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MAMMAL DIVERSITY AND CONSERVATION IN A SMALL ISOLATED FOREST OF SOUTHERN THAILAND

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ABSTRACT. – Knowledge of the presence and distribution of species is crucial for designing and evaluating conservation strategies within a region. We conducted a camera-trapping survey of terrestrial mammal and bird diversity in a small isolated forest of southern Thailand over 3 yr. A total of 15 camera traps, which accumulated 11,106 camera-days, were set in three forest types: primary, logged, and hill forests. Despite its small size, isolation, and surrounding agricultural areas, a total of 35 mammal species, eight bird species, and one reptile species were recorded in the forest system. The total number of species photographed was similar among forest types (26-30 species), and rarefaction curves of each forest did not indicate any differences in the relationship between sampling effort and recorded species richness. As the activity period of these animals does not appear to be affected by human activities, we believe that the effect of direct poaching on large mammals in the study area is negligible. Although we did not observe any previously unrecorded animals in our study site, our findings are very valuable and point to the importance of biodiversity conservation efforts in these small fragmented and human-modified forest landscapes.

KEY WORDS. **–** Camera trapping, dipterocarp forest, Hala-Bala Wildlife Sanctuary, rarefaction curve.

INTRODUCTION

Tropical forests are becoming increasingly fragmented, which in turn threatens the survival of their resident species (Sodhi et al., 2004b; Primack & Corlett, 2005; Laurance, 2007). Changes in the size, shape, or configuration of habitat that result from human disturbances strongly affect populations of various animals. Species extirpation is driven by the direct effects of hunting and illegal trading, by the indirect effects of habitat loss (deforestation and fragmentation), and by interactions among these factors (Peres, 2001; Dirzo et al., 2007; Wright et al., 2007). No tropical forests are more threatened and no tropical fauna are more endangered than those of Southeast Asia (Sodhi et al., 2004a; Corlett, 2007; Laurance, 2007).

Research into the presence and distribution of species is crucial for planning and evaluating conservation strategies within a region (Tobler et al., 2008). Even though studies on mammals in tropical forests are often difficult, a great deal of comprehensive work has focused on mammals in Southeast Asia (Carbone et al., 2001; Lynam et al., 2001; Fernando et al., 2003; Kinnaird et al., 2003; O'Brien et al., 2003; Wong et al., 2004; Fredriksson et al., 2006; Wilting et al., 2006; Meijaard & Sheil, 2008). Many of these species are charismatic and/or flagship species for the conservation of habitats or ecosystems.

Studies of large mammals in tropical forests have benefited greatly from recent technological improvements that provide various ready-made camera traps with tiny infrared-motion sensors, built-in-flashes, and data packs at a reasonable cost (Swann et al., 2004; Yasuda, 2004). In fact, infrared-triggered camera systems are now widely used in vertebrate ecology, with applications to nest ecology, population estimation, behavioural ecology, mammal inventories, and studies of animal damage (Carthew & Slater, 1991; Cutler & Swann, 1999). Even in tropical forests, recent studies have determined that sampling medium- to large-sized mammals using camera traps is a practical, non-invasive method that requires little effort and is particularly useful when compared to alternative methods, such as line transects, direct observations, track and faeces identification, trapping, and interviews of local people (Silveira et al., 2003; Srbek-Araujo & Chiarello, 2005).

In Southeast Asia, camera traps have been used in a number of studies for a variety of research purposes, e.g., mammal inventories of specific areas (Numata et al., 2005; Mohd-Azlan & Engkamat, 2006; Giman et al., 2007; Dinata et al., 2008); monitoring animals visiting a particular site, such as natural licks (Matsubayashi et al., 2007a; Matsubayashi et al., 2007b), natal dens (Lim & Ng, 2008), or fruiting trees (Miura et al., 1997; Kitamura et al., 2004; Kitamura et al., 2006; Suzuki et al., 2007; Yasuda et al., 2007; Van der Meer et al., 2008; Kitamura et al., 2009); recording animal activity periods (Griffiths & van Schaik, 1993b; van Schaik & Griffiths, 1996; Grassman et al., 2005a; Grassman et al., 2005b; Grassman et al., 2006; Mohd-Azlan, 2006; Mohd-Azlan & Sharma, 2006; Suzuki et al., 2006; Kawanishi & Sunquist, 2008); identifying seed dispersers/predators (Yasuda et al., 2000; Kitamura et al., 2004; Kitamura et al., 2006; Kitamura et al., 2008); and estimating the relative and absolute abundance of a particular species, such as tigers (Mohd-Azlan & Sharma, 2003; O'Brien et al., 2003; Kawanishi & Sunquist, 2004; Linkie et al., 2006; Mohd-Azlan & Sharma, 2006; Lynam et al., 2007; Simcharoen et al., 2007), leopards (Ngoprasert et al., 2007), Malayan sun bears (Wong et al., 2004; Linkie et al., 2007), or Malayan tapirs (Holden et al., 2003).

Relatively undisturbed lowland forest is now rare in the Sundaic region (Lambert & Collar, 2002), particularly in southern Thailand, where more than 95% of the natural forest has been destroyed (Round, 1988). Most of the remaining forests in southern Thailand are highly fragmented and isolated as a result of human activities, including illegal logging, rubber plantations, and fruit orchards (Bird Conservation Society of Thailand, 2004). With such a rapid destruction of natural habitats, it is important to document the presence, diversity, and distribution of large mammals occurring in various forest patches in southern Thailand and to study mammal species that may not be able to survive in small isolated forests. Such research will provide essential information for conservation and management efforts. Moreover, the data can be used to assess loss of diversity elsewhere if isolation/fragmentation occurs in a similar manner. Here, we present data on mammalian fauna obtained from a 3-year camera-trap study in an isolated forest of southern Thailand.

MATERIALS AND METHODS

Study site. – The Bala forest is part of the Hala-Bala Wildlife Sanctuary (hereafter, Bala), on the Thai-Malaysian border (5°44'N 101°46'E–5°57'N 101°51'E; Fig. 1). The Bala portion of the sanctuary is 111.5 km^2 in area and is isolated from other forests by agricultural lands on the Thai side of the border (the 314 km^2 Hala portion of the sanctuary lies approximately 22 km to the west) and a mix of forest and agriculture on the Malaysian side. Bala ranges in elevation from 50 to 960 m above sea level and is broadly classified as tropical lowland evergreen forest (Bird Conservation Society of Thailand, 2004). The forests primarily comprise species typical of the Sundaic or Malesian region (Malay Peninsula, Borneo, Sumatra, Java), many of which are uncommon in Thailand and have their primary home ranges farther south on the Malay Peninsula. During 1987–1992, Bala was partly logged along the paved road that bisects the lower one-third of the site and was sporadically (and illegally) logged elsewhere in the sanctuary.

Bala forest receives an average annual rainfall of 3,500 mm (in some years nearly 5,000 mm), mostly from southeast monsoons between October and January. The clear, dry season lasts from February to April, and the mean monthly temperature is 23°C. Fruit production is highly seasonal, and an abundance of ripe fruits peaks during July and September, while periods of fruit scarcity strongly differ across years (S. Kitamura, unpublished data). Most field studies conducted in the Bala forest have focused on describing specific taxa, such as figs (Chantarasuwan & Thong-Aree, 2006), ants (Noon-Anant, 2003), and bats (Bumrungsri et al., 2006), with the exception of several ecological studies on hornbills (Gale & Thong-Aree, 2006; Kemp et al., 2007; Thong-Aree, 2007).

Camera trapping. – Each remote camera was equipped with a built-in infrared motion sensor, a built-in flash, and a data pack that stamped each photograph with the time and date of

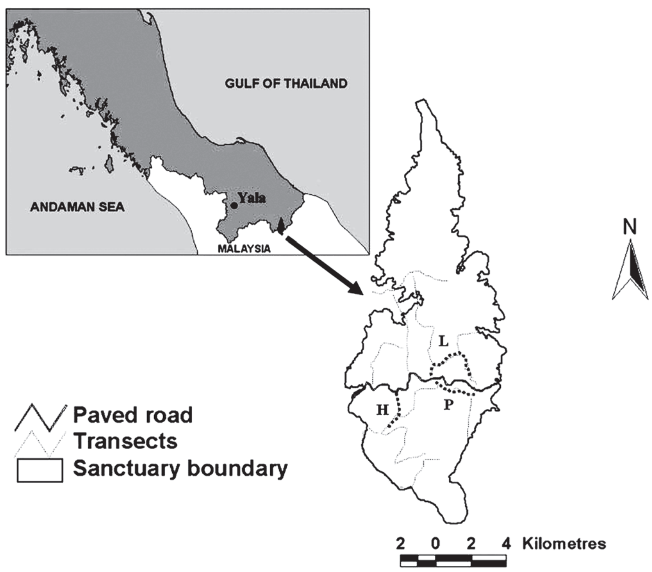

Fig. 1. Hala-Bala Wildlife Sanctuary (Bala forest) in southern Thailand, and the road cutting through the forest and associated trails on either side, as used by Gale and Thong-Aree (2006).

the event (Sensor Camera Fieldnote, Marif Co., Ltd., Iwakuni, Yamaguchi, Japan). Power was supplied by a CR123A lithium battery, which lasted approximately three months. Colour print film (ISO 400) was used in each camera, and no photographic delay interval was available for the model used. If an animal or a group of animals remained at the site, the camera was triggered every 10–15 sec. Each camera was wrapped tightly in a transparent polypropylene bag and encased in an unsealed plastic box for waterproofing.

Cameras were deployed at 15 locations in three different forest types (Fig. 1). In each forest type, cameras were deployed 300–500 m apart along an existing trail: primary forest (trail #4, southern part of the paved road, P1-5: 323 ± 11 m a.s.l., mean ± SD), logged forest (trail #8, northern part of the paved road, L1-5: 301 ± 44 m a.s.l.), and hill forest (trail #12, western part of Bala, H1-5: 715 ± 95 m a.s.l.). The sampling effort varied among forests. In the primary and logged forests, the same camera locations were maintained for 36 months (Oct.2004 to Oct.2007), whereas those in the hill forest were maintained for 18 months (May 2006 to Sep.2007).

In the primary and logged forests, several cameras were also set up along animal trails and around common fruiting trees, such as *Anisophyllea cornei* (Anisophylleaceae), *Baccaurea parviflora* (Euphorbiaceae), *Canarium littorale* (Burseraceae), *Cheilosa malayana* (Euphorbiaceae), *Elaeocarpus stipularis* (Elaeocarpaceae), *Garcinia* sp.1 (Guttiferae), *Irvingia malayana* (Irvingiaceae), *Palaquium impressinervium* (Sapotaceae), and *Sterculia macrophylla* (Sterculiaceae). Ten fruits were collected from the ground around fruiting trees and were placed at the base of the same trees as animal bait. Cameras were set approximately 2 m away from the bait. When fruits were consumed by animals or damaged by insects, they were replaced with new samples. Although the photographing duration was limited by the length of fruit availability, each session continued for at least one month. All camera-trapping stations were marked using a global positioning system (GPS; GARMIN eTrex). Cameras were checked every month to reload new film. In several instances, the film had finished prior to checking; therefore, some records may have been missed.

Species identification and their conservation status in Thailand. – After the film was developed, the photographs were examined for images of animals. Animal nomenclature follows (Lekagul & Round, 1991) for birds, and (Corbet & Hill, 1992) for mammals. The identification of some small mammals was difficult when based solely on photographs. In addition to photographing, we also conducted live trapping of small mammals in the primary and logged forests of Bala (S. Kitamura, unpublished data). Thus, we were able to identify small mammals by comparing body sizes and colours of those in the pictures to those that had been trapped. Based on the Thailand Red Data Book (Nabhitabhata & Chan-Ard, 2005; Sanguansombat, 2005), we determined the conservation status in Thailand of the photographed animals.

Data analysis. – Camera-trapping data are often difficult to interpret when a series of photographs depict the same species, which leads to issues of self-dependence and unsuitability for statistical analysis (O'Brien et al., 2003; Yasuda, 2004). One way to minimise self-dependence in camera-trapping results is to consider a series of photographs of the same species taken within a certain period of time as a single event (Otani, 2001; O'Brien et al., 2003). In this study, we treated a picture as indicating a single visit by a given species if that picture was taken >30 min after the previous picture of that species (O'Brien et al., 2003; Yasuda, 2004).

Researchers and conservation planners are often interested in the number of species supported by a particular habitat, region, or protected area. In our study, unequal sampling effort (36 mo for both primary and logged forests versus 18 mo for the hill forest) limited our ability to compare species richness among habitat types. When animal abundance varies between sites, comparisons of diversity will favour the more abundant site with more animals because of higher species detection rates (Gotelli & Colwell, 2001). To control for this issue, we implemented the rarefaction approach with EstimateS Win 8.0.0 (Colwell, 2005), and we used species accumulation curves to compare richness levels among habitats.

In our study area, sunrise annually varies between 0557 and 0629 hrs and sunset varies between 1756 and 1834 hrs. According to the standard time near Bala, we divided the day into two time zones, i.e., daytime (0600 to 1800 hrs) and nighttime (1800 to 0600 hrs). Time periods were pooled in 1-hour intervals. We assumed that the numbers of photographs taken were correlated with animal activity, and we classified the activity patterns of captured animals based on previous studies in Southeast Asia (van Schaik & Griffiths, 1996; Grassman et al., 2005a; Grassman et al., 2006). For species with > 10 captures, we defined diurnally active species as those with < 10 percent of captures at night, and nocturnally active species as those that had > 90 percent captures at night. We considered species with between 10 and 90 percent nocturnal captures as arrhythmic, i.e. they showed no clear activity pattern (Grassman et al., 2006).

RESULTS

Species diversity of photographed animals in Bala. – The total number of camera-days was 11,106 over 36 months (4,428 camera-days in the primary forest, 3,965 in the logged forest, 1,891 in the hill forest, 613 along animal trails, and 389 around fruiting trees). In total, 8,414 photographs were exposed, 3,750 of which (44.6%) contained no animal image. The remaining 4,664 photographs (55.4%) showed images of 44 species, including 35 mammal species, eight bird species, and one reptile species (Table 1). Of these, 2,087 photographs (44.7%) were considered independent visits and were used for further analysis.

Some species of bats and birds were photographed several times but could not be identified from the photographs.

Table 1. Summary of animals recorded in the Hala-Bala Wildlife Sanctuary, Thailand, from November 2004 to October 2007. Species with > 10 photo-captures are underlined. Site abbreviations: P: primary forest; L: logged forest; H: hill forest; A: animal trail; and F: fruiting tree. TRD: Thailand Red Data (Nabhitabhata & Chan-Ard, 2005; Sanguansombat, 2005), EN: endangered, VU: vulnerable, NT: near threatened, LC: least concern.

Family	Scientific name	English name	N	Site	TRD
Mammalia					
Tupaiidae	*Ptilocercus lowii*	Feather-tailed treeshrew	2	F	VU
	Tupaia glis	Common treeshrew	55	P, L, A, F	
Erinaceidae	*Echinosorex gymnurus*	Moonrat	47	P, L, F	VU
Cercopithicidae	*Macaca nemestrina*	Pig-tailed macaque	237	P, L, H, A, F	NT
	Trachypithecus obscurus	Dusky langur	12	P, L, H	VU
Manidae	*Manis javanica*	Sunda pangolin	5	P, L, F	NT
Sciuridae	*Callosciurus caniceps*	Grey-bellied squirrel	1	L	
	C. notatus	Palntain squirrel	5	P, L, H, F	
	Lariscus insignis	Three-striped ground squirrel	9	P, L, F	VU
	Rhinosciurus laticaudatus	Shrew-faced ground squirrel	1	F	VU
Muridae	*Leopoldamys sabanus*	Noisy rat	83	P, L, F	
	Maxomys surifer	Red spiny rat	293	P, L, H, A, F	
	M. whiteheadi	Whitehead's rat	6	P, L, F	VU
	Sundamys muelleri	Muller's rat	1	P	
Hystricidae	*Atherurus macrourus*	Bush-tailed porcupine	5	L, H, A	LC
	Hystrix brachyura	Malayan porcupine	160	P, L, H, A, F	LC
Mustelidae	*Martes flavigula*	Yellow-throated marten	17	P, L, H, F	
Viverridae	*Arctictis binturong*	Binturong	7	P, L, H	
	Hemigalus derbyanus	Banded palm civet	13	P, L, H, A, F	EN
	Paguma larvata	Masked palm civet	21	P, L, H, A	
	Paradoxurus hermaphroditus	Common palm civet	1	L	
	Prionodon linsang	Banded linsang	7	P, L, H, A	VU
Herpestidae	*Herpestes javanicus*	Javan mongoose	1	H	
Felidae	*Catopuma temminckii*	Asian golden cat	43	P, L, H, A, F	VU
	Panthera pardus	Leopard	2	P, L	VU
	P. tigris	Tiger	5	P, H	EN
	Pardofelis nebulosa	Clouded leopard	4	H	VU
	Prionailurus bengalensis	Leopard cat	13	P, L, H, A	
Tapiridae	*Tapirus indicus*	Malayan tapir	99	P, L, H, A	EN
Suidae	*Sus scrofa*	Common wild pig	426	P, L, H, A, F	
Tragulidae	*Tragulus kanchil*	Lesser mouse deer	58	P, L, A, F	
	T. napu	Greater mouse deer	12	P, L, F	EN
Cervidae	*Muntiacus muntjak*	Common barking deer	396	P, L, H, A, F	
Bovidae	*Naemorhedus sumatraensis*	Southern serow	1	H	NT
	Bat spp.	Bat spp.	5	L, H, A	
	Mammal total	35 spp.	2,053		
Aves					
Accipitridae	*Spilornis cheela*	Crested serpent eagle	1	H	
Phasianidae	*Argusianus argus*	Great argus	18	L, H	VU
	Gallus gallus	Red junglefowl	1	A	
Columbidae	*Chalcophaps indica*	Emerald dove	2	F	
Bucerotidae	*Anorrhinus galeritus*	Bushy-crested hornbill	1	H	NT
Turdidae	*Zoothera citrina*	Orange-headed thrush	1	P	
	Copsychus malabaricus	White-rumped shama	1	F	
	Bird spp.	Bird spp.	3	P, H	
	Bird total	8 spp.	28		
Reptilia					
Varinidae	*Varanus* sp.1	Monitor lizard	6	L, H, A, F	
	Reptile total	1 spp.	6		
			2,087		

Mammals accounted for 98.3 percent of all animals identified from the photographs. Of the identified species, wild boar, *Sus scrofa*, was the most frequently photographed (426 times, 20.4% of the total), followed by common barking deer, *Muntiacus muntjak* (396 times), red spiny rat, *Maxomys surifer* (293 times), pig-tailed macaque, *Macaca nemestrina* (237 times), and Malayan porcupine, *Hystrix brachyura* (160 times). These five species accounted for 72.5 percent of all identified photographs. In contrast, six species of mammals and five species of birds were photographed only once during the study (Table 1). Most animals were photographed alone or in pairs, except for the Malayan porcupine (up to three individuals), pig-tailed macaque (up to six individuals), and wild boar (up to 17 individuals). Of the 44 animal species photographed, 21 are listed in the Thailand Red Data Book, including four endangered, 11 vulnerable, four near threatened, and two species of least concern (Table 1).

***Species accumulation curves*. –** In total, 30, 28, and 26 species were photographed in the primary, logged, and hill forests, respectively. The identity of species substantially overlapped in the primary and logged forests (24 species in common) but overlapped to a lesser extent in the logged and hill forests (19 species) and the hill and primary forests (17 species). Rarefaction of the source pool of species sampled in each forest indicated no differences among forests in the relationship between sampling effort and recorded species richness (Fig. 2). The number of photographs per 100 camera-days also did not differ among forest types: 20.2 ± 4.3 (mean ± SD) in the primary forest, 17.1 ± 14.4 in the logged forest, and 16.6 ± 11.4 in the hill forest. Similarly, the number of photographed species per 100 camera-days did not substantially differ among forests: 1.9 ± 0.6 in the primary forest, 2.1 ± 0.9 in the logged forest, and 3.1 ± 1.7 in the hill forest.

In both the primary and logged forests, the number of photographed species was significantly higher during the first year than during the second or third years (Fig. 3). In contrast, the number of species photographed during the second compared to the third year did not significantly differ in either the primary or logged forest. Most animal species were photographed in the first year (93% of recorded species in both the primary and logged forests). Similarly, the number of species photographed within the first 12 mo accounted for 85% of the total species recorded for 18 mo in the hill forest.

***Activity period*. –** The activity periods were based on filtered data and were determined for only 18 species (Fig. 4). Six species of mammals (*Echinosorex gymnurus*, *Leopoldamys sabanus*, *Maxomys surifer*, *Hystrix brachyura*, *Hemigalus derbyanus*, and *Prionailurus bengalensis*) were classified as nocturnal, whereas three mammal species and one bird species (*Macaca nemestrina*, *Trachypithecus obscurus*, *Tupaia glis*, and *Argusianus argus*) were considered diurnal.

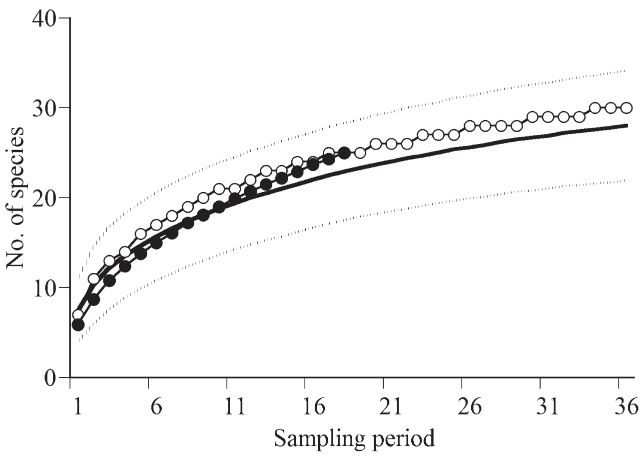

Fig. 2. Rarefaction curves for photo-captured animal assemblages in three forest types (thick line: primary forest; open circles: logged forest; solid circles: hill forest) in the Hala-Bala Wildlife Sanctuary, Thailand, from Nov.2004 to Oct.2007. The dotted line represents the 95% CI for the primary forest. For clarity, the 95% CI for the logged and hill forests are not presented.

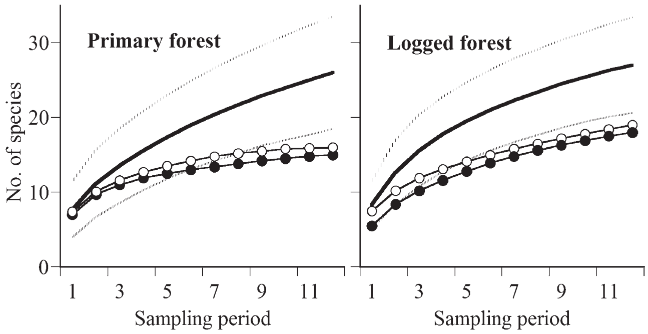

Fig. 3. Rarefaction curves for photo-captured animal assemblages in primary and logged forests over 3 years (thick line: first year; open circles: second year; solid circles: third year) in the Hala-Bala Wildlife Sanctuary, Thailand. The dotted line represents the 95% CI for the first year. For clarity, the 95% CI for the second and third years are not presented.

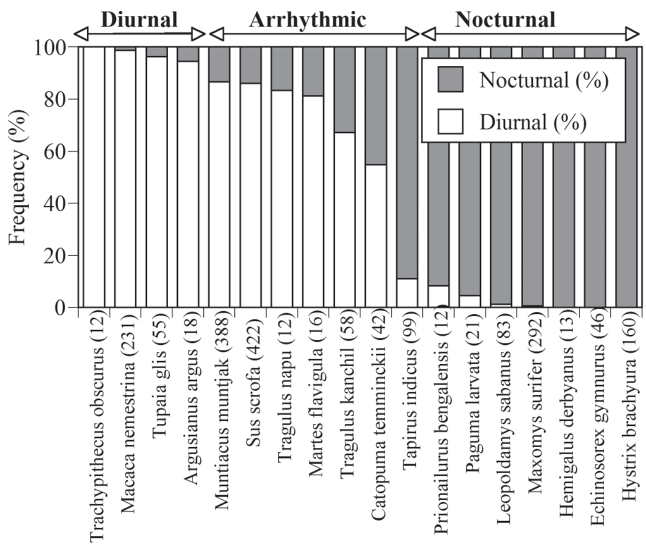

Fig. 4. Activity periods of photo-captured animals (N>10) in the Hala-Bala Wildlife Sanctuary, Thailand, from Nov.2004 to Oct.2007. Species are listed in order of decreasing frequency of diurnal activity. Numbers in parentheses indicate sample size.

DISCUSSION

***Species diversity of mammals and birds photographed in Bala*. –** Our study revealed that at least 44 species of animals, of which 21 (47.7%) are listed in the Thailand Red Data Book, were found in an isolated forest of Bala in southern Thailand. One method of assessing the relative conservation value of Bala is to compare its species richness as assessed by photography to that evaluated by photography elsewhere, assuming that higher species richness implies higher quality habitat. The species richness of large- and medium-sized mammals photographed in the Jerangau Forest Reserve, Peninsular Malaysia, was 27 species over 5,972 camera-days (Mohd-Azlan, 2006), and that of three study sites in Taman Negara National Park, Peninsular Malaysia, was 27 species over 4,336 camera-days, 25 over 4,847 camera-days, and 26 over 4,871 camera-days (Kawanishi, 2002). Compared to these studies, the species richness of large- and medium-sized mammals (not including that of small mammals belonging to Tupaiidae, Erinaceidae, Sciuridae, Muridae, and bats) in Bala was relatively low (21 species).

Despite the huge sampling effort in our study, we did encounter certain limitations that deterred us from examining the relative importance of the Bala forest in greater depth. Because we continuously maintained our camera trappings at the same locations for three years, and the minimum distance between each camera location was short (300–500 m), the effective sampling area in our study was rather limited. Although the rarefaction curve for photo-captured animal assemblages continued to increase throughout the study period (Fig. 2), the number of species photographed in the first year included most of the photographed species. Some species may actually be more abundant or even restricted to one habitat type. To increase the probability of capturing species that rarely use trails or are habitat specialists, it is important to ensure that all major habitat types are sampled. Indeed, clouded leopard and southern serow were not recorded in the primary or logged forests over the three study years but were observed in the hill forest during one year. Even in the primary and logged forests, several rare species in Bala, such as the Asian elephant *Elephas maximus* and the Malayan sun bear *Ursus malayanus* went undetected by our camera trappings. To prevent camera malfunction, no cameras were deployed near streams due to flooding or near steep rocky slopes. Together, these factors indicate that a comprehensive mammal list has yet to be compiled for this area, particularly for secretive animals that are strictly arboreal or associated with aquatic habitats. To obtain a complete list of the mammals of Bala, other methods of observation must be combined with camera-trapping studies.

In our photographs, bird species accounted for only 1.7 percent of all animals identified. In general, the frequency of photographed mammals is much greater than that of birds in tropical forests of Southeast Asia (Miura et al., 1997; Mohd-Azlan & Davison, 2006; Dinata et al., 2008). The great argus *Argusianus argus*, a true ground dweller, was the most commonly photographed bird species (Table 1), as previously reported in this region (Mohd-Azlan & Davison, 2006; Dinata et al., 2008). In Bala, the call of this species is also the most commonly heard birdsong; thus, camera trapping would not be necessary for a general survey. Although camera trapping provides some baseline information for species records (Mohd-Azlan & Davison, 2006) and can sometimes detect very rare species (Dinata et al., 2008), we did not record any new birds for the Bala forest. For certain mammal species, camera trapping is a promising survey technique that generates useful data; however, camera trapping used solely for the study of birds is impractical in Bala.

***Activity periods of mammals*. –** Research into animal activity periods using camera trapping in tropical forests in Southeast Asia is increasing (Griffiths & van Schaik, 1993a; b; van Schaik & Griffiths, 1996; Miura et al., 1997; Mohd-Azlan & Sharma, 2003; Grassman et al., 2005a; Grassman et al., 2006; Mohd-Azlan, 2006; Mohd-Azlan & Engkamat, 2006; Mohd-Azlan & Sharma, 2006; Suzuki et al., 2006; 2007). For 11 animal species, we found documentation of activity periods for the same species in previous studies from the Phu Kheio Wildlife Sanctuary (Grassman et al., 2005a; Grassman et al., 2006) and Khao Yai National Park (Suzuki et al., 2006; 2007) in Thailand and Jerangau Forest Reserve (Mohd-Azlan, 2006), Taman Negara National Park (Kawanishi & Sunquist, 2004), and Pasoh Forest Reserve (Miura et al., 1997) in Peninsular Malaysia (Table 2). There were no differences between the activity periods determined in our study and those reported in the previous studies, with the exception of the leopard cat, which we classified as nocturnal but others categorised as arrhythmic (Table 2). The activity periods of mammals common to Bala generally do not differ from those at other study sites, despite its small isolated habitat surrounded by agricultural areas, such as fruit orchards and rubber plantations. In areas severely disturbed by humans, some large game mammals shift their activity periods from diurnal to nocturnal (Griffiths & van Schaik, 1993a; b; van Schaik & Griffiths, 1996). We did not observe this trend at our sites, nor did we record any hunting of large animals during our study, although we did witness the collection of non-forest timber products (e.g., wild fruits and mushrooms) and the trapping of small passerines (e.g., bulbuls and leaf birds) by local peoples. Thus, we believe that the effect of direct poaching on large mammals in Bala is negligible, and the activity period of these animals is likely not affected by such human activities.

The protected area of Bala is only 111.5 km^2, a threshold below which tigers and some other large mammals may rapidly become extirpated from this region (Laidlaw, 2000). Most large mammals photographed in this study have large home ranges (Table 3) and require large areas of contiguous forest for their long-term survival (Karanth & Nichols, 2002). Habitats for large mammals are highly fragmented and are lost through the construction of roads, power networks, plantations, urban expansion, dams, irrigation, and other development in this region (Bird Conservation Society of Thailand, 2004; Lynam et al., 2007). Although we did not record any animals that were previously unknown to Bala, we did confirm the existence of some endangered

Table 2. Comparison of activity periods of 11 mammal species photographed in this study at five different sites in Thailand and Peninsular Malaysia. Activity abbreviations: D: diurnal; N: nocturnal; A: arrhythmic.

	Thailand			**Peninsular Malaysia**		
Species	This study	(Grassman et al., 2005a; 2006)	(Suzuki et al., 2006; 2007)	(Mohd-Azlan, 2006)	(Kawanishi & Sunquist, 2004)	(Miura et al., 1997)
Common treeshrew	D		D			D
Pig-tailed macaque	D	D	D	D		D
Noisy rat	N		N			N
Red spiny rat	N		N			N
Malayan porcupine	N	N	N	N		
Asian golden cat	A			A		
Leopard cat	N	A	A	A		
Malayan tapir	A			A	A	
Common wild pig	A	A	A	A	A	A
Lesser mouse deer	A	A	A	A	A	A
Common barking deer	A	A	A	A	A	

Table 3. Home-range sizes of various mammals photographed in the Hala-Bala Wildlife Sanctuary, Thailand. Only studies conducted in tropical Asia are cited. NA: not available.

Family	Scientific name	Home range (ha)	References
Mammalia			
Tupaiidae	*Ptilocercus lowii*	1.9–6.4	(Emmons, 2000)
	Tupaia glis	0.33	(Walker & Rabinowitz, 1992)
Erinaceidae	*Echinosorex gymnurus*	NA	
Cercopithicidae	*Macaca nemestrina*	62–828	(Caldecott, 1986)
	Trachypithecus obscurus	17–33	(Curtin, 1980)
Manidae	*Manis javanica*	5.6–7.0	(Lim & Ng, 2008)
Sciuridae	*Callosciurus caniceps*	0.7–2.4	(Saiful et al., 2001)
	C. notatus	0.7–1.8	(Saiful et al., 2001)
	Lariscus insignis	0.2–3.7	(Saiful et al., 2001)
	Rhinosciurus laticaudatus	NA	
Muridae	*Leopoldamys sabanus*	0.25–0.32	(Wells et al., 2008)
	Maxomys surifer	0.12–0.84	(Walker & Rabinowitz, 1992)
	M. whiteheadi	0.02–0.14	(Nakagawa et al., 2007)
	Sundamys muelleri	NA	
Hystricidae	*Atherurus macrourus*	NA	
	Hystrix brachyura	NA	
Mustelidae	*Martes flavigula*	350–1180	(Grassman et al., 2005c)
Viverridae	*Arctictis binturong*	470–650	(Grassman et al., 2005c)
	Hemigalus derbyanus	NA	
	Paguma larvata	60–145	(Rabinowitz, 1991)
	Paradoxurus hermaphroditus	210–630	(Rabinowitz, 1991)
	Prionodon linsang	NA	
Herpestidae	*Herpestes javanicus*	NA	
Felidae	*Catopuma temminckii*	3260–4770	(Grassman et al., 2005e)
	Panthera pardus	500–4800	(Odden & Wegge, 2005)
	P. tigris	7800	(Lynam et al., 2001)
	Pardofelis nebulosa	2290–4510	(Grassman et al., 2005e)
	Prionailurus bengalensis	220–3710	(Grassman et al., 2005d)
Tapiridae	*Tapirus indicus*	1275	(Williams, 1978)
Suidae	*Sus scrofa*	NA	
Tragulidae	*Tragulus kanchil*	3.5–6.2	(Matsubayashi et al., 2003)
	T. napu	NA	
Cervidae	*Muntiacus muntjak*	647–592	(Heydon, 1994)
Bovidae	*Naemorhedus sumatraensis*	NA	

species in Thailand (Table 1). Therefore, our findings are crucial for the development of biodiversity conservation in this small fragmented forest that is largely surrounded by human-modified landscapes. Because we are interested in the long-term management of relatively rare or threatened species, unbiased estimates of density, which incorporate some estimates of detectability, are more valuable than the presence/absence or relative abundance data presented in this study. Measurements of density provide managers with survey results that are comparable over time and space and are thus more accurate assessments of habitat suitability in relation to different degrees of human disturbance. Thus, density estimates are the primary dataset necessary for monitoring populations and for assessing the success or failure of conservation and management efforts. Such studies have been conducted for hornbills in Bala (Gale & Thong-Aree, 2006; Kemp et al., 2007), and further studies of large- and medium-sized mammals in this highly valuable forest are warranted.

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