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Habitat occupancy patterns and activity rate of native mammals in tropical fragmented peat swamp reserves in Peninsular Malaysia

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A B S T R A C T

Intensive land use plays a major role in tropical peat swamp deforestation in Southeast Asia. In Peninsular Malaysia, the North Selangor Peat Swamp Forest (NSPSF) is the second largest remaining peatland ecosystem. Although the NSPSF is recognized as a biodiversity hotspot area in the region, this peat swamp forest is rapidly shrinking because of the expansion of commercial oil palm agriculture. More than 87% of the NSPSF has been designated as reserves, but in reality, this is not comparable to protected area status. The NSPSF is under constant threats from forest conversions, forest fires, and road constructions. Faunal biodiversity loss is likely to occur in the NSPSF unless immediate action is taken by stakeholders. To determine the habitat occupancy and activity rate of native mammals, we conducted camera-trap survey at 45 sites located within the NSPSF. From a total survey effort of 2565 trap nights in an area of 778 km^2, 16 mammal species were recorded. Our data provide vital information on the occupancy of high conservation value species in the NSPSF. However, we did not record Sumatran rhinoceros (*Dicerorhinus sumatrensis*) and Malayan tiger (*Panthera tigris*), nor did we find any indirect evidence such as footprints, indicating that these species are extirpated from this region. We found that mammal activity rate responded differently to *in situ* habitat quality and landscape factors according to feeding guild. Government stakeholders should focus on prohibiting further forest conversion and prioritize the upgrading NSPSF's conservation status from reserve to protected area.

1. Introduction

The expansion of agriculture around the world has caused significant controversy and debate over the past 30 years (Yaffee, 1994; Angelstam, 1996; Lindenmayer and Franklin, 2003; Rudel et al., 2009). Rapid agricultural expansion has replaced forest and poses a serious threat to many natural ecosystems in the next 50 years (Tilman et al., 2001). Land modification by humans, including habitat conversion and fragmentation is currently the biggest threat to biodiversity worldwide (Primack, 2001; Kerr and Deguise, 2004). The tropical rainforests of Southeast Asia are disappearing at an alarming rate, partly as a result of forest conversion to oil palm plantations (Linkie et al., 2003; Fitzherbert et al., 2008; Danielsen et al., 2009). The oil palm industry with fiber plantations and logging concessions are often highlighted as the major drivers of deforestation and biodiversity loss in Southeast Asia (Clements et al., 2010; Linkie and Ridout, 2011; Abood et al., 2014). Despite being considered by environmental NGOs as a serious threat to forest biodiversity, oil palm cultivation continues to expand (Rudel et al., 2009; Sodhi et al., 2004; Sodhi and Brook, 2006) and it has become a key driver of tropical peat swamp forest clearance (Carlson et al., 2012).

Between 1990 and 2005, oil palm plantations in Malaysia have expanded by a total of 1.87 million ha (MPOB, 2007) and, as of 2013, a total area of 5.22 million ha of the country has been planted with oil palm (MPOB, 2013). As a result, the impacts of industrial oil palm expansion on tropical forests and biodiversity in the region are a major conservation concern (Koh and Wilcove, 2007; Scharlemann and Laurance, 2008). To date, little research has focused on the actual impacts of oil palm expansion on forest biodiversity, although it is clear from existing studies that oil palm plantations support a significantly lower biodiversity

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across a range of taxonomic groups, compared to forest habitats and most other commercial crops (Fitzherbert et al., 2008; Foster et al., 2011). In a meta-analysis, Danielsen et al. (2009) recorded a 62% drop in vertebrate species richness and an 11% drop in invertebrate species richness between forest and oil palm plantations. This loss of species is likely the result of reduced structural complexity in oil palm plantations and more extreme microclimatic conditions (Luskin and Potts, 2011; Hardwick et al., 2015), as well as an increased density of roads, which can lead to access for illegal hunting and killing of wildlife by vehicles (Azhar et al., 2013a; Luskin et al., 2014).

The protection and restoration of peat swamp forests are conservation priorities that require urgent action, because peat swamp forests are more vulnerable to human disturbances than other forest ecosystems (Posa et al., 2011). Peat swamp forests are critical for biodiversity conservation and support many specialized species and unique ecosystem types. In addition, they can provide a refuge for species that are extirpated from non-peat swamp areas, affected by degradation and climate change (Parish et al., 2008). Peat swamp forests are also important for the large volumes of carbon they store and disturbance of these areas can result in large releases of carbon dioxide, contributing to global green-house gas effects. Indeed a recent study indicated that Peninsular Malaysia, Sumatra and Borneo may have net annual carbon emissions of 230–310 Mt CO_{2e-}, as a result of the conversion of 20% of their total peatland areas to oil palm (Miettinen et al., 2012).

In Malaysia, out of 336 mammal species recorded, a total of 71 species are threatened (IUCN, 2014; Vié et al., 2009). Deforestation and fragmentation can affect large-bodied mammals more than other species, because of their large home-range requirements (Kinnaird et al., 2003). Extinction risk may be determined by human population density, because human exploitations such as direct persecution, destruction of habitats and reduction in prey numbers are the main causes of population decline (Cardillo et al., 2004). Large mammals, especially carnivores, face the highest extinction risks, because they are more vulnerable to human activities, such as habitat destruction and fragmentation (Forero-Medina et al., 2009). Retaining forest fragments is therefore important, both because of the habitat it contains and because it can act as a corridor between contiguous areas of forest (Laurance et al., 2008; Lees and Peres, 2009).

Mammals have been a focus of conservation for a long time and continue to serve as the traditional focus of government spending on wildlife conservation (Ceballos et al., 2005; Schipper et al., 2008; Redford et al., 2011). However, crucial monitoring work is often overlooked, resulting in the under-recording of species in different areas. For example, the most significant species recorded at the North Selangor Peat Swamp Forest (NSPSF) is the Sumatran Rhinoceros (Prentice and Aikanathan, 1989), but this has not been captured or sighted since 1994 (Tan, 2003). Camera traps represent an extremely useful tool for wildlife research into secretive and cryptic mammal species (Rowcliffe and Carbone, 2008; Matsubayashi et al., 2011; Bernard et al., 2012). Camera trapping can be used to obtain biological data on mammal species, such as diversity, relative abundances, activity patterns and presence or absence (Kawanishi et al., 1999; Srbek-Araujo and Chiarello, 2005; De Luca and Rovero, 2006; Grassman et al., 2006; Linkie et al., 2007; Rovero et al., 2013a). Camera traps are also rapidly becoming one of the most important tools in conservation, especially in occupancy estimation studies (Linkie et al., 2007). Indirectly, photographs of mammal species can also be used to provide other important information such as the relationship between predators and prey (Kawanishi and Sunquist, 2003; Azlan and Davison, 2006).

Our goal was to determine the diversity of native mammals in the NSPSF. As well as estimating the habitat occupancy for the different mammal species, we also investigated the role of *in situ* habitat quality (i.e. vegetation structure) and landscape attributes in determining animal activity. Such work in the NSPSF is particularly timely, owing to the range of threats this area currently faces. Besides plantation expansion, increased cattle grazing and new road construction, such as the recent Ijok-Teluk Intan highway, may also threaten mammal diversity, as it has in other parts of the world (Bissonette, 2002; Laurance et al., 2008). Since 2002, 592 ha of the area has been lost to fire (Parish et al., 2014), which is also likely to impact species in the area. Such a range of different land-uses and increasing pressures on remaining forest habitats may also exacerbate human-wildlife conflict and extinction of wide-ranging carnivores in large protected areas (Woodroffe and Ginsberg, 1998).

2. Methodology

2.1. Study area

The North Selangor Peat Swamp Forest (NSPSF; 3′40′26.56″N, 101′4′29.52″E and 3′32′4.40″N, 101′27′33.36″E) is one of the largest remaining extensive patches of peat swamp forest found on the western coast of Peninsular Malaysia. It includes of the Sungai Karang Forest Reserve (50,106 ha), the Sungai Dusun Wildlife Reserve (4330 ha) and the Raja Musa Forest Reserve (23,486 ha) (Parish et al., 2014). The NSPSF covers approximately 779 km^2 and was actively logged for 30 years before being designated as a forest reserve in 1990 (Kumari, 1996). The forest reserves have different levels of forest degradation and the edges of the forests are generally heavily disturbed (e.g. cattle farming and oil palm farming) (see Fig. 1).

The original pristine forest has been entirely logged over and it is unlikely that any old growth forest remains (Prentice and Aikanathan, 1989; Chan, 1989). Intensive logging ceased 25–30 years ago, before which commercial timber were extracted throughout the reserves. At present, although being designated a forest reserve, some parts of the forest are still being converted to oil palm, with more than 1000 ha within the NSPSF being recently cleared for new plantations. More than 60% of the NSPSF's perimeter is surrounded by oil palm plantations or small holdings (Azhar et al., 2011). Only the Sungai Dusun Wildlife Reserve is officially classified as a protected area (Abdul, 1996), and therefore is expected to remain intact forest for conservation into the future.

The forest is a secondary mixed swamp forest with trees such as: *Macaranga pruinosa*, *Campnosperma coriaceum*, *Shorea platycarpa*, *Parartocarpus venenosus*, *Ixora grandiflora*, *Pternandra galeata*; ferns such as: *Stenochlaena palustris*, *Asplenium longissimum*, *Nephrolepsis biserrata*; palms such as: *Crytostachys* sp.; sedges such as: *Cyperus rotundus* and abundant stands of *Pandanus atrocarpus* (Yule and Gomez, 2008). Thirty-five fish species (Beamish et al., 2003), 173 bird species, four primate species and 16 mammal species (Prentice and Aikanathan, 1989) have been recorded in the NSPSF.

2.2. Sampling design

We established 45 sampling sites randomly across the NSPSF (Fig. 2), at which all measurements were made. Each point of camera-trap deployment was chosen on the basis of the presence of visible animal trails, footprints, scats and tree marks by wildlife. Accessibility to the points from the highway was also an important factor to choose camera-trap points. The furthest distance between sites was 40 km and the closest was 500 m. The Universal Transverse Mercator coordinates of the sample sites were determined using a handheld Global Positioning System (GPS) receiver (Garmin 72H).

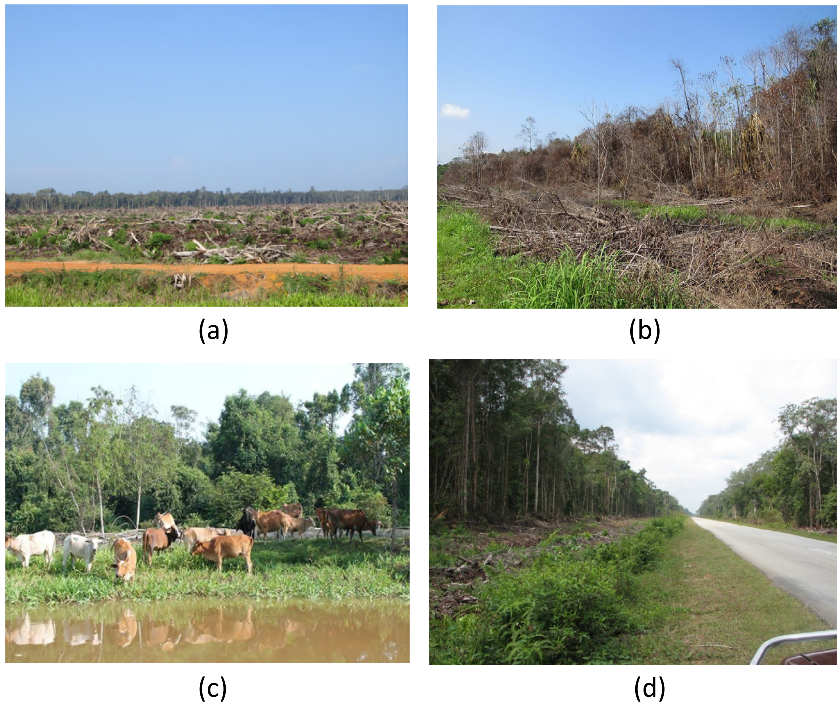

Fig. 1. The North Selangor Peat Swamp Forest is being threatened by anthropogenic activities – (a) recently cleared forest area for oil palm expansion, (b) forest fire attributed to illegal forest clearing activity, (c) cattle farming along the river bank and (d) highways and roads splitting the peat swamp forest.

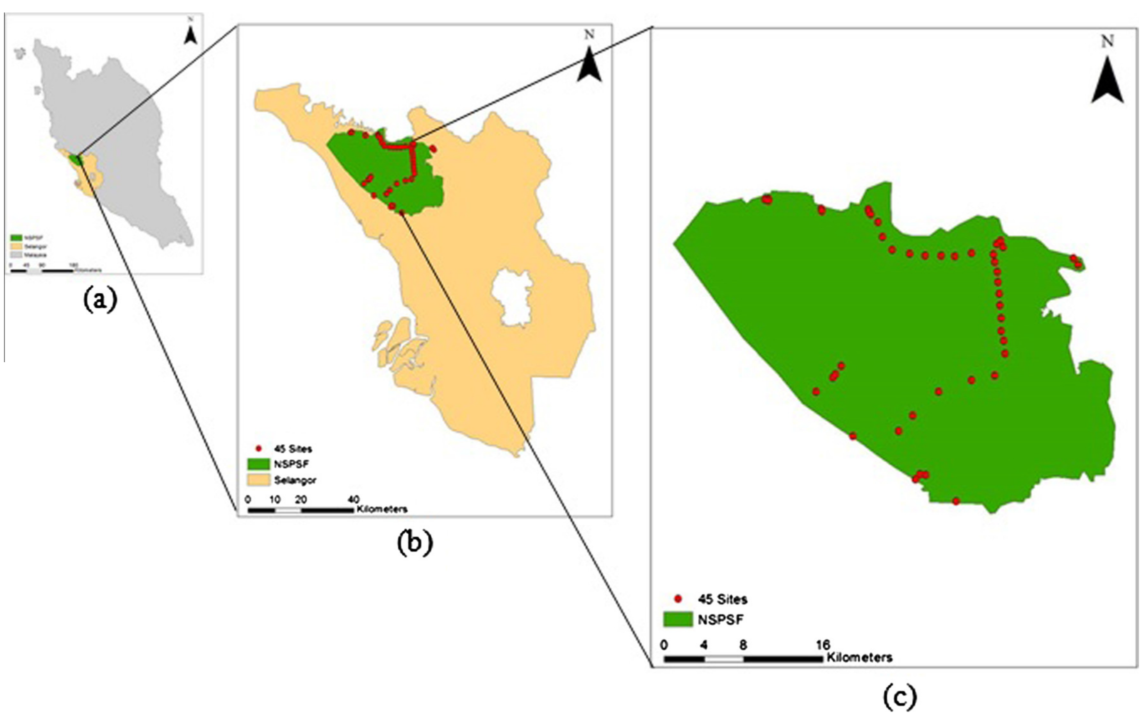

Fig. 2. (a) Map of Peninsular Malaysia, (b) Selangor region and the location of study site and (c) approximate locations of 45 cameras distributed across the North Selangor Peat Swamp Forest.

2.3. Assessment of vegetation structure attributes and landscape metrics

To study the *in situ* habitat attributes, we established a 20 m × 50 m plot at each sampling site and counted or measured the following variables: (1) number of saplings with diameter at breast height (DBH) of 1–5 cm, (2) number of palms, (3) trees with DBH of more than 45 cm, (4) trees with DBH less than 45 cm, (5) percentage of canopy cover, (6) tree canopy height, (7) number of fallen trees with DBH less than 45 cm, and (8) number of fallen trees with DBH more than 45 cm. Using Google Earth Pro, we calculated five landscape-level attributes for each site: (1) distance to the nearest road from the camera-trapping site, (2) distance to the nearest river from the camera-trapping site, (3) coverage of forest vegetation within a 1 km radius, (4) coverage of oil palm planted area within a 1 km radius, and (5) compositional heterogeneity (i.e. the number of different landscapes) within a 1 km radius. We collected data of vegetation stand from all 45 camera-trapping sites. Distances from camera-trap points to nearest road and river were measured using measuring tools in Google Earth Pro.

2.4. Camera trapping

We set up one camera per site and left them for two months before relocating them to increase the number of sampling units and maximize the detection probability (Boulanger et al., 2002). Our sampling effort was limited by a small number of camera units and difficulty to access remote areas of the forest or areas inundated with water. Hence the camera trapping was conducted opportunistically along former logging roads and at selected access points. We conducted the camera trapping survey from March 2013 to October 2014. A detection/non-detection sampling technique was used to estimate the habitat use and photograph-based animal activity. We used 20 units of camera traps (Bushnell Trophy Cam and Bushnell Trophy Cam HD). Although it is said that a period of two weeks were ideal sampling period (Nichols and Karanth, 2002), we extended the duration of sampling up to two months in order to obtain adequate data for analysis. The infrared cameras were triggered by a heat or motion sensor (Kays and Slauson, 2008). Cameras were attached to a suitable tree about 40–50 cm above the ground and overlooking animal trails and were checked once a month to replace their memory cards and batteries. The cameras were active 24 h a day, set with an interval of 10 s between exposures and were adjusted to take three images per second. Cameras were programmed to record time and date of every image taken.

Our sampling unit is the site, where we deployed the camera traps. In mammal surveys, a "visit" to the site is equivalent to a single sampling occasion and it occurs within a sampling period. For each site and each occasion, sequences of '1' indicated the presence (photograph) of a mammal species, while sequence '0' indicated the non-detection of mammals. The number of sampling occasions usually can be determined after data collection, with more occasions resulting in higher precision (Henschel and Ray, 2003). We applied the occupancy model of single-season to our data.

2.5. Data analysis

After completing the survey, all cameras were retrieved and the animals in each of the photographs identified. Non-mammal photographs (e.g., Red Junglefowl) were excluded from the data analysis. Blank captures and exposures in which the species was unidentifiable were also excluded. We analyzed the data using software PRESENCE 7.3 (Hines, 2006) that fits single-season models for detection/non-detection data. We used presence/absence, single species constant occupancy and constant detection probability models on all species recorded, without evaluating the effect of site covariates. Because of small design sample size, occupancy models with multiple covariates were not used to estimate rate of occupancy (Rovero et al., 2013b).

Trap success rate for each species was calculated as the number of individuals captured over the total trap nights. Consecutive photographs of the same species at the same camera trap that were detected less than 30 min apart were not regarded as independent events since number of images was used to represent the activity level at the site. Throughout the study, we make an assumption that occupancy and detection probability are constant across both space and time (MacKenzie and Royle, 2005).

We treated the entire survey as one "season" with the assumption that survey sites were not resampled across the season, the population was assumed to be closed (no colonization). Within these detection histories, the eight month sampling period was divided into 16 week sampling occasions. We assumed that animal activity is intrinsically linked with the quality of habitat. Animal species would stay longer at any particular sites simply because food sources are abundant, refugia are available to escape predators, and human disturbances are rare at those sites. This habitat usage and activity determined by photographic rate estimations were linked to vegetation indices and landscape metrics. To compare the total number of animal images between daytime and nighttime, we used a two-sample Poisson test. We also compared diurnal and nocturnal images with respect to feeding guild.

To understand the effects of habitat and landscape attributes on mammals with different diet groups, the feeding guild was used as response variable. The guild was determined by images of herbivores, carnivores and omnivores. Prior to modeling work, we performed correlation tests to check for multi-collinearity among all 13 predictor variables which includes habitat and landscape attributes. We removed any predictor variables that were strong enough ($|r| > 0.7$) to distort the model estimation and its subsequent prediction (Dormann et al., 2013). We regressed the number of photographic images categorized by feeding guild with the existing vegetation and landscape attributes using Generalized Linear Models (GLMs) in GenStat v12 (VSN International, Hemel Hempstead, UK) and used Wald tests to determine significant covariates. We fitted data to a Poisson distribution with a logarithm link function. We applied backward elimination method as all variables of each analysis that were not significant ($p > 0.05$) were eliminated.

3. Results

3.1. Capture frequencies and species list

The total field effort comprised 2565 camera trap nights. A total of 4997 photographs were captured, which included 16 mammal species (Fig. 3). Out of the recorded photographs, about 7.78% ($n = 389$) were of carnivores, 19.97% ($n = 998$) were herbivores and the rest (72.24%; $n = 3610$) were omnivores. On the basis of relative activity (Table 1), the most commonly detected species per site (all making up more than 20% of total capture) were the Eurasian wild pig (*Sus scrofa*), Malayan Tapir (*Tapirus indicus*), Sun Bear (*Helarctos malayanus*), Leopard (*Panthera pardus*), Lesser Mousedeer (*Tragulus kanchil*) and Southern Pig-tailed Macaque (*Macaca nemestrina*). The Sumatran Rhinoceros (*Dicerorhinus sumatrensis*) was not recorded through camera traps and no visible tracks were found during the study. Throughout the sampling duration, we detected the tracks of Malayan Tapir (*T. indicus*), Eurasian Wild Pig (*S. scrofa*) and few tracks belonging to smaller ungulates.

Our results indicated that the total number of diurnal image (mean = 63.38 images per site) was significantly greater (Normal approximation = 10.001; $p < 0.001$) than nocturnal image (mean = 47.67 images per site). Carnivore images captured at night (mean = 7.667 images per site) was significantly greater (Normal approximation = −15.332; $p < 0.001$) than those captured in the daytime (mean = 0.956 images per site). Similarly, herbivore images captured at night (mean = 18.47 images per site) was significantly greater (Normal approximation = −23.324; $p < 0.001$) than those captured in the daytime (mean = 2.53 images per site). In contrast, omnivore image captured in the daytime

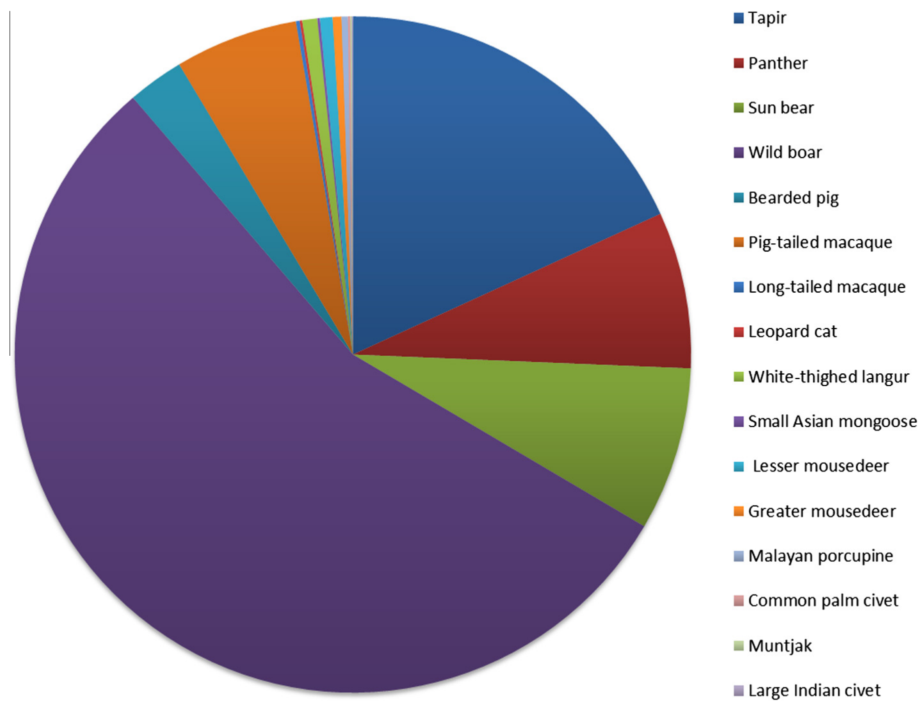

Fig. 3. Sixteen mammal species found at the North Selangor Peat Swamp Forest, totaling up to 4997 captured images from 2700 camera trap nights from March 2013 to October 2014.

Table 1
Number of sites recorded and number of images for each mammal species recorded from the North Selangor Peat Swamp Forest.

Species	Relative activity	
	Sites present	Number of images
Tapirus indicus (Malayan Tapir)	18 (40%)	908
Panthera pardus (Leopard)	10 (22.2%)	374
Helarctos malayanus (Sun Bear)	17 (37.8%)	391
Sus scrofa (Eurasian Wild Pig)	34 (75.6%)	2761
Sus barbatus (Bearded Pig)	6 (13.3%)	134
Macaca nemestrina (Southern Pig-tailed Macaque)	11 (24.4%)	294
Macaca fascicularis (Crab-eating Macaque)	2 (4.4%)	9
Prionailurus bengalensis (Leopard Cat)	1 (2.2%)	6
Presbytis siamensis (White-thighed Langur)	2 (4.4%)	36
Herpestes javanicus (Small Asian Mongoose)	1 (2.2%)	6
Tragulus napu (Greater Mousedeer)	2 (4.4%)	21
Tragulus kanchil (Lesser Mousedeer)	10 (22.2%)	30
Muntiacus muntjak (Red Muntjac)	1 (2.2%)	3
Paradoxurus hermaphroditus (Common Palm civet)	1 (2.2%)	6
Hystrix brachyura (Malayan Porcupine)	3 (6.7%)	15
Viverra zibetha (Large Indian Civet)	1 (2.2%)	3

(mean = 59.89 images per site) was significantly greater (Normal approximation = 28.514; $p < 0.001$) than those captured at night (mean = 21.53 images per site).

3.2. Occupancy of native mammals

In this study, we were only able to estimate occupancy rate using seven days occasion for ten species and occupancy rate derived from 14 days occasion for nine species (Table 2). The occupancy for Crab-eating Macaque (*Macaca fascicularis*), Small Asian Mongoose (*Herpestes javanicus*), Lesser Mousedeer (*T. kanchil*), Red Muntjac (*Muntiacus muntjak*), Malayan Porcupine (*Hystrix brachyura*) and Large Indian Civet (*Viverra zibetha*) could not be estimated because of limited data. Our estimations of habitat occupancy are conservative because we could not use covariates because the number of sampling sites (i.e. 45 sites) was too small to allow us to include habitat quality or landscape metrics in the analyses (Rovero et al., 2013b).

Photographs recorded from 2700 camera traps nights produced seven days model and 14 days model constant occupancy estimates of 44.4% and 45.8% for the Malayan Tapir (*T. indicus*) (Table 2). The other threatened mammals such as the Leopard (*P. pardus*), Sun Bear (*H. malayanus*) and Southern Pig-tailed Macaque (*M. nemestrina*) had the occupancy of 33.7%, 47.7%, and 36.5% in the seven days model, followed by 38.4%, 40.8%, and 35.1% respectively in the 14 days model (Table 2). The Bearded Pig (*Sus barbatus*) has the occupancy estimates of 19% and 15.9%, based on seven days model and 14 days model while the Eurasian Wild Pig (*S. scrofa*) has the highest occupancy estimates of 77.5% and 78.7% respectively (Table 2).

3.3. Mammal activity rate according to feeding guild

The activity rate of different mammal guilds responded differently to *in situ* habitat quality and landscape factors. For herbivores, six out of eight vegetation characteristics and three out of five landscape metrics determined activity rate. Activity rate of carnivores was significantly influenced by four out of eight vegetation characteristics and two out of five landscape metrics. Activity rate of omnivores was significantly influenced by six out of eight vegetation characteristics and four out of five landscape metrics.

We found that activity level of all mammal species, regardless of feeding guild decreases with compositional heterogeneity, herbivore ($p < 0.001$), omnivore ($p < 0.001$) and carnivore ($p < 0.001$) (Table 3). The activity level of herbivores decreased as distance to river increased ($p < 0.001$) whereas omnivore activity level decreased as distance to road increased ($p < 0.001$). Oil palm area significantly reduced the herbivore activity level ($p < 0.001$) and increased omnivore activity level ($p < 0.001$) (Table 3).

Table 2
IUCN status, feeding guild and estimated site occupancy of the recorded species in the North Selangor Peat Swamp Forest. ID – Insufficient Data. SE – Standard Error. CI – Confidence Interval.

Species	IUCN status	Feeding guild	Occupancy based on 7 days occasion			Occupancy based on 14 days occasion		
			Estimate	SE	95% CI	Estimate	SE	95% CI
Tapirus indicus (Malayan Tapir)	Endangered	Herbivore	0.444	0.083	0.292–0.607	0.458	0.088	0.297–0.628
Panthera pardus (Leopard)	Near threatened	Carnivore	0.337	0.102	0.172–0.555	0.384	0.135	0.17–0.655
Helarctos malayanus (Sun Bear)	Vulnerable	Omnivore	0.477	0.101	0.292–0.669	0.408	0.086	0.255–0.58
Sus scrofa (Eurasian Wild Pig)	Least concerned	Omnivore	0.775	0.066	0.622–0.878	0.7865	0.067	0.627–0.89
Sus barbatus (Bearded Pig)	Vulnerable	Omnivore	0.19	0.085	0.074–0.408	0.159	0.064	0.069–0.326
Macaca nemestrina (Southern Pig-tailed Macaque)	Vulnerable	Omnivore	0.365	0.106	0.19–0.585	0.351	0.101	0.185–0.563
Macaca fascicularis (Crab-eating Macaque)	Least concerned	Omnivore	ID	ID	ID	ID	ID	ID
Prionailurus bengalensis (Leopard Cat)	Least concerned	Carnivore	0.027	0.028	0.003–0.183	0.025	0.025	0.003–0.165
Presbytis siamensis (White-thighed Langur)	Near threatened	Herbivore	0.073	0.065	0.012–0.339	0.066	0.056	0.012–0.293
Herpestes javanicus (Small Asian Mongoose)	Least concerned	Carnivore	ID	ID	ID	ID	ID	ID
Tragulus napu (Greater Mousedeer)	Least concerned	Herbivore	0.0484	0.034	0.012–0.177	0.05	0.035	0.012–0.186
Tragulus kanchil (Lesser Mousedeer)	Least concerned	Herbivore	ID	ID	ID	ID	ID	ID
Muntiacus muntjak (Red Muntjac)	Least concerned	Herbivore	ID	ID	ID	ID	ID	ID
Paradoxurus hermaphroditus (Common Palm civet)	Least concerned	Omnivore	0.027	0.028	0.003–0.183	ID	ID	ID
Hystrix brachyura (Malayan Porcupine)	Least concerned	Omnivore	ID	ID	ID	ID	ID	ID
Viverra zibetha (Large Indian Civet)	Near threatened	Carnivore	ID	ID	ID	ID	ID	ID

Table 3
GLMs of responses of mammal feeding guilds to various significant ($p < 0.001$) *in situ* habitat quality and landscape attributes.

Independent variable	Dependent variable							
	Overall activity		Herbivore activity		Omnivore activity		Carnivore activity	
	Slope	Wald statistics	Slope	Wald statistics	Slope	Wald statistics	Slope	Wald statistics
In situ habitat quality								
Canopy cover	0.009	183.6			0.006	55.6	0.031	29.16
Canopy height	−0.171	217.2	−0.091	14.71	−0.202	133.4	−0.481	38.86
Fallen DBH < 45			1.365	205.75	0.303	270.9	−0.597	16.37
Fallen DBH > 45	−0.97	105.8			−0.926	112.3		
Number of wild palm	0.022	100	−0.019	12.39	0.052	347.2		
Number of sapling			0.04	191.43	−0.041	214.4		
Tree DBH > 45	−0.061	356.4	0.0262	61.91	−0.045	14.2	−0.623	20.61
Tree DBH < 45	0.028	40.5	0.172	94.4	−0.007	15	0.142	232.68
Landscape metric								
Compositional heterogeneity			−0.443	80.8	−0.414	464.6	1.015	40.86
Distance to river	0.113	191.3	−0.589	177.63				
Distance to road	0.047	25.2			−0.08	32.7		
Forest area					−0.006	131.2	0.027	35.57
Oil palm cultivation area	0.001	130.9	−0.001	15.56	0.003	355.4		

The activity level of herbivores significantly increased with canopy height ($p < 0.001$), omnivores ($p < 0.001$) and carnivores ($p < 0.001$). When canopy cover increased, so did the activity level of omnivores ($p < 0.001$) (Table 3) and carnivores ($p < 0.001$). Higher numbers of saplings was also found to be associated with an increase in herbivore activity ($p < 0.001$) and a decrease in omnivore activity ($p < 0.001$). Herbivore activity ($p < 0.001$) and omnivore activity ($p < 0.001$) were lower in areas with few palms. The activity level of carnivores increased with forest area ($p < 0.001$) and trees with a DBH of more than 45 cm ($p < 0.001$) and decreased significantly with the number of trees with DBH of less than 45 cm ($p < 0.001$) and fallen trees with DBH of less than 45 cm ($p < 0.001$) (Table 3).

The activity level of omnivores increased significantly with the number of fallen trees with DBH less than 45 cm ($p < 0.001$) (Table 3) but decreased with an increase of forest area ($p < 0.001$), the number of fallen trees with a DBH of more than 45 cm ($p < 0.001$), the number of trees with DBH of more than 45 cm ($p < 0.001$) and the trees with a DBH less than 45 cm ($p < 0.001$). The activity level of herbivores increased with the number of fallen trees with a DBH of less than 45 cm ($p < 0.001$), the number of trees with a DBH of less than 45 cm ($p < 0.001$) and the number of trees with a DBH of more than 45 cm ($p < 0.001$) (Table 3).

4. Discussion

4.1. Diurnal and nocturnal patterns

Our results showed that most of the peat swamp species are predominantly diurnal even though some are in nature thought to be nocturnal predators, especially the omnivores and carnivores. The presence of other predators and availability of prey in the area may affect the activity period of these species (Cheyne et al., 2010).

4.2. Occupancy patterns of peat swamp mammals

This study is the first camera trap research to be conducted in the peat swamps of Peninsular Malaysia and NSPSF. By deriving from detection/non-detection survey data, occupancy estimates provide an effective approach for assessing animal distribution in natural habitats when some species are not always detected with certainty (Nichols et al., 2008). Our findings from the constant occupancy-based models indicate that most of the peat swamp area is occupied by high conservation value species. Few photographs had revealed that oil palm plantations affected the detection probability of mammals, especially the large-bodied mammals in terms of resource availability (e.g. food, salt lick and cover) (Steinmetz et al., 2011). Forest conversion in these habitats may disrupt the mammals' habitat use by altering existing foraging patterns (Bali et al., 2007). Habitat use of these mammals needs additional research because of the high level of conversion forest to agricultural land.

The constant model used in this study provides a benchmark for the detection/non-detection of mammals across the study site but an intensive sampling involving more sampling sites and coverage of wide area is needed to study the complexity of the habitat and species (Linkie et al., 2007; Wong and Linkie, 2013).

4.3. Relationship between activity rate and in situ habitat quality and landscape factors

Different large mammal species respond differently to landscape-level attributes and spatial and temporal scales are important in determining the efficacy of conservation measures (Clevenger and Waltho, 2005). Our study showed the *in situ* habitat quality (i.e. vegetation characteristics) and landscape metrics that influences the activity of wildlife that belong to different feeding guilds. Mammals are particularly vulnerable to anthropogenic threats such as forest disturbances by agricultural expansion (Sodhi et al., 2004). The NSPSF is close to agricultural areas such as oil palm plantations and rice fields. The proximity to agricultural land is likely to limit wildlife, especially large species that do not travel far outside of the forest area (Laidlaw, 2000; Jennings et al., 2015) thus compositional heterogeneity affects all mammals regardless feeding guilds negatively.

Canopy height and canopy cover play a large factor on the activity level of rodents (Rovero et al., 2013a), canopy mammals (Bernard et al., 2014) and bird species (Azhar et al., 2013b; Kuhnen et al., 2012). From our data, canopy cover may help carnivores and omnivores in their daily hunting strategies such as stalking camouflage. The negative correlation between carnivore activity and fallen trees with DBH less than 45 cm and tree stand with DBH less than 45 cm may influence the carnivore predatory strategy. Carnivore activity is associated with large trees with DBH more than 45 cm because of the stealthy nature of carnivores in the forest complex.

Results from this study showed that canopy cover did not affect herbivores in terms of activity rate. Canopy height on the other hand is important for the omnivorous ungulates and agile climbers such as carnivorous Leopard (*P. pardus*) and large Indian civet (*V. zibetha*). Omnivore activity level relates negatively with fallen trees with DBH more than 45 cm, maybe as a result of their limitation of movement such as obstruction while foraging. Detection probability of certain omnivore species, such as the sun bear (*H. malayanus*) tend to depend only on several important factors such as fruiting trees availability (Wong et al., 2012).

Distances from river and road did not affect mammals of all feeding guilds. The lack of road effects may have been because omnivorous mammals would exploit a wide range of food resources in and at the edges of the forest (Azhar et al., 2014). Also, the abundance of herbivores increased with the loss of natural forest patches. The increase in herbivores may be attributed to increased food production at edge habitats in small patches than in a large one (Bender et al., 1998). Forest area influenced carnivore activity positively, which could be the result of their large home range sizes especially for the large-bodied predators (Laidlaw, 2000). Tigers may use wide and established trails for movement (Kawanishi, 2002) and since the Malayan tiger (*Panthera tigris*) was absent in this forest complex, the leopard (*P. pardus*) would fill the vacuum left by the tiger (Ickes, 2001).

Oil palm cultivation affected the activity level of omnivores in a positive manner because of the availability of food that exists in those plantations. Even though, certain species like the Malayan porcupine (*H. brachyura*) are often regarded as a pest and killed (Azhar et al., 2013a). Leopard cats (*Prionailurus bengalensis*) prefer open areas like oil palm plantations, possibly because Murid rodents are more abundant in such areas compared to more closed generating secondary forests (Rajaratnam et al., 2007).

5. Conclusion

Around the world, tropical peat swamps are being exploited for timber or drained for plantation forestry (Parish et al., 2008). Native forests representing this unique ecosystem should not be cleared for oil palm plantations because of the serious negative impacts on biodiversity (Brooks et al., 1999; Sodhi et al., 2004; Wilcove and Koh, 2010) and carbon stores. We recommend that the legal status of the NSPSF should be upgraded from unsecured forest reserve to protected area. Large blocks of the NSPSF need to be protected in order to ensure wildlife populations are demographically stable and genetically viable (Miquelle et al., 1995). Agriculture and habitat conservation can be compatible under certain circumstances. Plantation stakeholders around the NSPSF must protect the forest biodiversity by prohibiting poachers from entering the forest via their plantations (Azhar et al., 2013a). With more natural forests being converted to monoculture plantations each year, efforts must be directed toward conserving existing forests areas.

The importance of protecting peat swamps for maintaining tropical biodiversity is always sidelined by government agencies. The sustainable management of peat swamps requires the integration of approaches for biodiversity, climate change and land degradation in close coordination between different stakeholders (e.g. government agencies and plantations). Continued monitoring will provide critical information on the occurrence of native species and will contribute to the effectiveness of conservation interventions. Monitoring data is important to evaluate the cost-effectiveness of different conservation strategies, such as mitigation of forest habitat loss and forest degradation (Linkie et al., 2007). Such information could also be used to inform national policy makers on more conservation compatible land use management (Linkie et al., 2007, 2013). The application of camera trap method for non-intrusive monitoring in the field now enables studies on the impact of the different threats to wild animal populations and their response to human disturbances (Linkie et al., 2013).

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