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CAMERA-TRAPPING SURVEY OF MAMMALS IN AND AROUND IMBAK CANYON CONSERVATION AREA IN SABAH, MALAYSIAN BORNEO

Henry Bernard and **Abdul Hamid Ahmad**
Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
**Email: hbtiandun@gmail.com (Corresponding author)*

Jedediah Brodie
Department of Zoology and Botany, Biodiversity Research Centre, University of British Columbia
Vancouver, British Columbia, Canada

Anthony J. Giordano
Department of Natural Resources Management, Texas Tech University, Lubbock, Texas, USA
S.P.E.C.I.E.S., LifeScape International, New York, New York, USA

Maklarin Lakim
Research and Education Section, Sabah Parks, Kota Kinabalu, Sabah, Malaysia

Rahimatsah Amat
Sabah Environment Trust, Kota Kinabalu, Sabah, Malaysia

Sharon Koh Pei Hue and **Lee Shan Khee**
WWF-Malaysia (Sabah Office), Kota Kinabalu, Sabah, Malaysia

Augustine Tuuga and **Peter Titol Malim**
Sabah Wildlife Department, Kota Kinabalu, Sabah, Malaysia

Darline Lim-Hasegawa, **Yap Sau Wai** and **Waidi Sinun**
Conservation and Environmental Management Division, Yayasan Sabah, Kota Kinabalu, Sabah Malaysia

ABSTRACT. — As part of an effort to develop a comprehensive management plan for the Imbak Canyon Conservation Area in central Sabah, Malaysian Borneo, we conducted a rapid but extensive mammal survey using camera-trapping techniques. We gathered baseline data on mammal species richness and community composition, as well as information on activity patterns for some mammal species. Eighty motion-triggered digital camera-traps were set in the primary and logged forests in and around the Imbak Canyon. The total accumulated camera-trapping effort of 1,436 camera trap-nights yielded 1,641 digital photographs of mammals represented by 27 species in 14 families and five orders. The species photo-captured included common species, as well as rare and elusive species and species that are of high conservation value, such as the Sunda clouded leopard, *Neofelis diardi* and orang utan, *Pongo pygmaeus*. Our results indicated that the primary forest of the Imbak Canyon and its surrounding disturbed forests are important habitats for mammal conservation. Of particular importance are the carnivores, with 13 species recorded. Game animals, such as bearded pig, *Sus barbatus*, muntjac, *Muntiacus* spp., and mousedeer, *Tragulus* spp., were found to be among the most frequently photo-captured and the most widespread species. The activity patterns of mammals investigated did not show that they were affected by human activities. Even so, we found substantial evidence of poaching and illegal collection of the aromatic gaharu tree resin (*Aquilaria* spp.) in the surveyed areas, raising management concerns and highlighting the urgent need for law enforcement activities in the area.

KEY WORDS. — camera trapping, Imbak Canyon, mammal species richness, activity patterns

INTRODUCTION

Borneo is the world's third largest island and widely considered to contain some of the highest levels of biodiversity in the world (Myers et al., 2000). Despite this richness, it is under substantial threat from logging and other human-related pressures such as large-scale agriculture (Sodhi et al., 2004). The Malaysian state of Sabah, which occupies less than 10 percent of the northern part of Borneo, is no exception. Although approximately 51% of its 73,631 km^2 of land area remains under forest cover, much of this area consists of a highly heterogeneous landscape of logged forests in various stages of regeneration (Reynolds et al., 2011).

Biodiversity surveys are important to document patterns of species richness, diversity and compositions in different sites, as well as in different forest conditions, in order to facilitate sound decisions regarding biodiversity conservation. Camera-trapping is an increasingly popular method to study biodiversity especially wildlife. Despite that camera-trapping may be biased towards detecting mainly terrestrial species (e.g., Wilting et al., 2010), this technique has been shown to be highly effective in biodiversity surveys in areas where long term study via direct observation and live-trapping is difficult for logistical reasons, such as remote areas in dense forest (Mohd-Azlan, 2006). This technique is also very effective for detecting wildlife species that are rare, secretive or elusive, such as many rainforest mammal species (Brodie & Giordano, 2011, 2012; Matsubayashi et al., 2011; Bernard et al., 2012; Samejima & Semiadi, 2012).

Mammals are important taxa for study given that many species fill key ecological roles in the forest ecosystem, including predation, herbivory and seed dispersal, some of which can potentially influence forest regeneration and recovery (Nakashima et al., 2010). Many mammals are also charismatic and/or flagship species, while some are important as game animals, which often makes them of particular conservation and management concern (Mohd-Azlan & Sharma, 2003; Mohd-Azlan & Lading, 2006; Kitamura et al., 2010). A recent meta-analysis found that mammals are also the most sensitive group to habitat disturbance in Southeast Asia (Sodhi et al., 2010); thus mammals are often considered for monitoring of forest management systems (e.g., Ancrenaz et al., 2005; Giman et al., 2007; Matsubayashi et al., 2007; Samejima et al., 2012).

There are at least 221 known mammal species on Borneo (Payne et al., 1985). However, we still have a lack of even basic knowledge about patterns of mammal species richness and community composition in most parts of the island. Given the threats posed by logging and more recently, conversion of forested habitats to large-scale monoculture plantations, it is important to acquire data on mammals in all remaining unlogged areas as well as logged over areas to develop a baseline understanding of mammal communities in this mega-diverse region. In this respect, research in areas that have never been subjected to biodiversity surveys is of paramount importance. Although mammal surveys have been conducted in the past at a few localised sites in Imbak Canyon Conservation Area, these have resulted only a preliminary mammal species checklist, most of which is represented by the area's bat and small mammal fauna, among the most common species (Matsubayashi et al., 2011; Bunya et al., 2012). Our study is the first broad-scale, robust survey of terrestrial mammals across the area.

We conducted a rapid but extensive mammal survey of the Imbak Canyon region using camera-trapping. This survey formed part of a collaborative, multi-institution, wildlife survey known as the "ICCA Wildlife Survey 2012" that covered the entire Imbak Canyon Conservation Area and its surrounding secondary logged forests. The larger survey included avifauna via mist-netting and direct observations, bats and reptiles based on opportunistic observations, and information on mammals based on camera-trapping and direct observations from recce walks. The aim of our survey was to gather baseline data on mammal species richness and composition in and around the Imbak Canyon Conservation Area, as well as record other ecological information about the mammals that might be useful for developing a comprehensive conservation management and monitoring plan. Here we report on the findings of the mammal survey based on camera-trapping data.

MATERIAL AND METHODS

Study site. — Embedded within the 10,000 km^2 Yayasan Sabah Forest Management Area in central Sabah, Malaysian Borneo (5°01'35.9"N, 117°02'41.8"E; Fig. 1), the Imbak Canyon Conservation Area (ICCA) together with Danum Valley Conservation Area (438 km^2) and Maliau Basin Conservation Area (588 km^2) are three of South East Asia's most important conservation areas (Reynolds et al., 2011). The ICCA is approximately a 300 km^2 crescent-shaped elongated valley. The Imbak Canyon, which is drained by the Imbak river (a tributary of the upper Kinabatangan river), is approximately 750 m deep, 3 km wide and 30 km long (Tongkul et al., 2012). The floor of the canyon lies about 250 m a.s.l., whereas the rim of the canyon is about 1000 m a.s.l. with gentle slopes on its north and southern sides (Tongkul et al., 2012). The highest point is Mount Kuli (1,684 m a.s.l.) located in the southern rim of Imbak Canyon (Mustapha et al., 2012). The habitat is mostly lowland dipterocarp rainforest and upper montane forest, including patches of montane heath or "Kerangas" forest (Sugau et al., 2012; Suleiman et al., 2012). The ICCA was gazetted as a Class I (Protection) Forest Reserve in 2009, making logging activities totally prohibited in the area. Being logged in the past and located in proximity to some human settlements and plantations, the forest habitats surrounding the fringes of the ICCA are generally heavily disturbed. However, forests inside the canyon of the ICCA are still relatively pristine. Areas around the northern and southern rim of the ICCA are part of a Virgin Jungle Reserve (Latif & Sinun, 2012).

Camera trapping. — Given the shortcomings of camera-trapping to detect arboreal and small terrestrial mammals, we aimed to detect medium-to large-sized terrestrial mammals using this survey method. We deployed eighty automatic remote motion-triggered digital camera traps of three commercial brands (Bushnell, Trophy Cam ™ [30 units], Reconyx, RM45 [30 units], and Cuddeback, Capture [20 units]) in 13 circular plots, each of which was prescribed by a 3.5 km radius. Since areas outside of the ICCA covered a larger area, 10 plots (P3–P11 & P13) were located in the surrounding areas outside of the ICCA, while three plots (P1, P2 & P12) were located inside the core area of the ICCA (Fig. 1). Some plots overlapped to a certain extent with each other. Distances between nearest plots ranged from 0 to 5 km. During the survey, it was intended that the entire 80 camera traps were to be deployed simultaneously at all plots. To achieve this, more than 100 personnel from various institutions based in Sabah and Sarawak were involved in the exercise and they were divided into 13 smaller groups of 7–10 personnel. Each group (Group 1 to 13) was stationed at their designated plot (P1 to P13, respectively) and stayed there throughout the survey period. Personnel were deployed to four of the plots (P1, P2, P10 & P11) via helicopter as access to these plots by foot was difficult and/or time consuming. All other plots however were accessed via a 4WD vehicle or on foot.

Five camera stations were established in each of plots P3–P11 and P13 (total: 50 camera stations), and 10 camera stations each were established in plots P1, P2 and P12 (total: 30 camera stations). Selection of stations was made in such a way that they would increase the likelihood of photo-capture of as many different terrestrial mammal species as possible. Therefore, camera stations were positioned in areas that were thought to be travelled frequently by animals such as along small (<2 m width) and large (>2 m width) animal trails, human-made trails along slopes and ridge-tops, on abandoned logging roads, and in areas near mud wallows, rivers, streams, or under fruiting trees.

Only one camera trap was placed at each camera station. Bushnell and Reconyx cameras were set at high sensitivity to take three shots at rapid fire during every trigger with a time delay of 60 seconds between triggers. Cuddeback cameras were set with similar settings as Bushnell and Reconyx cameras except that this camera type can only take one shot per trigger and it has no setting for sensitivity. As different camera models likely exhibit differences in sensitivity, potentially resulting in variations in detection frequency even for the same animal species, different camera types were randomly assigned to each plot so that bias in 'detectability' between plots was distributed across all plots. All cameras were attached to the base of trees close to the ground (<0.4 m). All camera station locations were marked using a portable GPS (GARMIN eTrex). The mean distance between camera stations within plots was 819 m (range: 134–3,047 m) and the mean elevation of the camera stations was 294 m a.s.l. (range: 123–623 m a.s.l.). All cameras were active 24 hours per day and used either infrared or white flash at night.

Since plots located outside the ICCA (P3–P11 & P13) were in close proximity to human settlements and plantations, there were concerns with disturbance or loss of cameras due to theft. Therefore cameras located at these plots were left in the forest at the same location for a maximum period of 10 days only, i.e., corresponding to the actual wildlife survey period (8–20 Jul.2012). Cameras located inside the ICCA (plots P1, P2 & P12) were left at the same location for at least 60 days in the forest (8 Jul. – 13 Sep.2012), at which point survey teams retrieved them.

To minimise human error when setting cameras in the field and to facilitate the standardisation of the camera trapping protocol across all plots (e.g., with respect to choosing camera location placement), training and demonstration on the practical aspects of camera-trapping in the field were conducted at the beginning of the survey using human instruction, and the handbook for wildlife monitoring using camera-traps (Ancrenaz et al., 2012).

Data analysis. — At the end of the survey periods all cameras were retrieved and the animal species in each of the photograph captured was identified with the aid of Payne et al. (1985). The time and date of all photos were recorded automatically. The global or regional conservation status of each species was determined based on the IUCN *Red List of Globally Threatened Species* (IUCN, 2009). In addition, the local protection status accorded to the species was determined based on the Wildlife Conservation Enactment of the state of Sabah (WCE, 1997).

Photographs of animals that could not be identified with certainty because of poor lighting, blurred photographs, or where only parts of the animals were captured were excluded from the photographic analysis. Some small mammals such as rats, tree shrews, bats, and squirrels (except for the Bornean endemic large tufted ground squirrel, *Rheithrosciurus macrotis*, which is easily identifiable), were too small in size for positive species identification and along with all birds, reptiles and domestic animals were likewise excluded from the analysis. The greater mouse-deer, *Tragulus napu*, and lesser mouse-deer, *T. kanchil*, were sometimes hard to distinguish in the photographs; therefore these species were treated as one morphospecies, *Tragulus* spp. For similar reasons, the muntjac, divided into two species, the Bornean red muntjac, *Muntiacus muntjak*, and the Bornean yellow muntjac, *M. atherodes*, were regarded as one morphospecies, *Muntiacus* spp.

Overall camera trap success rates were determined for all combined species and for every species photographed. Trap success for each species was calculated as the number of animal captures per 100 trap-nights using the formula: $TS_i = (N_i / \Sigma TN) \times 100$, where TS_i is trap success for species i, N_i is the number of independent events or photographs for species i, and ΣTN is the total number of camera-trap-nights. Consecutive photographs of the same species at the same trap station that are detected more than an hour apart were regarded as independent events. For consecutive photographs depicting the same species within the period of <1 hour, the photograph with the most number of individuals was chosen as the independent sample for that species.

To assess for sampling saturation of mammals in the ICCA and surrounding areas, we calculated an 'observed species accumulation curve' using an abundance-based rarefaction approach (i.e., based on the cumulative number of independent photographs captured) with 95% confidence intervals constructed in EstimateS Version 8.2.0 (Colwell, 2009) and based on 100 random iterations. Sampling saturation was assumed to be met when the observed cumulative number of mammal species reached an approximate asymptote with the cumulative number of independent photographs captured. Additionally, we assessed sampling saturation by calculating the sampling completeness ratio (i.e., observed species number/estimated species number) using the mean of four commonly used abundance-based species richness estimators (i.e., ACE, CHAO1, JACK1, and Bootstrap) computed using EstimateS Version 8.2.0 (Edwards et al., 2009). Here sampling saturation was assumed when the sampling completeness ratio approached one.

Analyses of activity patterns were conducted for mammal species that were photo-captured frequently (≥8 independent photographs). As Imbak Canyon is located only 5°N of the equatorial line, daytime and nighttime was assumed to be equal, i.e., 12 hours from 0600 to 1800 hours (daytime) and 12 hours from 1800 to 0600 hours (nighttime). Thus time periods were pooled in 1-hour intervals. The number of independent photographs of a given species was assumed to correlate with animal activity. Comparison of animal activity patterns in this study were mainly based on descriptive information by Payne et al. (1985) and other literature. Following van Schaik & Griffiths (1996), Grassman et al. (2006), and Kitamura et al. (2010), we generally defined diurnally active species as those with <10% of captures at night, and nocturnally active species as those that had >90% captures at night. Species with between 10–90% nocturnal captures were regarded as arrhythmic, i.e., showing no clear activity pattern.

RESULTS

Trapping effort, mammal species richness and composition. — All 80 camera traps were successfully deployed in the field within a span of three days; however, not all cameras were deployed to their a priori designated plots. Group 2 did not manage to deploy their camera traps at their designated plot of P2 due to failure of the helicopter to land at its predetermined site. Members of group 2 alighted close to P1 and consequently, all cameras of group 2 were placed in the same general area as plot P1 (Fig. 1). Group 3 and Group 4 also did not manage to reach their designated plots (i.e., P3 and P4, respectively) due to collapsed bridges; hence, some camera traps were distributed outside of their designed plot areas. Other cameras were not functional throughout the study period. For example, the settings of all 10 cameras of Group 1 in Plot 1 were not correct, resulting in all cameras in this plot being non-operational throughout the survey period. In addition, three cameras malfunctioned at the start of the survey (i.e., one each from plots P1, P9, and P12) and another one each malfunctioned at P1 and P12 after only one day and 13 days respectively, while in the field.

The total camera-trapping effort for all 12 plots combined (excluding plot P2 and the 10 cameras that were non-functional in P1) was 1,436 camera trap-nights, with plots P1 and P12 having the most trapping effort with 495 trap-nights and 428 trap-nights, respectively. The other plots recorded an average of 46 trap-nights (Range: 37–50 trap-nights). In total 1,641 digital photographs of mammals were captured, of which 564 were independent photographs.

A total of 27 mammal species represented by 14 families and five orders were photo-captured (Table 1). This is approximately where the observed species accumulation curve approaches an asymptote (Fig. 2). The mean estimated species richness computed with EstimateS was 30.43 (ACE=29.85; CHAO1=29.67; JACK1=32.57; Bootstrap=29.61), which resulted in a sampling completeness ratio of 0.89. This suggests that the sampling saturation of the camera trapping survey was relatively high despite the relatively short sampling period.

As expected, all species detected in the present survey were of terrestrial animals or arboreal mammals that spend at least some time on the ground (Payne et al., 1985). Of the 27 species recorded, five species were Bornean endemics including the tufted ground squirrel, *Rheithrosciurus macrotis* and orang utan, *Pongo pygmaeus* (Table 1). Two of the species

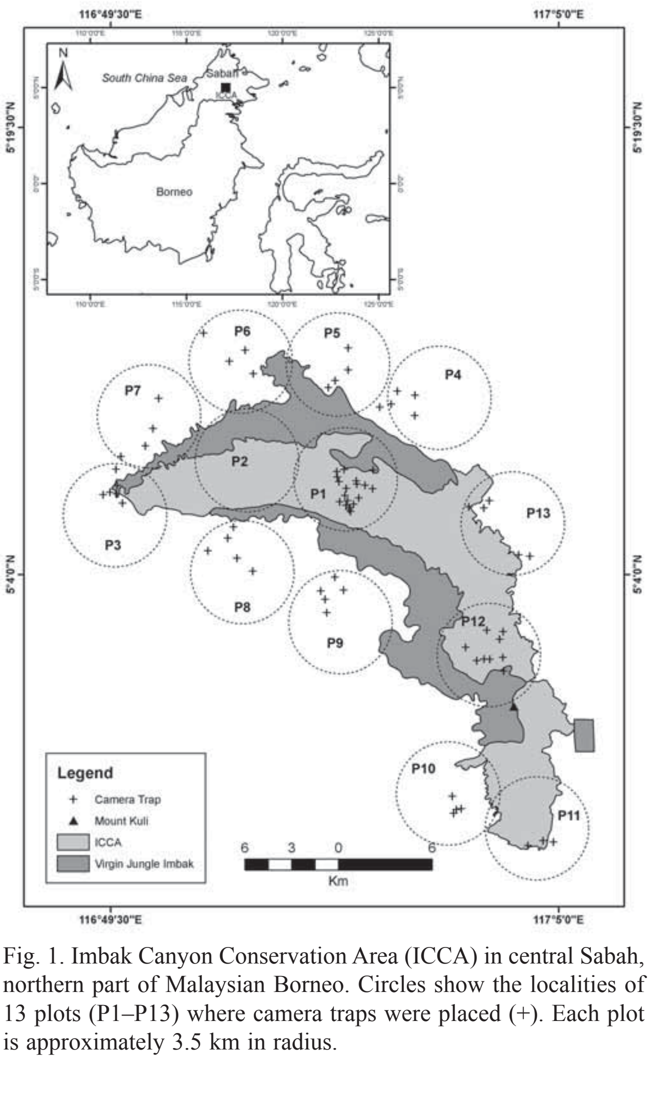

Fig. 1. Imbak Canyon Conservation Area (ICCA) in central Sabah, northern part of Malaysian Borneo. Circles show the localities of 13 plots (P1–P13) where camera traps were placed (+). Each plot is approximately 3.5 km in radius.

are listed as "Endangered" under the IUCN (2009)—the orang utan and the pangolin, *Manis javanica*, while 11 species are listed as "Vulnerable". The remaining 13 species are classified as "Least Concern", "Data Deficient" or "not assessed" under IUCN (2009) criteria. Three species, including the Bornean sun bear *Helarctos malayanus euryspilus*, are afforded "Totally Protected Species" status, under the Sabah Wildlife Conservation Enactment (WCE, 1997). Another 18 species are afforded "Protected Species" status, while five species are regarded as a game animal and are thus subject to limited hunting via an authorised hunting license as issued by the Sabah Wildlife Department.

The combined photographic rate of all species across all plots was 39.28 photographs/100 trap-nights. The four species with the highest photographic rates in descending order were the mouse deer, *Tragulus* spp. (with 7.45 photographs/100 trap-nights), muntjac, *Muntiacus* spp. (6.89 photographs/100 trap-nights), bearded pig, *S. barbatus* (6.41 photographs/100 trap-nights) and pig-tailed macaque, *M. nemestrina* (5.29 photographs/100 trap-night) (Table 1). All four species combined accounted for 66% (or 374) of all independent photographs.

Species that were photographed in the most number of plots, again in descending order, included the bearded pig, *S. barbatus* (from 11 plots), mouse deer, *Tragulus* spp. (8 plots), muntjac, *Muntiacus* spp. (8 plots), and pig-tailed macaque, *M. nemestrina* (8 plots). These species not surprisingly also had the highest recorded photographic rates. Five species were photographed on only one occasion and therefore represented the least widespread species in this study. They included the banded linsang, *Prionodon linsang*, smooth-coated otter, *Lutrogale perspicillata*, tufted ground squirrel, *Rheithrosciurus macrotis*, Hose's langur, *Presbytis hosei*, and orang utan, *P. pygmaeus*.

Thirteen species of Carnivora in six families were recorded making it the most diverse order of mammals recorded during our survey. The order Artiodactyla was represented by four species in three families. However, if the two species of mouse deer, *T. napuh* and *T. kanchil*, and two species of muntjac, *M. muntjac* and *M. atherodes*, were taken into account as separate species respectively, the actual number of Artiodactyl species recorded was six.

Activity patterns. — We analysed the activity patterns of the 14 mammal species recorded in ≥8 independent photographs (Fig. 3). Four species were classified as diurnal (pig-tailed macaque, *M. nemesterina*, long-tailed macaque, *M. fascicularis*, yellow-throated marten, *Martes flavigula*, and muntjac, *Muntiacus* spp.), five species as arrhythmic (bearded pig, *S. barbatus*, Sambar deer, *Rusa unicolor*, Bornean sun bear *H. malayanus euryspilus*, mouse deer, *Tragulus* spp., and Sunda clouded leopard, *N. diardi*) and five species were considered nocturnal (Malay civet, *Viverra tangalunga*, common porcupine, *Histryx branchyura*, banded civet, *Hemigalus derbryanus*, thick-spined porcupine, *H. crassispinis*, and long-tailed porcupine, *Trichys fasciculata*).

DISCUSSION

Mammal species richness in Imbak. — Although photographic capture rates may serve as an index of relative abundance (Carbone et al., 2001), this index may not be directly comparable among species (Jennelle et al., 2002) as detectability is not the same across species. Therefore we did not attempt to compare relative abundance across species.

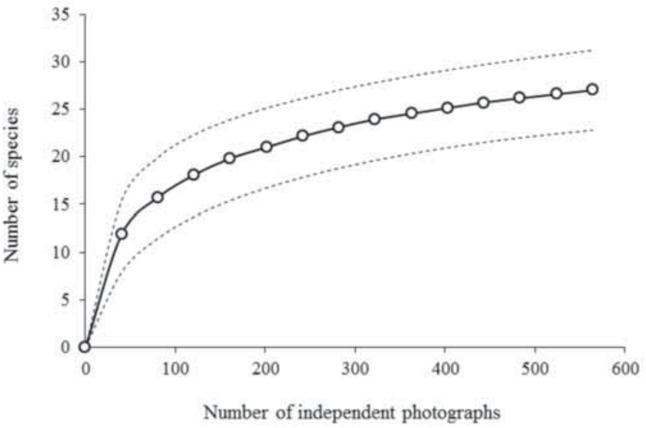

Fig. 2. The observed species accumulation curve (-o-) and 95% CIs (---) for mammalian species in and around Imbak Canyon Conservation Area. The curve was constructed using abundance-based rarefaction approach (i.e., by using the number of independent photographs captured) with 100 randomisation runs in EstimateS (Colwell, 2009).

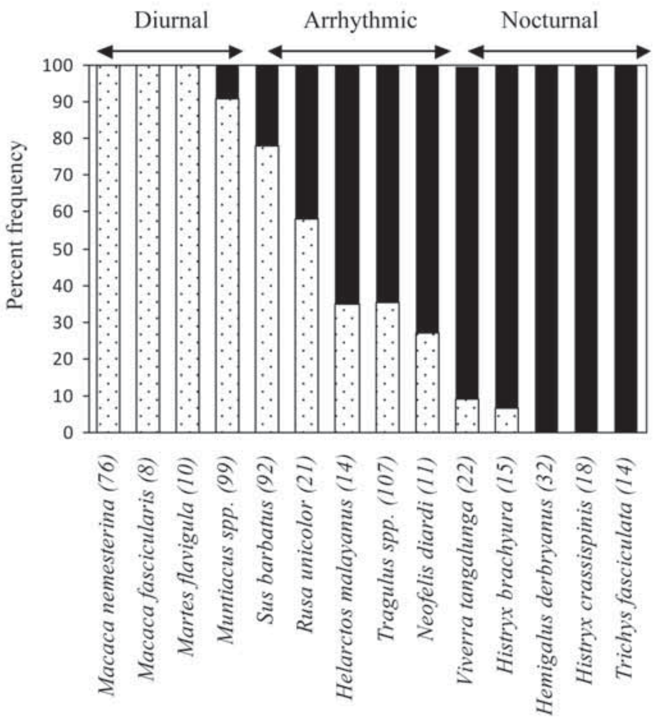

Fig. 3. Activity patterns for 14 mammal species (with n ≥ 8) photo-captured in and around Imbak Canyon Conservation Area in central Sabah, Malaysian Borneo. Dotted bar indicates percent frequency of independent photographs taken during the day time (0600–1800 hours); Black bar indicates percent frequency of independent photographs taken during night time (1800–0600 hours). Species are listed in order of decreasing frequency of diurnal activity. Numbers in parentheses indicate sample size.

Table 1. Summary of animals photo-captured in and around the Imbak Canyon Conservation Area (ICCA) in Sabah, Malaysian Borneo, during the ICCA Wildlife Survey 2012. **NIP**, number of independent photographs; **NID**, number of individual animals; **SPR**, photographic rate of species captured, i.e., NIP per 100 camera trap-nights. **SITE**: P#, indicates plots where animals were photo-captured (see Fig. 1 for location of plots). **IUCN**, Red List of globally threatened species status, EN=endangered, VU=vulnerable, LC=least concern, DD=data deficient; Na=assessment is not available for this species. **WCE**, Sabah Wildlife Conservation Enactment (1997) protection status, TP=Totally Protected, P=Protected, G=Game animals. Note: (E) denotes Bornean endemic species, (E)* Bornean yellow muntjac, *Muntiacus atherodes*.

Order	Family	Scientific name	English name	NIP	NID	SPR	SITE	IUCN	WCE
Carnivora	Felidae	*Neofelis diardi*	Sunda clouded leopard	11	11	0.77	P5, P9, P12	VU	TP
		Pardofelis marmorata	marbled cat	2	2	0.14	P5, P12	VU	P
		Prionailurus bengalensis	leopard cat	2	2	0.14	P12, P4	LC	P
	Viverridae	*Viverra tangalunga*	Malay civet	22	22	1.53	P2, P11, P12	LC	P
		Hemigalus derbyanus	banded civet	32	32	2.23	P2, P12	VU	P
		Paguma larvata	masked palm civet	3	3	0.21	P12, P13	LC	P
		Arctictis binturong	binturong	3	3	0.21	P2, P12	VU	P
	Prionodontidae	*Prionodon linsang*	banded linsang	1	1	0.07	P12	Na	P
	Mustelidae	*Martes flavigula*	yellow-throated marten	10	12	0.70	P2, P12	LC	P
		Lutrogale perspicillata	smooth-coated otter	1	6	0.07	P9	VU	P
	Herpestidae	*Herpestes semitorquatus*	collared mongoose	2	2	0.14	P9, P13	DD	P
		H. brachyurus	short-tailed mongoose	2	2	0.14	P12	LC	P
	Ursidae	*Helarctos malayanus*	sun bear	14	14	0.97	P2, P12	VU	TP
Artiodactyla	Cervidae	*Muntiacus* spp.	muntjac (E)*	99	104	6.89	P2, P4, P6, P7, P10, P11, P12, P13	LC	G
		Rusa unicolor	Sambar deer	21	23	1.46	P2, P5, P9, P10, P12	VU	G
	Tragulidae	*Tragulus* spp.	mouse deer	107	112	7.45	P2, P6, P7, P9, P10, P11, P12, P13	LC	G
	Suidae	*Sus barbatus*	bearded pig	92	97	6.41	P2, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13	VU	G
Pholidota	Manidae	*Manis javanica*	pangolin	3	3	0.21	P2, P12	EN	P
Rodentia	Hystricidae	*Hystrix brachyura*	common porcupine	15	21	1.04	P2, P4, P12	LC	G
		Trichys fasciculata	long-tailed porcupine	14	14	0.97	P2, P3, P5, P6, P12, P13	LC	P
		Hystrix crassispinis	thick-spined porcupine (E)	18	20	1.25	P2, P3, P9, P13	LC	P
	Sciuridae	*Rheithrosciurus macrotis*	tufted ground squirrel (E)	1	1	0.07	P6	VU	P
Primates	Cercopithecidae	*Macaca fascicularis*	long-tailed macaque	8	9	0.56	P2, P3, P6, P10, P12	LC	P
		M. nemestrina	pig-tailed macaque	76	138	5.29	P2, P3, P4, P5, P6, P7, P12, P13	VU	P
		Presbytis rubicunda	maroon langur	3	6	0.21	P8, P12	LC	P
		P. hosei	Hose's langur (E)	1	2	0.07	P12	VU	P
	Pongidae	*Pongo pygmaeus*	orang utan (E)	1	1	0.07	P12	EN	TP
	Total	27 spp.		564	663	39.28			

However, photographic rates as used here can provide a valuable way to compare the relative abundance at different locations within particular species, as well as provide initial information about general patterns of species richness. While longer studies are more desirable, our findings suggest that our camera trapping survey using a large number of camera traps (80 cameras) distributed across a large area over a relatively short sampling period (ca. 2 months) is sufficient to provide baseline data on medium to large-sized terrestrial mammal species richness and terrestrial mammal community composition.

The species richness of medium to large-sized mammals photographed in the moderately disturbed forests of Deramakot Forest Reserve (FR), located to the northeast of ICCA, was 35 species as recorded over 15,400 trap-nights (Samejima et al., 2012). Using a similar camera trapping method however, Mohamed (2013) recorded 32 mammal species over 1,916 camera trap-nights in the same location. In Tangkulap FR and Segaluid Lokan FR, areas both contiguous with Deramakot FR, Mohamed (2013) recorded 29 mammal species (over 2,203 trap-nights) and 31 mammal species (over 2,933 trap-nights), respectively. Compared to these studies, the richness of medium to large-sized mammals in and around the ICCA was somewhat lower (i.e., 27 species over 1,436 trap-nights).

The lower number of mammal species recorded in and around the ICCA could not have been due to the low sampling effort, as sampling saturation in our study was reasonably high. A more likely explanation may be attributed to the failure of our study to distribute camera traps over all representative habitats available in our study area. Although the number of camera traps used in the present study was large, camera-trap stations within a particular plot were not as spaced apart as initially intended, particularly in areas of high elevation primary forest. Some mammal species may be restricted to such specific habitat types and therefore would have been missed if that habitat type was not represented during sampling. Indeed, in this study all camera-trap stations were located within a very narrow elevation range. No cameras for example were located higher than 650 m a.s.l. and hence, we completely missed those montane forest habitats located above 750–850 m a.s.l. (Hazebroek et al., 2004). Thus although sampling saturation by camera-trapping may have been reached in areas of low elevations, a comprehensive mammal list has yet to be obtained for the ICCA and its surrounding areas. Future surveys would therefore do well to ensure that all major habitats are sampled in order to increase the probability of photo-capturing additional species in the ICCA not previously recorded.

The ICCA has a higher recorded number of mammal species than two other areas of highly disturbed forest or converted habitats in Sarawak. Camera-trapping conducted in a highly disturbed forest of Lambir Hills National Park in the northern part of Sarawak revealed only 15 terrestrial mammal species (excluding bats, small squirrels, and rats) over 1,127 trap-nights (Mohd-Azlan & Lading, 2006). In addition, camera-trapping in mixed planted forest of *Acacia mangium* that contained about 26% secondary forest in the studied areas, located in south central part of Sarawak, yielded only 18 species of mammals (excluding small squirrels, rats and treeshrews) over 1,632 trap-nights (Giman et al., 2007). Assuming that within a particular habitat type more species implies higher habitat quality, the results of the present study suggest that the ICCA and surrounding forests taken together are valuable habitats for mammal species conservation, particularly as they contain many species that are charismatic and of high conservation value such as the vulnerable Sunda clouded leopard, the largest felid on Borneo, and the endangered orang utan.

One of the least known carnivores in South East Asia and possibly even the world, the Bornean endemic Hose's civet, *Diplogale hosei*, has been photo-captured (using banana baited camera trap) near Mount Kuli research station in the ICCA in an earlier survey by Matsubayashi et al. (2011) and in the nearby (ca. 25 km) Maliau Basin Conservation Area (Brodie & Giordano, 2011). These were respectively only the fifth and sixth confirmed records of this species in Sabah. Even though plot P12 of the present survey was located in the same general area where Matsubayashi et al. (2011) conducted their camera-trapping study, we did not capture the Hose's civet during our study, suggesting that this species might be rare. Brodie & Giordano (2011) detected the Hose's civet at 1,115 m elevation in primary dipterocarp forest near an ecotone with Kerangas forest. We did not sample the Kerengas forest during our study.

The ICCA is clearly an important area for carnivore conservation in Sabah. Including the Hose's civet, 14 species have been confirmed in the ICCA and surrounding areas out of a total of 24 species of carnivores known to exist in Sabah (Payne et al., 1985). This is comparable to that of the Maliau Basin Conservation Area where 15 carnivore species were photo-captured over 2,915 trap-nights (Brodie & Giordano, 2011, 2012).

Management implications. — Overall, mammal species with the highest photographic rates in the present survey were common terrestrial species—mouse deer, *Tragulus* spp., muntjac, *Muntiacus* spp., pig-tailed macaque, *M. nemestrina*, and bearded pig, *S. barbatus*—several of which are also habitat generalists. Some of the species were also communally living animals such as pig-tailed macaque and bearded pig. All of these species were also the most spatially widespread. For long term wildlife management and conservation monitoring using the camera-trapping system, all of these species are potentially good candidates for the ICCA area.

It is interesting to note that the most frequently photo-captured and widespread species consisted mainly of game animals or animals that are usually targeted by hunters, such as bearded pig, *S. barbatus*, mouse deer, *Tragulus* spp., muntjac, *Muntiacus* spp., and Sambar deer, *R. unicolor*. The Sambar deer are rare in heavily hunted areas elsewhere. In an area in Sarawak for example (Lambir Hills), large mammals, including Sambar deer, were extirpated due to over-hunting; similarly, the bearded pig, *S. barbatus*, another important game animal, was photo-captured on only one occasion in a camera-trapping study over a period of eight months (Mohd-Azlan & Lading, 2006).Thus not only are these game animals present in and around the ICCA, there is anecdotal evidence from the present survey to suggest that some of the game animals populations are actually thriving.

Several studies have shown that the increased access to the forest as provided by new roads will directly result in increased poaching activity, especially if no appropriate measures are taken to prevent hunting (Laurance et al., 2006; Mohd-Azlan & Lading, 2006). Areas surrounding the entire border of the ICCA are fraught with logging roads, either active or abandoned, providing easy access to hunters going into the protected ICCA area. The northern and western borders of the ICCA are in close proximity to human settlements and oil palm plantations. Poaching activity may be carried out by outsiders from the nearby towns (e.g., Telupid, Nabawan, Keningau, and Sook), but local villagers and oil palm plantation workers will likely hunt game animals by using homemade guns or other methods. Indeed during the survey, we found evidence of poaching activity including discarded bullet casings (at P3–P6 & P11) and abandoned illegal camps located inside (P1) and outside (P7) of the ICCA. Several camera traps also photographed suspected hunters with firearms at the fringe of the ICCA area near old logging roads (e.g., P7). One survey group at P4 also witnessed a group of seven unidentified people suspected to be illegal gaharu (*Aquilaria* spp.) tree resin collectors. Moreover, many old and recent signs of graffiti on the tree trunks suspected to be left behind by gaharu resin collectors possibly to mark forest travel routes were found in almost all plots. Although collectors of gaharu tree resin may enter the ICCA area with the pretext of collecting resin, they likely also hunt game animals, as they normally stay in the forest for up to three months at a time. More regular law enforcement activities and the establishment of guard posts by the relevant authorities are urgently needed for this area. The exact locations for the establishment of guard posts require further study but would likely be located at strategic positions near suspected hunter entry or exit points along the boundary of the ICCA.

The widespread illegal activities taking place in the surrounding areas of the ICCA warrants the establishment of a buffer zone. This zone would provide added protection to the ICCA by preventing habitat conversion for development, and by limiting unauthorised access of people that may pose a threat to the forest in the ICCA and its inhabitants. To be successful, buffer zone restrictions would need to be effectively enforced by rangers. Even though consisting mainly of secondary forest, this zone will also act as an important wildlife corridor for animal movements between protected sites especially the Maliau Basin Conservation Area in the south to Danum Valley in the east of the ICCA. Moreover, although not equivalent to areas of primary forests, there are an increasing number of studies offering evidence that large areas of regenerating logged forests, such as those surrounding the ICCA, that are contiguous with areas of primary forests can provide habitat for many or even most of their original inhabitants (e.g., Johns, 1985; Bernard, 2004; Chazdon et al., 2009).

Activity patterns. — Although research into activity patterns of mammals using camera trapping in tropical forest in South East Asia is increasing (van Schaik & Griffiths, 1996; Kitamura et al., 2010), studies from Borneo are rather limited. Most studies have been conducted in Thailand (Grassman et al., 2005, 2006) and in peninsular Malaysia (Miura et al., 1997; Kawanishi & Sunquist, 2004; Mohd-Azlan, 2006; Mohd-Azlan & Sharma, 2006). Three camera-trapping studies relating to the activity patterns of mammals in Borneo, which included only one or a few of the 14 mammal species studied in the present study, were by Mohamed (2013) in Sabah and Mohd-Azlan & Lading (2006) and Giman et al. (2007) in Sarawak. General comparisons of the activity patterns (i.e., diurnal, nocturnal or arrhythmic) of mammal species reported by these studies and the present study showed that there were no differences. Similarly, the activity patterns of animals of the present study were generally comparable to the descriptive information on Bornean mammals activity patterns in Payne et al. (1985). In fact, comparisons of activity patterns with those recorded for similar mammal species from Thailand and peninsular Malaysia also revealed similarities. In areas severely disturbed by humans, some large game mammals have been found to shift their activity periods from diurnal to nocturnal (Griffiths & van Schaik, 1993). However, we did not observe this trend despite evidence of poaching in several localities inside and outside of the ICCA.

Conclusion. — Our results show that camera-trapping when employed using a large number of camera traps over a sampling period of <3 months can be effective in acquiring baseline data on medium to large-sized terrestrial mammal species richness and composition. The sampling saturation achieved by us for the ICCA was relatively high and we obtained numerous total records of 27 medium to large-sized terrestrial mammals, including several species that are of management and conservation concern. The use of camera-traps also allowed us to detect mammal species that are rare, cryptic and elusive which otherwise would have been difficult to detect via alternative methods such as direct observation or live trapping. Of particular interest were the carnivores, represented by 13 species, which included the Sunda clouded leopard, the island's top predator. These findings indicate that the Imbak canyon and surrounding areas are important habitats for the mammal community. The species photographic rates obtained have provided us with useful information on which species could potentially be monitored with a camera-trapping system in the long run. This information may also be useful as a gauge to monitor the effectiveness of potential conservation management programmes to be established in the ICCA in the near future.

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LITERATURE CITED

Ancrenaz, M., A. J. Hearn, J. Ross, R. Sollmann & A. Wilting, 2012. *Handbook for Wildlife Monitoring Using Camera-traps.* BBEC Publication, Sabah Parks and Japan International Cooperation Agency. 71 pp.

Ancrenaz, M., O. Gimenez, L. Ambu, K. Ancrenaz, P. Andau, B. Goossens, J. Payne, A. Sawang, A. Tuuga & I. Lackman-Ancrenaz, 2005. Aerial surveys give new estimates for orangutans in Sabah, Malaysia. *PLoS Biology*, **3**: 1–8.

Bernard, H, 2004. Effects of selective logging on microhabitat-use patterns of non-volant small mammals in a Bornean tropical lowland mixed-dipterocarp forest. *Nature and Human Activities*, **8**: 1–11.

Bernard, H., E.L. Baking, H. Matsubayashi & A.H. Ahmad, 2012. Records of Bornean felids in and around Tabin wildlife reserve, Sabah, Malaysia. *Cat News*, **56**: 4–7.

Brodie, J & A. J. Giordano, 2011. Small carnivores of the Maliau Basin, Sabah, Borneo, including a new locality for Hose's civet *Diplogale hosei*. *Small Carnivore Conservation*, **44**: 1–6.

Brodie, J. & A. J. Giordano, 2012. Density of the vulnerable Sunda clouded leopard *Neofelis diardi* in a protected area in Sabah, Malaysian Borneo. *Oryx*, **46**: 427–430.

Bunya, K., W. Marni, H. I. Hussin, T. P. Malim, K. N. Kamaruddin, M. N. M. Saad, F. Abang & M. T. Abdullah, 2012. Preliminary taxonomic checklist of mammals in Imbak Canyon Conservation Area. In: Latif, A. & W. Sinun (eds.), *Imbak Canyon Conservation Area, Sabah: Geology, Biodiversity and Socio-economic Environment*. Academy of Sciences Malaysia and Yayasan Sabah. Pp. 253–263.

Carbone, C., S. Christie, K. Conforti, T. Coulson, N. Franklin, J. R. Ginsberg, M. Griffiths, J. Holden, K. Kawanishi, M. Kinnaird, R. Laidlaw, A. Lynam, D. W. Macdonald, D. Martyr, C. McDougal, L. Nath, T. O'Brien, J. Seidensticker, D. J. L. Smith, M. Sunquist, R. Tilson & W. N. Wan Shahruddin, 2001. The use of photographic rates to estimate densities of tigers and other cryptic mammals. *Animal Conservation*, **4**: 75–79.

Chazdon, R. L., C. A. Peres, D. Dent, D. Sheil, A. E. Lugo, D. Lamb, N. E. Stork & S. E. Miller, 2009. The potential for species conservation in tropical secondary forests. *Conservation Biology*, **23**: 1406 –1417.

Colwell, R. K., 2009. *EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples. Version 8.2.0 User's Guide and Application*. http://purl.oclc.org/estimates.

Edwards, D. P., F. A. Ansell, A. H. Ahmad, R. Nilus & K. C. Hamer, 2009. The value of rehabilitating rainforest for birds. *Conservation Biology*, **23**: 1628–1633.

Giman, B., R. Stuebing, N. Megum, W. J. Mcshea & C. M. Stewart, 2007. A camera trapping inventory for mammals in a mixed use planted forest in Sarawak. *Raffles Bulletin of Zoology*, **55**: 209–215.

Grassman, L. I., A. M. Haines, J. E. Janeeka & M. E. Tewes, 2006. Activity periods of photo-captured mammals in north central Thailand, *Mammalia*, **70**: 306.

Grassman, L. I., A. M. Haines, M. E. Tewes & N. J. Silvy, 2005. Stouffer® wildlife timers as an index of vertebrate activity periods in a tropical forest. *Wildlife Society Bulletin*, **33**: 1174–1177.

Griffiths, M. & C. P. van Schaik, 1993. The impact of human traffic on the abundance and activity periods of Sumatran rain-forest wildlife. *Conservation Biology*, **7**: 623–626.

Hazebroek, H. P., T. Z. Adlin & W. Sinun, 2004. *Maliau Basin Sabah's Lost World*. Natural History Publication (Borneo). 235 pp.

IUCN, 2009. *IUCN Red List of Threatened Species. Version 2009.2*. http://www.iucnredlist.org.

Jennelle, C. S., M. C. Runge & D. I. Mackenzie, 2002. The use of photographic rates to estimate densities of tigers and other cryptic mammals: A comment on misleading conclusions. *Animal Conservation*, **5**: 119–120.

John, A. D., 1985. Selective logging and wildlife conservation in tropical rain-forest: Problems and recommendations. *Biological Conservation*, **31**: 355–375.

Kawanishi, K. & M. E. Sunquist, 2004. Conservation status of tigers in a primary rainforest of Peninsular Malaysia. *Biological Conservation*, **120**: 329–344.

Kitamura, S., S. Thong-Aree, S. Madsari & P. Poonswad, 2010. Mammal diversity and conservation in a small isolated forest of southern Thailand. *Raffles Bulletin of Zoology*, **58**:145–156.

Latif, A. & W. Sinun, 2012. *Imbak Canyon Conservation Area, Sabah: Geology, Biodiversity and Socio-economic Environment*. Academy of Sciences Malaysia and Yayasan Sabah. 414 pp.

Laurance, W. F., B. M. Croes, L. Tchignoumba, S. A. Lahm, A. Alonso, M. E. Lee, P. Campbell & C. Ondzeano, 2006. Impacts of roads and hunting on central African rainforest mammals. *Conservation Biology*, **4**: 1251–1261.

Matsubayashi, H., H. Bernard & A. H. Ahmad, 2011. Small carnivores of the Imbak Canyon, Sabah, Malaysia, Borneo, including a new locality for the Hose's civet *Diplogale hosei*. *Small Carnivore Conservation*, **45**: 18–22.

Matsubayashi, H., P. Lagan, N. Majalap, J. Tangah, J. R. A. Sukor & K. Kitayama, 2007. Importance of natural licks for the mammals in Bornean inland tropical rain forest. *Ecological Research*, **22**: 742–748.

Miura, S. M., M. Yasuda & L. C. Ratnam, 1997. Who steals the fruits? Monitoring frugivory of mammals in a tropical rain forest. *Malayan Nature Journal*, **50**: 183–193.

Mohamed, A., 2013. *Population Ecology of the Leopard Cat (*Prionailurus bengalensis*) in Three Commercial Forest Reserves in Sabah, Malaysia.* Unpublished MSc thesis, Universiti Malaysia Sabah. 117 pp.

Mohd-Azlan, J. & D. S. K. Sharma, 2003. Camera trapping the Indochinese tiger (*Panthera tigris corbetti*) in a secondary forest, Peninsular Malaysia. *Raffles Bulletin of Zoology*, **51**: 421–427.

Mohd-Azlan, J. & D. S. K. Sharma, 2006. The diversity and activity patterns of wild felids in a secondary forest in Peninsular Malaysia. *Oryx*, **40**: 36–41.

Mohd-Azlan, J. & E. Lading, 2006. Camera trapping and conservation in Lambir Hills National Park, Sarawak. *Raffles Bulletin of Zoology*, **54**: 469–475.

Mohd-Azlan, J., 2006. Mammal diversity and conservation in a secondary forest in Peninsular Malaysia. *Biodiversity and Conservation*, **15**: 1013–1025.

Mustapha, K. A., W. H. Abdullah, F. Tongkul, C. A. Ali, K. R. Mohamad, B. Musta, A. A. Kadir & F. T. Wong, 2012. Organic petrological characteristics of the Kapilit Formation sedimentary sequence in the southern part of Imbak Canyon Conservation Area. In: Latif, A. & W. Sinun (eds.), *Imbak Canyon Conservation Area, Sabah: Geology, Biodiversity and Socio-Economic Environment*. Academy of Sciences Malaysia and Yayasan Sabah. Pp. 27–43.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca & J. Kent, 2000. Biodiversity hotspots for conservation priorities. *Nature*, **403**: 853–858.

Nakashima, Y., E. Inoue, M. Inoue-Murayama & J. R. A. Sukor, 2010. Functional uniqueness of a small carnivore as seed dispersal agents: A case study of the common palm civets in the Tabin Wildlife Reserve, Sabah, Malaysia. *Oecologia*, **164**: 721–730.

Payne, J., C. Francis & C. Phillips, 1985. *A Field Guide to the Mammals of Borneo*. Sabah Society & WWF Malaysia. 332 pp.

Reynolds, G., J. Payne, W. Sinun, M. Gregory & R. D. W. Walsh, 2011. Changes in forest land use and management in Sabah, Malaysian Borneo, 1990–2010, with a focus on the Danum Valley region. *Philosophical Transactions of the Royal Society, Series B*, **366**: 3168–3176.

Samejima, H. & G. Semiadi, 2012. First record of Hose's civet *Diplogale hosei* from Indonesia, and records of other carnivores in the Schwaner Mountains, Central Kalimantan, Indonesia. *Small Carnivore Conservation*, **46**: 1–7.

Samejima, S., R. Ong, P. Lagan & K. Kitayama, 2012. Camera-trapping rates of mammals and birds in a Bornean tropical forest management. *Forest Ecology and Management*, **270**: 248–256.

Sodhi, N. S., M. R. C. Posa, T. M. Lee, D. Bickford, L. P. Koh & B. W. Brook, 2010. The state and conservation of Southeast Asian biodiversity. *Journal of Biodiversity and Conservation*, **19**: 317–328.

Sodhi, N. S., L. P. Koh, B. W. Brook & P. K. L. Ng, 2004. Southeast Asian biodiversity: An impending disaster. *Trends in Ecology and Evolution*, **19**: 654–660.

Sugau, J. B., P. J. Muin, S. Sabran & U. Majawal, 2012. Study on diversity and distribution of Dipterocarp in imbak Canyon Conservation Area around Gunung Kuli Research Station. In: Latif, A. & W. Sinun (eds.), *Imbak Canyon Conservation Area, Sabah: Geology, Biodiversity and Socio-economic Environment*. Academy of Sciences Malaysia and Yayasan Sabah. Pp. 305–313.

Suleiman, M., M. S. Chua & F. A. Kanak, 2012. Mosses from the southern part of Imbak Canyon Conservation Area. In: Latif, A. & W. Sinun (eds.), *Imbak Canyon Conservation Area, Sabah: Geology, Biodiversity and Socio-economic Environment*. Academy of Sciences Malaysia and Yayasan Sabah. Pp. 269–281.

Tongkul, F., B. Musta, F. P. Wong, C. A. Ali, K. R. Mohamed, K. A. Mustapha & A. A. Kadir, 2012. The geology of the southern part of Imbak Canyon Conservation Area. In: Latif, A. & W. Sinun (eds.), *Imbak Canyon Conservation Area, Sabah: Geology, Biodiversity and Socio-economic Environment*. Academy of Sciences Malaysia and Yayasan Sabah. Pp 5–25.

van Schaik, C. P. & M. Griffiths, 1996. Activity periods of Indonesian rain forest mammals. *Biotropica*, **28**: 105–112.

WCE, 1997. *Sabah Wildlife Conservation Enactment. No. 6 of 1997*. Sabah Government Printing, Kota Kinabalu. 301 pp.

Wilting, A., H. Samejima & A. Mohamed, 2010. Diversity of Bornean viverrids and other small carnivores in Deramakot Forest Reserve, Sabah, Malaysia. *Small Carnivore Conservation*, **42**:10–13.