Angelieri et al., 2016; Radnezhad et al., 2015). This finding is similar to a study conducted in Taman Negara National Park which found that the suitable habitat for *Tragulus* sp. was not connected due to the presence of road between forest blocks (Mohd Taher et al., 2018). However, the moderately suitable habitats, including the Taman Negara National Park, Tembat FR, and Lebir FR, which surround the viaducts, are predicted to enhance viaducts' usage and the PL 7 as well. The strategic location of viaducts facilitates mammals' movement across the road and directly increases viaducts' usage. Hence, the present study supports the selection of viaducts' location and the PL 7 area as an ecological linkage since this area is located between the important wildlife roaming habitats (Magintan et al., 2015).

The road's suitability value as roaming areas for *T. indicus* was higher than *E. maximus* indicates that *T. indicus* has a higher chance of crossing the road. From 2006-2010, 142 individuals of Malayan tapir were displaced from its natural habitats in Peninsular Malaysia. From this number, 27 individuals have died due to injuries and WVC (Magintan et al., 2012). The high PCRI and P-value at viaducts and no roadkill recorded in the study area indicate viaducts' success in attracting utilisation by the Malayan tapir.

Camera Trapping

A field survey of medium- to large-mammal species by camera trapping is required to support the predictive model developed by MaxEnt. MaxEnt algorithm works with single species (Baldwin, 2009) and provides a useful predictive model for a species. However, many other important wildlife species inhabit the study area, which also needs to be surveyed. Hence, camera trapping is required to collect simultaneous multiple species data in the study area (Burgar et al., 2018). The results from both analyses can be compared to determine the effectiveness of mitigation measures taken at the low suitability areas predicted by undertaking the field survey after completing the mitigation plans, such as the habitat enrichments.

The present study revealed a slightly decreasing pattern of mammal species diversity than the previous studies conducted in the same area. Asian wild dog (*Cuon*

alpinus), bearcat (*Arctictis binturong*), and Malayan tiger, which were recorded by previous studies (Clements, 2013; Nurul-Adyla et al., 2016), were not recorded in the present study. Moreover, Nurul-Adyla et al., (2016) did not record the presence of Sambar deer (*Rusa unicolor*) and clouded leopard (*Neofelis nebulosa*), which were previously recorded by Clements (2013). However, the abundance of *S. scrofa* and *M. muntjak* in the present study was similar to that reported in the previous studies. The decreasing pattern of mammal diversity in the study area is most probably related to the clear-felling of natural forests to develop the hydroelectric dam in Tembat FR and Petuang FR in 2013 (Clements, 2013). About 43.41% increase of logged-over forest was detected in the same year (Magintan et al., 2017). In 2016, the water body's size increased by 96.60% from its initial size due to the dam's impoundment. A total of 244 mammals were rescued during the impoundment; however, no conflict or rescue of large mammals recorded (Nur-Syuhada et al., 2016). Large mammals were expected to leave the habitat, as reported by Magintan et al. (2020).

Similar to the present study, camera trap studies in Jerangau FR and Taman Negara Kelantan and Terengganu managed to record the presence of arboreal species; *M. fascicularis* and *M. nemestrina* (Abd Gulam Azad, 2006; Jambari et al., 2015). However, other species such as *Prebytis* sp. and *Trachypithecus* sp. could not be recorded by the camera traps due to their strictly arboreal behaviour. Because of the

restriction, road crossing activities involving these species could not be assessed.

Sampling effort was the highest at the forest edges, and the chosen area was the largest to maximise capture rate (Tobler et al., 2008) to determine the most common large-mammal in the study area. The presence of most of the common large-mammal at the CS indicates the success of both CS types in attracting the common large-mammal to utilise a narrow and limited wildlife crossing. This interpretation was made with reference to Srbeek-Araujo and Chiarello (2013), which found that the mammal communities sampled in the forest were supposed to differ significantly from those sampled on the roads. Furthermore, the comparable results among the viaducts and bridges also revealed the potential of standard bridges to indirectly facilitate road crossing at a reduced cost. The present study found the similarity in the number of species recorded at the forest edges and the viaducts, suggesting some similarity between enriched limited space located under the road and the unlimited space above the road.

The presence of the common large-mammal species was used as the subject for comparison due to the higher requirements for this group to move between habitat patches because of their larger home range sizes (Abd-Gani, 2010; Abidin et al., 2019; Bahar et al., 2018). Due to that reason, *E. maximus* was expected to be recorded at all study sites. Nevertheless, this species was not recorded at any bridge. Although the bridges can become a safer crossing option

for wildlife, this CS type was considered unfavourable to the elephants. An underpass is considered to be safer when it can reduce WVC (Magintan, 2012) and functional when it can reduce mortality and increase movement, meet the animals' biological requirements, facilitate dispersal and recolonisation, and assist redistribution of populations in response to disturbance (Clevenger & Huijser, 2011).

In some parts of this county, major roads increase the possibility of direct mortality due to WVC (Abd Gulam Azad, 2006). A study found that the Asian elephant is attracted to the roadsides (Wong et al., 2018a). A total of 750-road crossing events were recorded during the study period (Wadey et al., 2018). Due to their requirements to cross the road, many roadkill events involving this species were reported (Jamhuri et al., 2020; Kasmuri et al., 2020; Sukami, 2016; Timbuong, 2019; Wong et al., 2018a). These roadkill events can be reduced if the wildlife is attracted to cross the road via a bridge that is free from traffic.

Factors including the lack of habitat enrichment activity, essential sources, and other physical factors might cause elephants' avoidance of the bridges. The frequent presence of elephants on the East-West Highway (Wadey et al., 2018; Wong et al., 2018b) and the placement of warning signages for elephants on the road (Timbuong, 2019) show a high tendency for this species to not using the CS. On the other hand, the viaducts were explicitly designed to connect the elephants' main landscapes (Saaban et al., 2011).

The high species richness and RAI at viaducts justify that area's fitness as a suitable wildlife crossing area (Clements, 2011). This fitness, which was previously absent based on SDM, resulted from the government's financial support to mitigate road development's impact on wildlife movement inside the PL 7 area (Department of Wildlife and National Park [DWNP], 2013).

Both *H. brachyura* and *Tragulus* sp. were the common medium-mammal species in the forest edges based on the PCRI and P values. However, *Tragulus* sp. was neither recorded at any CS nor involved in WVC. According to Mohd Taher et al. (2018), *Tragulus* sp.'s habitat is more dependent on the river's presence but away from the urban area, such as roads. On the other hand, *H. brachyura* was frequently involved in WVC (Jamhuri et al., 2020; Kasmuri et al., 2020). The presence of this species at viaducts suggests viaducts' success in attracting the utilisation by *H. brachyura*.

The camera traps positioned at the viaducts captured a higher frequency of human images than other study locations. Researchers and local villagers were among the recorded humans at the viaducts. Since most of the mammalian species in the forest edges were recorded at the viaducts, the present study supports that most mammalian species can adapt to human presence. Furthermore, no significant differences in mammals' activity patterns recorded from the camera traps in the National Park between the open and closed tourist seasons suggest that human presence has limited

effects on wild mammals' behaviour (Ota et al., 2019).

Habitat Enrichment

Several habitat enrichment activities such as the deployment of artificial salt licks (Bakri et al., 2019; Magintan et al., 2015), the establishment of pastures (Bakri et al., 2019; DWNP, 2013), and the planting of local fruit trees (Shu-Aswad Shuaib, 2017) taken near the viaducts were among the factors that improve the usage of the viaduct and facilitates the large-mammals' movement across the road. These strategies are essential in upgrading the less suitable habitats (based on the MaxEnt analysis) to an effective wildlife crossing (based on the field survey data). The essential resources provided at the PL 7, including additional food, minerals, and water, have successfully attracted the herbivores to cross the road safely, although roads are known as one of the leading causes of wildlife avoidance (Fahrig & Rytwinski, 2009).

The PCRI and P values of *M. muntjak* and *T. indicus* at the viaducts were higher than other species suggesting viaducts' success in attracting a very high frequency of herbivore species. The strategic location of viaducts that connect the two main forest blocks (Saaban et al., 2011) also provides more suitable areas for wildlife crossings than other stations. The higher preference for viaducts was also aided by the rivers as a water source and dense bushes, which are one of the preferred herbivores' habitat features (Farida et al., 2006).

Roadkill

The success of enrichment activities taken at the viaducts in attracting wildlife to cross-over was observed. This finding also shows that the risk for wildlife not using the viaducts as a crossing option is low, except for certain medium-sized species such as *P. hermaphroditus* and *P. bengalensis*. Nonetheless, both species are commonly involved in traffic collisions (Kasmuri et al., 2020); as such, *P. bengalensis* was usually hit in the agricultural area, especially near oil palm and rubber plantations (Laton et al., 2017). The researchers also recorded a higher frequency of *P. hermaphroditus* on the roads compared to the forests (Wilting et al., 2010). This species uses roads as an excretory site, which is vital as a medium for communication (Nakabayashi et al., 2014). The presence of *P. hermaphroditus* on the roads also related to the abundance of plant food such as 'sesendok' (*Endospermum diadenum*) and figs (*Ficus* spp.) along the roadside (Nakashima et al., 2010).

The viaducts have successfully become the preferred crossing option for the large-sized herbivores based on their abundance at the viaducts and no roadkill recorded throughout the study period. Kasmuri et al. (2020) reported that among the most frequently hit species in Peninsular Malaysia was the *T. indicus*. Although no roadkill involving *T. indicus* was recorded in the present study, this species is at risk of being hit at any roads in Peninsular Malaysia since the forest in this country contains 69% of its predicted suitable habitats (Clements et al., 2012a). On the other hand, there was

no roadkill recorded for the barking deer in Peninsular Malaysia between 2012-2017 (Kasmuri et al., 2020). This result suggests the road avoidance behaviour adopted by this species, instead choosing to utilise the viaducts in the PL 7.

The present study found that the medium-mammal species was frequently hit at the road compared to the large-mammal. This finding suggests the enrichment of the CS to attract higher medium-mammal utilisation, particularly *P. hermaphroditus* and *P. bengalensis*. Fruit trees such as papaya (*Carica papaya*) and jackfruit (*Artocarpus heterophyllus*) can be planted to attract *P. hermaphroditus* and the prey of *P. bengalensis* (Jothish, 2011).

CONCLUSION

The present study had successfully recorded the utilisation of the Felda Aring - Tasik Kenyir Road as mammals' crossings. It was found that the road's surrounding was moderately suitable as roaming areas for both *Elephas maximus* and *Tapirus indicus*, and this suitability serves as a benchmark for assessing the roaming areas for other herbivorous species. Most of the common large-mammal species inhabiting the forest edges were recorded utilising the CS, and the viaducts were categorised as the most effective wildlife crossing along the road. However, the medium-mammal species were frequently hit on the road. The present study found that the essential resources provided near the viaducts are crucial to increasing the viaducts' utilisation, encouraging safer road crossings, and

facilitating the wildlife movement, primarily the herbivorous across forest patches. The present study suggests a follow-up study in the future to assess the viaducts usage when the trees planted at the viaducts start to bear fruits. It is predicted that the viaducts' utilisation will become more critical in the future when the road usage is increased and the surrounding habitat is reduced.

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