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IMPACTS OF HUMAN ACTIVITY ON WILD MAMMAL DETECTION RATES AND DIEL ACTIVITY PATTERNS IN ENDAU-ROMPIN NATIONAL PARK, MALAYSIA

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Nonlethal wildlife tourism has potential to support the sustainable use of protected rainforests; however, activities associated with tourism may negatively affect ecology and wildlife behaviour. Abundance and diel activity pattern of wildlife is crucial to understand how they respond to environmental factors. In the present study, we examined whether human activities impact the spatiotemporal patterns of wild mammal communities in a tourist area of Endau-Rompin (Peta) National Park, Malaysia. Using video camera traps, we assessed the detection rates and diel activity patterns of wild mammals along roads in an area near tourist lodgings and a remote area. During a 250-day camera trapping survey, we identified at least 21 species of medium and large mammal. Although the volume of car and motorcycle traffic was significantly higher in the visitor area than the remote area, there were no significant differences in the detection rates of most mammals between the two areas. The diel activity patterns of four species did not differ between the two areas. However, *Tragulus* species showed different diel activity patterns in the visitor and remote areas, possibly a response to predators, as large carnivores were not observed in the visitor area. These findings emphasise the importance of considering not only direct human impacts but also indirect impacts through interspecific interactions.

Keywords: Mammal community, park management, protected area, road, tourism, vehicle, video-camera trap, visitor

INTRODUCTION

The wildlife found in protected rainforests can attract tourists (Aihara et al. 2016), although wild animals often perceive humans as a threat, and seek to minimise human encounters (Frid & Dill 2002). Even when tourist activities are nonlethal, they may affect wildlife, such as feeding and breeding patterns, parent–offspring bonds and vulnerability to competitors (Roe et al. 1997).

Diel activity of wild mammals is crucial to understand not only their daily activities such as feeding and breeding, but also their coexistence mechanisms in relation to interspecific competition and/or niche separation, especially among species (e.g. Nakabayashi et al. 2021). The diel activity patterns of wild mammals are influenced by many physical and biological factors (Linkie & Ridout 2011, Ross et al. 2013, Bennie et al. 2014, Ngoprasert et al. 2017, Gaynor et al. 2018a). Wild mammals may alter their diel activity patterns in the presence of humans, such as tourist areas and settlements (Gray & Phan 2011, Gaynor et al. 2018b). For example, Ota et al. (2018) showed that the activities of bearded pigs (*Sus barbatus*) and southern red muntjacs (*Muntiacus muntjak*) inhabiting a Malaysian national park did not differ significantly between the open (with tourists) and closed (few tourists) seasons. By contrast, leopards (*Panthera pardus*) tended to move more frequently and exhibited more diurnal activity during periods closed to tourism in a national park in Thailand (Ngoprasert et al. 2017). The spatial context of human activities may also affect the diel activity patterns of wild mammals in protected areas. For example, African elephants (*Loxodonta africana*) in a national park in Mozambique exhibited more nocturnal activity near park boundaries and on roads used heavily by humans but more diurnal activity inside the park and away from roads, where human activities were limited (Gaynor et al. 2018b).

The sensitivity of wild mammals to human activity differs among species. For instance, large carnivores are typically sensitive to human activity (Treves & Karanth 2003); therefore, the presence of humans can provide shelter to less-sensitive prey animals from predators (Muhly et al. 2011). In such cases, increased human activity could have both negative and positive impacts on the spatial patterns of wild mammal communities (Gray & Phan 2011, Zhou et al. 2013, Gaynor et al. 2018b). However, limited information is available on the potential impacts of tourism-related activities in protected areas on wild mammal species.

In the present study, we performed video camera trapping (with the flash off) in Endau-Rompin (Peta) National Park (ERNP), Peninsular Malaysia. The detection rates of wild mammals and the diel activity patterns of commonly observed mammal species were assessed in two areas with different levels of human activity. To understand the impacts of tourism-related activities on mammal species, we first compared the activities of tourists and park staff in a visitor area and a remote area within the area of the park open to tourists. Then, we compared the detection rates and the diel activity patterns of various wild mammal species and guilds between the two areas.

MATERIAL AND METHODS

Study site

This study was conducted in ERNP, which is located on the border of the states of Johor and Pahang in Peninsular Malaysia. In 1989, 489.05 km^2 of virgin tropical rainforest was designated as ERNP. ERNP is managed by the semi-governmental Johor National Park Corporation (JNPC), while the area bordering the northern part of ERNP is managed by Pahang state as Endau-Rompin State Park (Aihara et al. 2016). On the Johor side, there are two tourist areas: Peta (195.62 km^2) and Selai (293.43 km^2). This study was conducted in the Peta area (2°31′N, 103°24′E, 40 m above sea level). The landscape of ERNP is largely hilly, mainly volcanic ignimbrite overlain in some areas by layers of shale and sandstone (Gumal et al. 2014). Two major rivers, Endau River and Rompin River, flow through the park.

ERNP has been open to the public since September 1993. Approximately 2,000 visitors enter the Peta area each year (JNPC, unpublished data). ERNP offers various tourist activities, including camping, jungle trekking, night walks, swimming, canoeing, river rafting and nature education. The Peta area hosts the Visitor Complex and Nature Education and Research Centre (NERC), which serve as a base for tourists; three campsites at Kuala Jasin, Kuala Marong and Batu Hampar; and the indigenous (Orang Asli) village of Kampung Peta. Tourists can be transported by guides from the Visitor Complex to the Kuala Jasin Campsite either by car along a paved road or by boat up the Endau River.

ERNP is covered by tropical rainforest and has an average annual temperature of 27°C, rainfall of 3,400 mm and humidity of 85%. The tropical forest includes lowland, hilly mixed dipterocarp forest dominated by keruing–red meranti (*Dipterocarpus–Shorea*) and kapur (*Dryobalanops*) (Wong et al. 1987). ERNP is uniquely located in the Riau Pocket, a convergence point of the western Borneo, Sumatran and Malayan flora that is characterised by a high degree of endemism; a large number of plant species that are locally endemic or restricted to the southern region of the Malay Peninsula are found in ERNP (Foo & Numata 2019).

In total, 149 mammal species from 11 orders (Carnivora, Cetartiodactyla, Chiroptera, Dermoptera, Eulipotyphla, Perissodactyla, Pholidota, Primates, Proboscidea, Rodentia and Scandentia) inhabit ERNP (Aihara et al. 2016). Among medium and large mammals in ERNP, the IUCN Red List 2020-2 lists two as critically endangered (Sumatran rhinoceros and Sunda pangolin) and ten as endangered: Tiger (*Panthera tigris*), flat-headed cat (*Prionailurus planiceps*), Sunda otter civet (*Cynogale bennettii*), large-spotted civet (*Viverra megaspila*), Malayan tapir (*Tapirus indicus*), southern pig-tailed macaque (*Macaca nemestrina*), dusky leaf monkey (*Trachypithecus obscurus*), lar gibbon

(*Hylobates lar*), slow loris (*Nycticebus coucang*) and Asian elephant (*Elephas maximus*). In ERNP, population estimation surveys of tigers and elephants have been conducted for conservation purposes (Gumal et al. 2014, Saaban et al. 2020) and basic information on various wild mammals has been collected through camera trap surveys (Aihara et al. 2016, Tan et al. 2018, Ota et al. 2019).

Data collection

Camera traps could minimise human disturbances and provide an inexpensive and time-efficient means of observing wildlife in tropical rainforest (Numata et al. 2005). To investigate the diel activity patterns of wild mammals at the study site, we used high-quality automatic day/night video camera traps with multiple infrared sensors (Ltl Acorn 6210, Ltl Acorn 6310W; Acorn Cameras, Shenzhen, China). The camera traps have been used widely for wildlife surveys in the rainforests of Asia and Africa (Wilson et al. 1996, Numata et al. 2005, Giman et al. 2007). In the present study, 10 cameras were installed for 250 days from 8 July 2019 to 13 March 2020. The trapping effort (camera-days) ranged from 89 to 249 days among the sites due to equipment failure (Table 1). Data were collected and the batteries and SD cards were replaced in November 2019. We recorded 15 seconds of video per record and set the minimum recording interval to 30 seconds in accordance with Ota et al. (2019).

The camera traps were installed on two types of road: near the visitor lodgings (hereafter, the visitor area) and in a remote area (hereafter, the remote area) (Figure 1). The visitor area road is paved with asphalt, and runs for about 7 km between the Visitor Complex and Kuala Jasin campsite. The Visitor Complex is close to an Orang Asli settlement. During the day, tourists and park staff drive by car or motorcycle to the Kuala Jasin campsite, as a base for activities. Moreover, tourists take part in night walks near the Visitor Complex and NERC. In the remote area, the logging road is unpaved or ill-paved, 5 km long and 5–10 m wide. It is used mainly by tourists and park staff on foot.

The camera traps were installed along the roads at six locations in the visitor area and four locations in the remote area at roughly regular distances of approximately 1 km. The cameras were positioned near animal trails that intersected with the road, based on the presence of animal signs such as tracks and dung. The camera traps were installed at a height of 0.5–1.5 m above the ground to record terrestrial mammals, and were oriented so as to record animals walking along the road or emerging from the trail. To avoid sampling large numbers of cars or motorcycles (hereafter, vehicles) and humans in the visitor area, the camera traps were re-positioned on 5 November 2019.

Table 1 Summary of the camera trapping, including the camera identifier (ID), numbers of independent events recorded by the camera traps and camera trap operation time (camera-days)

			Mammals			Humans		
	Camera ID	Camera-days	Small	Medium and large	Total	On foot	Vehicles	Other
Visitor area	A	172	49	73	122	40	2889	69
	B	89	1	9	10	20	790	4
	C	142	0	121	121	8	1826	14
	D	184	26	36	62	4	1374	19
	E	197	0	35	35	4	397	5
	F	114	10	41	51	2	1031	4
Remote area	G	249	0	68	68	27	116	4
	H	244	1	149	150	12	73	35
	I	174	1	90	91	6	82	32
	J	249	0	64	64	9	72	4
Total		1814	88	686	774	132	8650	190

Data analysis

Videos taken by the camera traps were classified as containing wild mammals, humans (visitors, park staff, etc.) or other animals (birds, insects, reptiles, unidentified mammals). To eliminate duplicate records of the same individual or group, records were counted as a single independent record if the same species was recorded multiple times within 30 minutes (Yasuda 2004). To estimate the level of human activity in the visitor and remote study areas, the detection rates of human activity (including foot traffic and vehicles) were evaluated based on the camera trap records from 8 July 2019 to 5 November 2019. For mammal species with more than 10 independent records, the detection rates were calculated as the number of records per 100 camera-days for each species.

For the analysis, carnivore, ungulate, and rodent species were each classified as their respective guild. Also, rats (Muridae), squirrels (Sciuridae), the lesser mouse-deer (*Tragulus kanchil*) and greater mouse-deer (*Tragulus napu*) have been reported to inhabit the study area (Aihara et al. 2016), but it was difficult to distinguish the species by video; therefore, we grouped all the records as small mammals (Muridae and Sciuridae) or mouse-deer species (*Tragulus* species). Finally, Asian elephants were recorded at short intervals of 1–2 h at the camera locations within the visitor or remote areas, suggesting that they travelled along the road, which could lead to duplicate records. Therefore, we did not include the Asian elephant data in the analyses.

We compared the numbers of mammal records between the visitor and remote areas using generalised linear mixed models (GLMMs) with a Poisson distribution, in which the period (daytime, night-time or twilight) was included as a fixed effect, the number of camera operating days was included as an offset term and each camera location was considered to be a random effect. P values were calculated using the Wald chi-square test with the 'car' R package (Fox & Weisberg 2011).

To determine which of the four diel activity patterns (i.e. diurnal, nocturnal, crepuscular or cathemeral) each species exhibited, we defined twilight as ±1 h from sunrise and sunset (Ota et al. 2019) and divided the day into three periods: daytime (08:00–18:00 UTC+8), night-time (20:00–06:00 UTC+8), and twilight (06:00–08:00 and 18:00–20:00 UTC+8). Each record of each mammal species was designated as having been recorded during daytime, night-time or twilight. We compared the number of

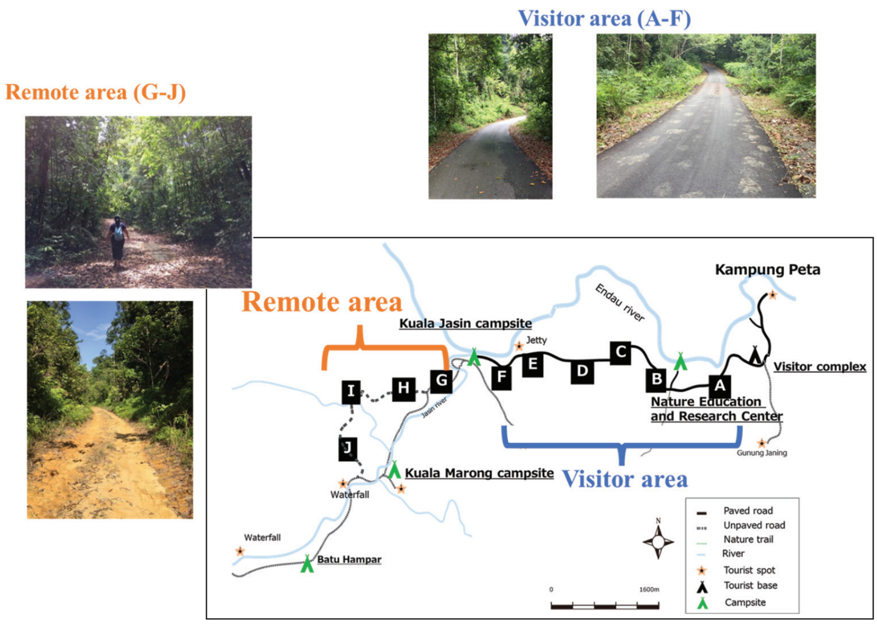

Figure 1 Map of the Peta area of Endau-Rompin National Park, Malaysia, and the locations of camera traps in the visitor area (A–F) and remote area (G–J)

independent records among the three periods using GLMMs with a Poisson distribution, in which the period was included as a fixed effect, the hours of camera operation were included as an offset term and each camera location was considered a random effect. P values were calculated using the Wald chi-square test with the 'car' R package. When the GLMM identified time period as significant, Tukey's HSD post hoc test was performed using the 'multcomp' R

Table 2 Information on the mammal species recorded by the camera traps, including the number of independent records per 100 camera-days for medium-to-large mammals in the visitor and remote areas, and the results of generalised linear mixed models and the Wald chi-square test

				Detection rate			
Common name	Scientific name	IUCN status	No. of events	Total	Visitor area	Remote area	P value
Southern red muntjac	*Muntiacus muntjak*	LC	175	9.65	9.91	9.39	0.6
Bearded pig	*Sus barbatus*	VU	102	5.62	1.22	9.93	< 0.001
Wild boar	*Sus scrofa*	LC	100	5.51	5.12	5.90	0.60
Mouse deer species	*Tragulus* species		85	4.69	3.56	5.79	0.57
Asian elephant	*Elephas maximus*	EN	32	-	-	-	-
Crab-eating macaque	*Macaca fascicularis*	VU	31	1.71	3.34	0.11	0.01
Malayan porcupine	*Hystrix brachyura*	LC	27	1.49	1.34	1.64	0.74
Leopard cat	*Prionailurus bengalensis*	LC	24	1.32	2.34	0.33	0.14
Malay civet	*Viverra tangalunga*	LC	19	1.05	1.56	0.55	0.73
Asiatic golden cat	*Catopuma temminckii*	NT	10	0.55	-	1.09	-
Leopard	*Panthera pardus*	VU	7	0.39	0	0.76	-
Banded linsang	*Prionodon linsang*	LC	3	0.17	0	0.33	-
Yellow-throated marten	*Martes flavigula*	LC	3	0.17	0.33	0	-
Southern pig-tailed macaque	*Macaca nemestrina*	EN	2	0.11	0	0.22	-
Sunda pangolin	*Manis javanica*	CR	2	0.11	0.11	0.11	-
Tiger	*Panthera tigris*	EN	2	0.11	0	0.22	-
Asian small-clawed otter	*Aonyx cinerea*	VU	1	0.06	0	0.11	-
Clouded leopard	*Neofelis nebulosa*	VU	1	0.06	0	0.11	-
Malayan tapir	*Tapirus indicus*	VU	1	0.06	0.11	0	-
Marbled cat	*Pardofelis marmorata*	NT	1	0.06	0.11	0	-
Sun bear	*Helarctos malayanus*	VU	1	0.06	0.11	0	-
Guild							
Carnivores			121	6.67	8.80	4.59	0.79
Ungulates			471	25.96	19.93	31.88	0.11
Rodents			115	6.34	10.91	1.86	0.18

Guilds: Carnivores: *Catopuma temminckii, Neofelis nebulosa, Panthera pardus, Panthera tigris, Pardofelis marmorata, Prionailurus bengalensis, Aonyx cinereus, Martes flavigula, Prionodon linsang, Viverra tangalunga*, unidentified Felidae, unidentified Viverridae, and unidentified Carnivora; Ungulates: *Muntiacus muntjak, Sus barbatus, Sus scrofa, Tragulus* species, *Tapirus indicus, Sus* species; Rodents: *Hystrix brachyura,* Muridae and Sciuridae species package (Bretz et al. 2011). This comparison was conducted by mammal species and guild groups for the visitor and remote areas, respectively.

For species or guilds recorded more than 10 times in either area, we also examined the diel activity patterns of wild mammals following the method of Rowcliffe et al. (2014) using the 'overlap' R package (Ridout & Linkie 2009, Meredith & Ridout 2020) in R (R Core Team 2020). The patterns were plotted using von Mises kernel density estimation.

RESULTS

Detection rates of wild mammals

The camera traps were operated for a total of 1,814 camera-days (Table 1). Mammals were recorded 774 times at the 10 camera trap locations, of which medium and large mammals were recorded 686 times, and small mammals (e.g. rats and squirrels) were recorded 88 times. We recorded at least 21 terrestrial species,

Table 3 Number of independent records per 100 camera-days for medium-to-large mammals in the visitor and remote areas, and the results of generalised linear mixed models and the Wald chi-square tests

		Visitor area			Remote area		
Species	No. of independent records	Daytime	Twilight	Night-time	Daytime	Twilight	Night-time
Southern red muntjac	175	14.97^{b}	20.04^{b}	0.80^{a}	13.36^{b}	18.34^{b}	1.83^{b}
Bearded pig	102	2.14	1.34	0.27	17.29^{b}	12.45^{b}	1.57^{a}
Wild boar	100	7.75^{b}	6.68^{b}	1.87^{a}	10.22^{b}	7.21^{b}	1.05^{a}
Mouse deer species	85	4.01	5.35	2.41	3.41^{a}	7.21^{ab}	7.60^{b}
Crab-eating macaque	31	6.95	2.67	0	0.26	0	0
Malayan porcupine	27	0	0	3.21	0	0	3.93
Leopard cat	24	0.27^{a}	0^{ab}	5.35^{b}	0.52	0	0.26
Malay civet	19	0	0	3.74	0	0	1.31
Asiatic golden cat	10	0	0	0	1.05	1.97	0.79
Sus species[1]	8	0	0	0	1.31	1.97	0
Leopard	7	0	0	0	1.31	1.31	0
Banded linsang	3	0	0	0	0	0	0.79
Yellow-throated marten	3	0.53	0.67	0	0	0	0
Southern pig-tailed macaque	2	0	0	0	0.52	0	0
Sunda pangolin	2	0	0	0.27	0	0	0.26
Tiger	2	0	0	0	0.26	0	0.26
Asian small-clawed otter	1	0	0	0	0	0.66	0
Clouded leopard	1	0	0	0	0	0	0.26
Malayan tapir	1	0	0	0.27	0	0	0
Marbled cat	1	0	0.67	0	0	0	0
Sun bear	1	0	0.67	0	0	0	0
Guild							
Carnivores	121	0.80^{a}	5.35^{b}	18.17^{c}	3.14	4.59	6.03
Ungulates	471	28.86^{b}	33.41^{b}	5.61^{a}	45.59^{b}	47.16^{b}	12.05^{a}
Rodents	115	5.35 a	4.68 a	18.98 b	0	0	3.93

[1]Grouped because of difficulty to distinguish bearded pig and wild boar by video. Multiple comparison test results are shown as superscript letters

including one critically endangered species (CR), three endangered species (EN) and seven vulnerable species (VU) (Table 2).

Most of the recorded humans on foot were park staff and tourists, and all recorded vehicles were driven by park staff. The respective detection rates (detection event per camera-day) of humans on foot and vehicles were 0.18 and 20.81 in the visitor area and 0.07 and 0.57 in the remote area. There were no significant differences in the detection rates of humans on foot between the two areas (GLMM and Wald chi-square test; $p = 0.316$). However, the detection rate of vehicles was significantly higher in the visitor area than the remote area ($p < 0.0001$). The activities of humans on foot and vehicles both showed diurnal activity patterns (Figure 2), and a high level of overlap between the two areas ($\Delta = 0.86$).

Although the detection rate of the total number of wild mammals recorded did not significantly differ between the visitor and remote areas, differences between the two areas were found among species and guilds. The detection rate of bearded pigs was significantly higher in the remote area than the visitor area ($\chi^2 = 17.6$, $p < 0.001$) whereas that of crab-eating macaque (*Macaca fascicularis*) was significantly higher in the visitor area than the remote area ($\chi^2 = 7.7$, $p = 0.006$). The detection rates of the three guilds (carnivores, ungulates and rodents) did not significantly differ between the two areas.

Diel activity patterns of wild mammals

We compared the detection rates of species and guilds among the daytime, night-time and twilight periods using GLMMs (Figure 3). The rates for southern red muntjac and wild boar (*Sus scrofa*) significantly differed among the three periods in the visitor area (southern

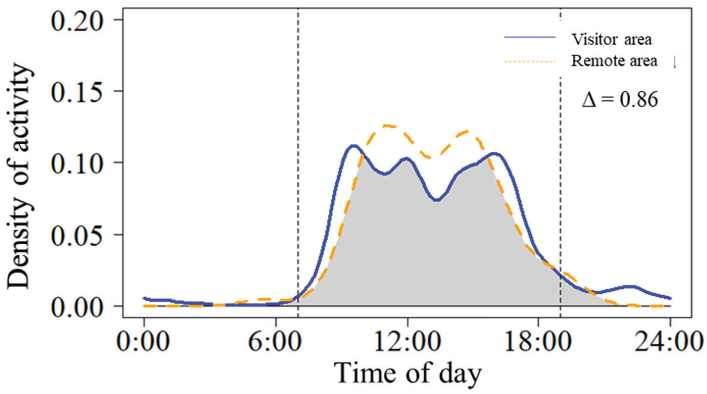

Figure 2 Density estimates of the human diel activity patterns (foot traffic and vehicles), and overlaps in human activities between the visitor and remote areas. The dashed lines indicate the time of sunrise (07:00) and sunset (19:00)

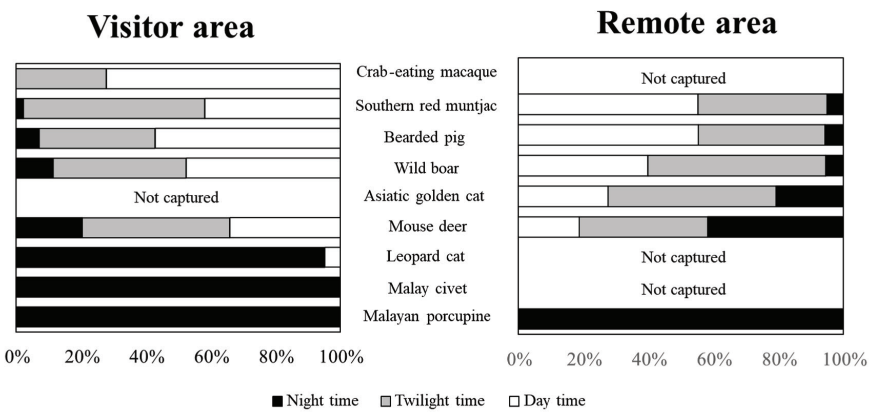

Figure 3 Activity periods of nine mammal species (n > 9). Open bars indicate the percent frequency of independent records during the daytime (08:00–18:00); grey bars indicate the percent frequency of independent records during twilight (06:00–08:00 and 18:00–20:00); solid bars indicate the percent frequency of independent records at night (20:00–06:00)

red muntjac: $\chi^2 = 29.0$, $p < 0.001$; wild boar: $\chi^2 = 11.7$, $p < 0.01$) (Table 3). In the remote area, the rates for southern red muntjac, bearded pig, wild boar, and mouse-deer significantly differed among the three periods (southern red muntjac: $\chi^2 = 30.5$, $p < 0.001$; bearded pig: $\chi^2 = 32.4$, $p < 0.001$; wild boar: $\chi^2 = 19.0$, $p < 0.01$; mouse-deer: $\chi^2 = 6.3$, $p < 0.05$) (Table 3). At the guild level, the rates for ungulates significantly differed among the three periods in both the visitor and remote areas (visitor area: $\chi^2 = 54.0$, $p < 0.001$; remote area: $\chi^2 = 70.0$, $p < 0.001$) and those of carnivores significantly differed among the three periods in the visitor area ($\chi^2 = 36.0$, $p < 0.001$).

Southern red muntjac, bearded pig, wild boar and mouse-deer were recorded throughout the day, whereas Malayan porcupine (*Hystrix brachyura*) was recorded more frequently at night (Figure 4). There were high degrees of overlap between the visitor and remote areas for southern red muntjac ($\Delta = 0.85$), bearded pig ($\Delta = 0.79$), wild boar ($\Delta = 0.83$) and Malayan porcupine ($\Delta = 0.88$). Conversely, the mouse-deer was active throughout the day but showed a low degree of overlap ($\Delta = 0.65$) between the two areas. Among the guilds, high degrees of overlap in diel activity patterns between the visitor and remote areas were found for ungulates ($\Delta = 0.91$) and rodents ($\Delta = 0.74$), whereas carnivores showed a lower degree of overlap ($\Delta = 0.69$).

DISCUSSION

Human impacts on mammal detection rates

The frequency of vehicle observations significantly differed between the visitor and remote areas but similar diurnal activity patterns of humans on foot and vehicles were found between the two areas. These results suggest that vehicular traffic could be a main human impact on wild mammals in the visitor area. Higher levels of road traffic can negatively affect the detection rates of wild mammals, especially predators (Muhly et al. 2011, Zhou et al. 2013). Differences in pavement condition may also indirectly impact the behaviour of some animals, such as ungulates (Mulero-Pázmány et al. 2016). In the present study, the pavement condition differed between the visitor area (well-paved) and remote area (unpaved or ill-paved), but the ungulate detection rate did not differ between the two areas (Table 2). This suggests that pavement condition minimally impacted the behaviour of the detected animals in ERNP.

The total mammal detection rate did not significantly differ between the visitor and remote areas (Table 2), but bearded pigs were more frequently recorded in the remote area. Thus, only some species may be sensitive to human traffic. However, based on the observation by Ota et al. (2018) that the diel activity patterns of bearded pigs did not differ between the park open and closed seasons, human traffic may have a limited effect on the diel activity patterns of bearded pigs. By contrast, crab-eating macaques were observed more frequently in the visitor area than the remote area. This may be because these macaques are drawn to the food carried by commuters and tourists (Hansen et al. 2019).

The carnivore guild included four medium-to-large carnivores (Asiatic golden cat, clouded leopard, leopard and tiger), which were recorded only in the remote area, indicating that they may be influenced by human traffic. Leopards prefer the more forested interior areas of protected areas (Ngoprasert et al. 2007). Moreover, the distance to human settlements is the most important factor of human disturbance affecting carnivore occupancy in Kenya (Schuette et al. 2013). In this study, however, few records of each carnivorous species were obtained; therefore, further study is necessary to interpret their detection rates.

Human impacts on the diel activity patterns of wild mammals

Our camera trapping similarly identified at least 21 terrestrial mammal species, including 11 carnivores and six ungulates (Table 2), and we made the first observation of a clouded leopard (*Neofelis nebulosa*) since a report by Gumal et al. (2014). We observed different diel activity patterns among the species detected in this study, which were generally consistent with previous studies that used camera trapping in tropical forests of Peninsular Malaysia (Mohd-Azlan 2006, Gumal et al. 2014, Tan et al. 2018, Ota et al. 2019), Borneo (Colon 2002, Bernard et al. 2013, Ross et al. 2013), Sumatra (Linkie & Ridout 2011), Thailand (Kitamura et al. 2010, Lynam et al. 2013) and Cambodia (Gray & Phan 2011).

The patterns of southern red muntjac, bearded pig, wild boar and Malayan porcupine did not differ between the visitor and remote areas (Figure 4), suggesting that human traffic has lower impacts on the diel activity patterns of wild mammals in ERNP. These results are consistent with a study that reported no significant differences in the diel activity patterns of bearded pig between the park open and closed seasons (Ota et al. 2018).

Meanwhile, mouse-deer showed a cathemeral activity pattern in both areas, with a tendency toward diurnal activity in the visitor area and nocturnal activity in the remote area (Figure 4). By contrast, carnivores exhibited nocturnal activity in the visitor area but were additionally observed during the daytime in the remote area (Figure 4). Thus, human activity may limit their activity. In the study area, Asian tigers and leopards represent apex predators; they were captured by camera trapping only in the remote area. The avoidance of humans by such predators could drive prey towards areas with higher human traffic to shelter themselves from predation (Berger 2007, Muhly et al. 2011). Therefore, changes to the diel activity patterns of apex carnivores might drive changes in the diel activities of prey species via top-down forcing and trophic cascades (Estes et al. 2011). However, further research is necessary to confirm how human activities impact the diel patterns of wild mammal species via interspecific interactions.

Implications for tourism and conservation

The present findings suggest that human traffic resulting from tourism and park management (e.g., trekking and transportation by car) in ERNP have relatively low impacts on the spatial patterns and diel patterns of common mammal species. However, large carnivores, such as the Asian tiger, were detected only in the remote area, suggesting that human traffic may impact the spatial patterns of apex predators. Thus, researchers should consider not only direct human impacts but also indirect impacts via interspecific interactions when assessing the impacts of tourism on wildlife (Muhly et al. 2011, Shannon et al. 2014). Conservation policies vary among species and groups, and information on mammal occurrence, diel activity patterns and interspecific interactions will help improve conservation practices.

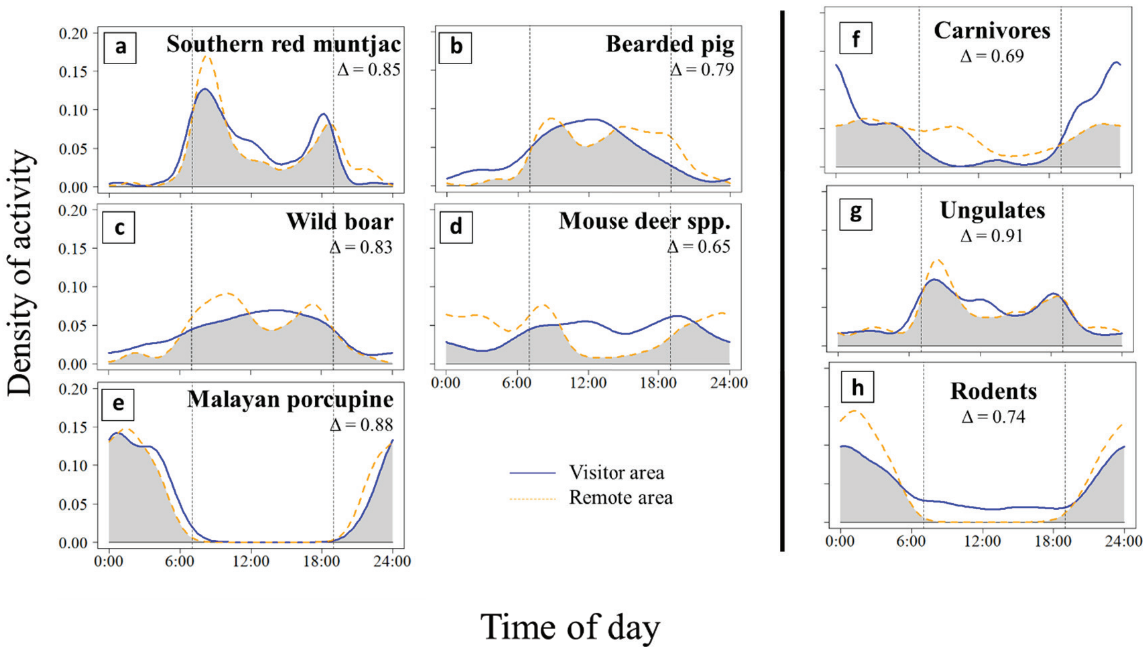

Figure 4 Density estimates of the diel activity patterns of a) *Muntiacus muntjak*, b) *Sus barbatus*, c) *Sus scrofa*, d) *Tragulus species*, e) *Hystrix brachyura*, f) carnivores, g) ungulates and h) rodents in the visitor and remote areas. Grey shading indicates an overlap between the two study areas. The delta (Δ) value is the overlap coefficient. The dashed lines indicate the time of sunrise (07:00) and sunset (19:00)

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