SPATIAL EFFECTS OF VIRGIN JUNGLE RESERVES (VJR) ON THE COMMUNITY OF INSECTIVOROUS BATS IN PENINSULAR MALAYSIA

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JOANN CHRISTINE L, FLETCHER C & ABD RAHMAN K. 2013. Spatial effects of virgin jungle reserves (VJR) on the community of insectivorous bats in Peninsular Malaysia. The virgin jungle reserve (VJR) network has been legally established amidst production forests in Peninsular Malaysia since 1984. However, the role of VJRs as natural arboreta and as genetic pool for forest bats has yet to be evaluated. Forest interior insectivorous bats are habitat-specific and sensitive to habitat changes, and many of them are listed as near threatened under the IUCN Red List. This paper looks at the influence of spatial patterning of VJRs such as size and distance from the boundary of logged forest on the species composition and distribution of these bats. The results of this study indicated that species richness and abundance did not increase with VJR size. Instead each study site had distinct species composition that was likely influenced by the dynamics of the landscape. Although most sites were dominated by cave/boulder dwelling bats, the habitat-sensitive tree- or foliage-roosting bats had relatively higher abundance in the larger VJRs. As for distance, no significant differences were detected between species composition within the VJR and the adjacent logged-over forest, which suggested that the VJRs might have helped in re-colonising the surrounding logged-over forest.

Keywords: Forest fragment, size, distance, forest bats

JOANN CHRISTINE L, FLETCHER C & ABD RAHMAN K. 2013. Kesan ruang hutan simpan dara (VJR) terhadap komuniti kelawar insektivor di Semenanjung Malaysia. Hutan simpan dara (VJR) telah ditubuhkan di dalam hutan pengeluaran di Semenanjung Malaysia sejak tahun 1984. Namun peranan VJR sebagai arboretum asli dan kolam genetik untuk kelawar hutan masih belum dinilai. Kelawar insektivor yang hidup di pedalaman hutan memerlukan habitat yang spesifik dan adalah sensitif terhadap perubahan habitat. Kebanyakan spesies kelawar tersebut dikategorikan sebagai spesies haiwan hampir terancam di bawah Senarai Merah IUCN. Kajian ini dijalankan untuk mengetahui bagaimana saiz dan jarak VJR dari sempadan hutan yang telah dibalak mempengaruhi komposisi spesies dan taburan kelawar insektivor. Keputusan kajian ini menunjukkan bahawa kekayaan dan kelimpahan spesies tidak meningkat dengan saiz VJR. Sebaliknya, setiap VJR mempunyai komposisi spesies yang tertentu yang besar kemungkinan dipengaruhi oleh dinamik landskap VJR itu sendiri. Walaupun kebanyakan tapak didominasi oleh kelawar yang mendiami gua, bilangan kelawar yang mendiami pokok yang peka terhadap habitat adalah tinggi di dalam VJR yang lebih besar. Dari segi jarak, tiada perbezaan yang signifikan dikesan antara komposisi spesies di dalam VJR dengan hutan sebelahnya yang telah dibalak. Oleh itu, kajian ini mencadangkan bahawa VJR mungkin telah membantu dalam pengkolonian semula hutan yang telah dibalak.

INTRODUCTION

Rapid and extensive human development in the tropics poses a serious threat to biodiversity. In South-East Asia, forests are being destroyed and fragmented every day due to land conversion for plantations, development, mining and logging (Sheil 2001, Meijaard et al. 2005). Forest susceptibility to disturbance is highly species-specific and determining this vulnerability in the tropics (where diversity is among the highest) is a challenging task. The various aspects of disturbance to a forest caused by logging, land conversion or development affect various species of mammals, beetles and birds differently. Therefore, it is important to understand the effects of disturbance on different species or functional groups in order to make better forest-management decisions, particularly in production forests. This study

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was aimed at determining the effectiveness of species conservation in virgin jungle reserves (VJRs) by using understorey insectivorous bats as a focal animal group. The role of VJRs in facilitating the recovery of insectivorous bats will enable us to better grasp the extent VJRs play in the conservation of these habitat-sensitive bats and quantify the response of flying mammals to this forest management strategy.

In Malaysia, conservation efforts have been an integral part of forest management since the enactment of the 1978 National Forestry Policy. Although the VJR system was in place before the 1950s (Wyatt-Smith 1950), it was not until the National Forestry Act was passed in 1984 that statutory protection was given to VJRs (Laidlaw 1999). One of the forest reserve classifications under Section 10 of this act is the Virgin Jungle Reserve. This network of protected forest patches was established amidst production forest to act as natural arboreta, seed sources for regenerating timber trees, genetic pools for forest species and resource for education and recreation (Sam 2001). There are more than 120 VJRs covering an area of about 111,800 ha in Peninsular Malaysia (Chan 2002). These VJRs have helped forest dwelling organisms survive the pressure caused by logging (Borhan & Cheah 1986).

The overall effectiveness of this forestry practice for the purpose of conservation is still unclear due to a lack of sufficient scientific information for evaluation (Sam 2001). Debate exists on the effective size of VJRs (Borhan & Cheah 1986, Kochummen et al. 1990) and their optimal location with respect to the boundary of the forest reserve (Laidlaw 1999, Lee et al. 2002). Current management practices impart non-natural disturbance regimes on the forest, making biodiversity conservation within production forest a challenge. Despite the challenges, it is imperative that we set aside adequate forest areas to represent the full range of habitats (Ashton 2008) and also evaluate their effectiveness for conservation.

The only fauna assessment comparing VJR and adjacent production forests in Peninsular Malaysia was carried out by Laidlaw (1996a). The study evaluated the community of primates, squirrels, tree shrews and mammals (excluding bats) in VJRs as well as logged, fragmented and plantation forests, and found that the smallest areas of natural forest studied (≤ 164 ha) had the lowest diversity of mammal species. Although bats are perceived as good indicator species (Medellin et al. 2000), there has not been any study in Malaysia assessing the recovery of bat populations after logging.

Bats are often assumed to be at low risk of extinction due to their large home range and ability to fly. However, there are also many forest interior insectivorous bat species that are habitat-specific and sensitive to habitat changes. Habitat specificity coupled with slow reproductive rate and specific roosting needs render them sensitive to habitat loss and disturbance and, thus, vulnerable to extinction. This is especially true for habitat-specific forest interior insectivorous bats that roost and forage in the forest (Henderson et al. 2008). They are an extremely diverse group in Peninsular Malaysia and are thus of essential conservation value and ecological importance (Kingston et al.2003).

Nearly half of the total bat species are considered to be under some form of threat. The Action Plan for Microchiropteran Bats designated 22% of bat species as threatened and a further 23% as near threatened (Hutson et al. 2001). In South-East Asia alone, 20% of bat species are predicted to become extinct by 2100 (Lane et al. 2006, Kingston 2008). With 125 species, Malaysia is home to 10% of the world's bat species (Kingston et al. 2006). Conserving bat diversity in Malaysia is crucial for international bat conservation. Like other tropical flora and fauna, the underlying threat to bats is habitat degradation and destruction due to increasing pressures from the expansion of human population.

In Peninsular Malaysia, primary forest had higher species richness and abundance of bats compared with logged forest (Zubaid 1993), and forest fragment size affected the diversity of insectivorous bats (Struebig et al. 2008). However, in these studies, comparisons were made between primary and logged-over forests that were not adjacent. It has been reported that edge habitat caused by forest harvesting did not favour bat population (Grindal & Brigham 1999). In the current study, we tested this theory on tropical understorey insectivorous bats by studying their community at different distances from the boundary of logged forest and across different VJR sizes. We hypothesised that (1) bat abundance and diversity would increase with increasing VJR size and (2) species composition within the VJR would be more similar to that nearest to the VJR boundary than to that further away.

MATERIALS AND METHODS

Study site

The study was conducted between September 2007 and June 2009, at six selected sites throughout Peninsular Malaysia; five sites were located in the western half and one on the east coast (Figure 1). Several criteria were applied during the site selection process: (1) lowland and hill dipterocarp forests, (2) elevation between 100–1500 m above sea level and (3) designated VJR surrounded by forest that had been logged at least 15 years ago. The VJRs were categorised into six ordered classes, Class I being the smallest and Class VI, the largest in hectarage. Details of each study site are included in Table 1.

Sampling design

Nine 300-m transect lines were set up in each study site 2–4 weeks prior to sampling. A set of three transects was established within a VJR (200 m within the VJR boundary) and the rest were established in the surrounding logged-over forest; a set of three transects at 200 m and another > 600 m away from the VJR boundary. The three transects in each set were 200–500 m apart to avoid repeated sampling of the same bat population.

Four bank-harp traps (approximately 2 m width and 3 m height) were used to trap bats. Due to limitations of the harp trap capture method, sampling was restricted to insectivorous bat species that were readily captured in the forest understorey. Traps were set up on clear pathways approximately 1 m above ground level, with trees and undergrowth above and on either side of the harp traps. This setting created a funnel-like effect directing bats into the trap. Each night, nine traps on three transects (three traps on each transect) were left open. The traps were positioned 50–75 m apart and left at the same location for three consecutive nights (Mohamed & Muhammad 2010). The process was repeated until all nine transects had been sampled.

Captured bats were identified according to Kingston et al. (2006) and Korad et al. (2007). Before releasing the bats, aluminum forearm bands with unique numbers were fastened on the right forearms of females and left forearms of males to account for recapture.

Habitat survey

To assess the vegetation in the study site, a 20 m × 80 m habitat survey plot was established parallel to each transect. Within each plot, trees ≥ 5 cm were measured for diameter at breast height (dbh) or diameter above buttress using a diameter tape. All sampled trees were measured for height using a rangefinder or a measuring pole for trees less than 15 m.

Statistical analysis

A linear regression on species richness vs VJR size and abundance vs VJR size was carried out to determine the correlation between VJR size and bat assemblage. Species rank abundance was calculated and graphed for bat assemblage in each site. To study the relationship between bat diversity and VJR size, diversity indices were calculated. Simpson's diversity index ($D = \text{sum } p\_i^2$) and Pielou's evenness index ($H = \text{-sum } p\_i \log(b)\ p\_i / N$ where p_i = the proportional abundance of species i, b = the base of the logarithm and N = the number of sites in the collection) which represented α-diversity, and Chao 1 estimator, i.e. $S\_P = S\_0 + a1 * (a1 - 1)/(2 * (a2 + 1))$ were compared across study sites where S_P = extrapolated richness in a pool, S_0 = observed number of species in the collection, a1 and a2 = number of species occurring only in one or two sites in the collection. Simpson's index was chosen because it provided good estimate of diversity with a relatively small sample size (Magurran 2004). Chao 1 estimator which takes into account the number of species by abundance is one of many species richness estimators that gauge the number of unobserved species and total number of species in an area (Chao 1984, Chao et al. 2006). The observed species

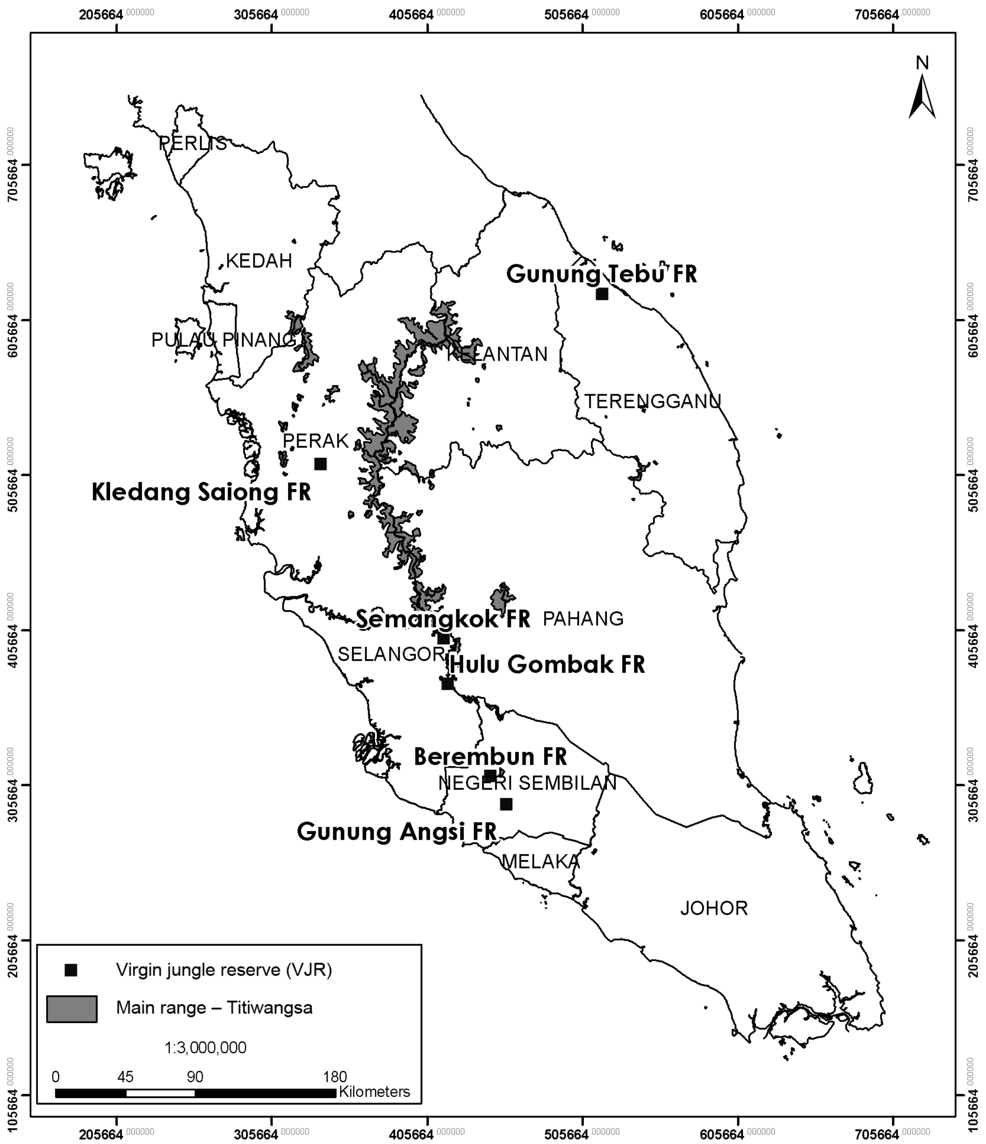

Figure 1 Location of the six study sites: Semangkok Forest Reserve (FR), Gunung Tebu FR, Gunung Angsi FR, Ulu Gombak FR, Kledang Saiong FR and Berembun FR in Peninsular Malaysia

richness was then divided by the Chao's estimated species richness to calculate the percentage of unobserved species (Tylianakis et al. 2006).

To determine the relationship between species composition and distances from and within the VJR, capture data on transect-level of all six VJRs were pooled together into three distance categories (within, > 200 m, > 600 m). A block multiple response permutation procedure (MRPP) (McCune & Grace 2002) was used to test differences in bat species composition between interior VJR and the surrounding secondary forests. A data matrix of species vs site based on number of individuals were used to conduct the analysis. In order to minimise the influence of extremely rare species, only those contributing at least 5% to the total sample were selected to calculate a dissimilarity matrix using Steinhaus distance metric and in the creation of the subsequent cluster dendogram. The relationship of these dominant species within distance sample of each size class is displayed in species space using non-metric multidimensional scaling (NMDS) (Rabinowitz 1975, Struebig et al. 2009).

Tree basal area was calculated to serve as an indicator for monitoring the extent of disturbance in a site (Seng et al. 2004). A linear

Table 1 Details of selected forest reserves with virgin jungle reserves in Peninsular Malaysia

VJR size class	Forest reserve (FR)	Forest type	Total forested area (ha)*	VJR size (ha)	Location of VJR with reference to FR edge	Site elevation (m asl)	Adjacent logged forest (years after logging)
Class I (1–49 ha)	Semangkok	Hill dipterocarp forest	27,376	28	Central	300–600	> 30
Class II (50–99 ha)	Gunung Tebu	Hill dipterocarp forest, upper dipterocarp forest, lower montane forest	39,655	50	Central	244–472	> 40
Class III (100–299 ha)	Gunung Angsi	Lowland, hill dipterocarp forest	26,406	143.3	Edge	200–500	> 40
Class IV (300–599 ha)	Ulu Gombak	Lowland, hill dipterocarp forest	28,573	449	Edge	457–1128	> 40
Class V (600–999 ha)	Kledang Saiong	Lowland, hill dipterocarp forest	32,823	814	Edge	100–600	> 30
Class VI (> 1000 ha)	Berembun	Lowland, hill dipterocarp forest	80,000	1834	Edge	200–700	> 40

*Area was calculated using ArcGIS

regression on mean basal area vs distance and mean tree height vs distance was conducted to determine the correlation between distances from the VJR (within, > 200 m, > 600 m). A Mantel test comparing distance matrix of bat species composition with habitat variables was carried out using Steinhaus distance (Kindt & Coe 2005) to establish the relationship between mean tree height and mean basal area per plot within and outside the VJR. The Mantel test was also conducted separately on habitat variables and dominant species (species contributing > 5% of the total bats captured).

The analyses were carried out with the vegan package in R (2011), an open source statistical software. Block MRPP was analysed using PCORD Version 5 (2006).

RESULTS

Differences in bat community between VJR size classes

A total of 27 insectivorous bat species were identified from 958 captured individuals (Table 2). Gunung Angsi Forest Reserve (FR) in Negeri Sembilan (Class III) had the most number of captures (29.23% of the total capture) whereas Ulu Gombak FR in Selangor (Class IV) had the least (6.68%) (Table 2). There was significant correlation between VJR size and bat species richness ($p = 0.001$, $r^2 = 0.1769$). However, there was no correlation between VJR size and bat abundance ($p = 0.2249$, $r^2 = 0.0281$).

For species diversity, Class VI had the highest evenness (Pielou's evenness index = 0.8477) while Class III, the lowest (0.651) (Table 3). Although Class I had the highest number of observed species (20), Simpson's index indicated that Class II was the most diverse with a value of 0.8988 (Table 3). The lower Simpson's index for Class I compared with Class II suggested that the abundance of species in the former was more disproportionate despite being rich in species count. The estimated total species richness from the Chao 1 estimator suggested that no new unobserved species were found in Classes II and VI (100% of total estimated species richness). On the contrary, Classes III and IV had the largest standard error

Table 2 List of bat family, species and their associated coding, abundance, IUCN status and habitat of insectivorous bats caught in six VJR sites across Peninsular Malaysia: Semangkok Forest Reserve (FR) (Class 1), Gunung Tebu FR (Class II), Gunung Angsi FR (Class III), Ulu Gombak FR (Class IV), Kledang Saiong FR (Class V) and Berembun FR (Class VI)

Family	Species	Class I	Class II	Class II	Class IV	Class V	Class VI	Total	IUCN status*	Habitat**
Hipposideridae	*Hipposideros bicolor* 131	11	48	28	4	5	10	106	LC	C/B
	Hipposideros bicolor 142	7	15	15	3	0	4	44	LC	C/B
	Hipposideros bicolor sp.#	11	109	142	4	23	11	300	LC	C/B
	Hipposideros cervinus	2	0	27	22	0	9	60	LC	C/B
	Hipposideros larvatus	35	43	14	0	0	0	92	LC	C/B
	Hipposideros doriae	4	0	0	0	1	0	5	NT	T
	Hipposideros galeritus	1	0	1	0	0	3	5	LC	C/B
Rhinolophidae	*Rhinolophus stheno*	25	3	9	3	2	4	46	LC	C/B/T
	Rhinolophus lepidus	3	6	5	0	0	6	20	LC	C/B
	Rhinolophus sedulus	2	0	0	0	0	0	2	NT	C/T
	Rhinolophus trifoliatus	8	3	3	16	6	6	42	LC	T
	Rhinolophus affinis	0	3	6	0	6	31	46	LC	C/B
	Rhinolophus pusillus	0	0	0	0	0	1	1	LC	C
	Rhinolophus luctus	0	0	4	1	0	1	6	LC	C/B/T
Murininae	*Murina suilla*	3	0	0	0	2	0	5	LC	T
	Murina cyclotis	0	0	1	0	1	1	3	LC	T
	Murina rozendaali	1	3	0	1	1	0	6	VU	T
Kerivoulinae	*Kerivoula papillosa*	22	6	3	0	11	3	45	LC	T
	Kerivoula hardwickii	18	7	8	5	7	3	48	LC	T
	Kerivoula pellucida	1	6	5	5	0	1	18	NT	T
	Kerivoula intermedia	4	8	8	0	6	3	29	NT	T
	Phoniscus atrox	0	3	0	0	0	0	3	NT	T
Vespertilioninae	*Glischropus tylopus*	11	0	0	0	0	0	11	LC	E
	Tylonycteris robustula	6	0	0	0	0	0	6	LC	T
	Myotis ridleyi	0	0	0	0	4	0	4	NT	C
Megadermatidae	*Megaderma spasma*	0	0	0	0	0	1	1	LC	T
Nycteridae	*Nycteris tragata*	3	0	1	0	0	0	4	NT	T
Total number of individuals		178	263	280	64	75	98	958		
Species richness		20	15	16	10	12	17	27		

VU = vulnerable, NT = near threatened, LC = least concern; C = roost in cave, B = roost in boulders/crevices, T = roost in trees/foliage; *Hipposideros 'bicolor'* comprises two phonic types with mean echolocation call frequencies of 131 and 142 kHz; they were distinguished in the field by forearm length, i.e. *H. bicolor* 131 > 45 mm and *H. bicolor* 142 < 43 mm; individuals with forearm 43–45 mm was identified as *H. bicolor* sp

with > 30% of unobserved species, indicating a possibility that the two areas were undersampled (Moreno & Halffter 2000).

Absolute species representation

All sites were dominated by either Hipposiderids or Rhinolophids (Figure 2). Most species in these two families are primarily cave-dwellers. Since 47% of all captures were of two species (*Hipposideros bicolor* 131 and *Hipposideros bicolor* sp.), they heavily influenced the results of this study. These species comprised 65.3% of all bats at Gunung Tebu (Class II) and 66.0% of all bats at Gunung Angsi (Class III) but merely 17.1% at Ulu Gombak (Class IV) and 16.2% at Semangkok (Class I). However, Semangkok, Ulu Gombak and Kledang Saiong (Class V) showed high abundance of tree- or foliage-roosting species such as *Kerivoula papillosa* and *Rhinolophus trifoliatus.* Of the 27 captured species, 8 were considered near threatened or vulnerable as listed under IUCN (IUCN 2012) and among them, 7 were tree- or foliage-roosting species.

Differences of bat community between VJR and the surrounding forest

All sites except Berembun (Class VI) had higher abundance and species richness outside the VJR (Table 4). The block MRPP

Table 3 Estimated total species richness with Chao estimator for six VJR size classes: Semangkok Forest Reserve (FR) (Class 1), Gunung Tebu FR (Class II), Gunung Angsi FR (Class III), Ulu Gombak FR (Class IV), Kledang Saiong FR (Class V) and Berembun FR (Class VI)

Size class	Species richness	% from total bats captured	Simpson's diversity index (1-D)	Pielou's evenness index	Chao 1 estimator	Chao 1 estimator SE	% of total richness estimated
Class 1	20	18.6	0.7629	0.6903	21.13	1.769	94.7
Class II	15	27.5	0.8988	0.8436	14.00	0	100.0
Class III	16	29.2	0.7159	0.651	26.00	11.662	69.2
Class IV	10	6.7	0.8005	0.8032	18.00	11.662	55.6
Class V	12	7.8	0.8562	0.8161	12.67	1.305	94.7
Class VI	17	10.2	0.8473	0.8477	17.00	0	100.0

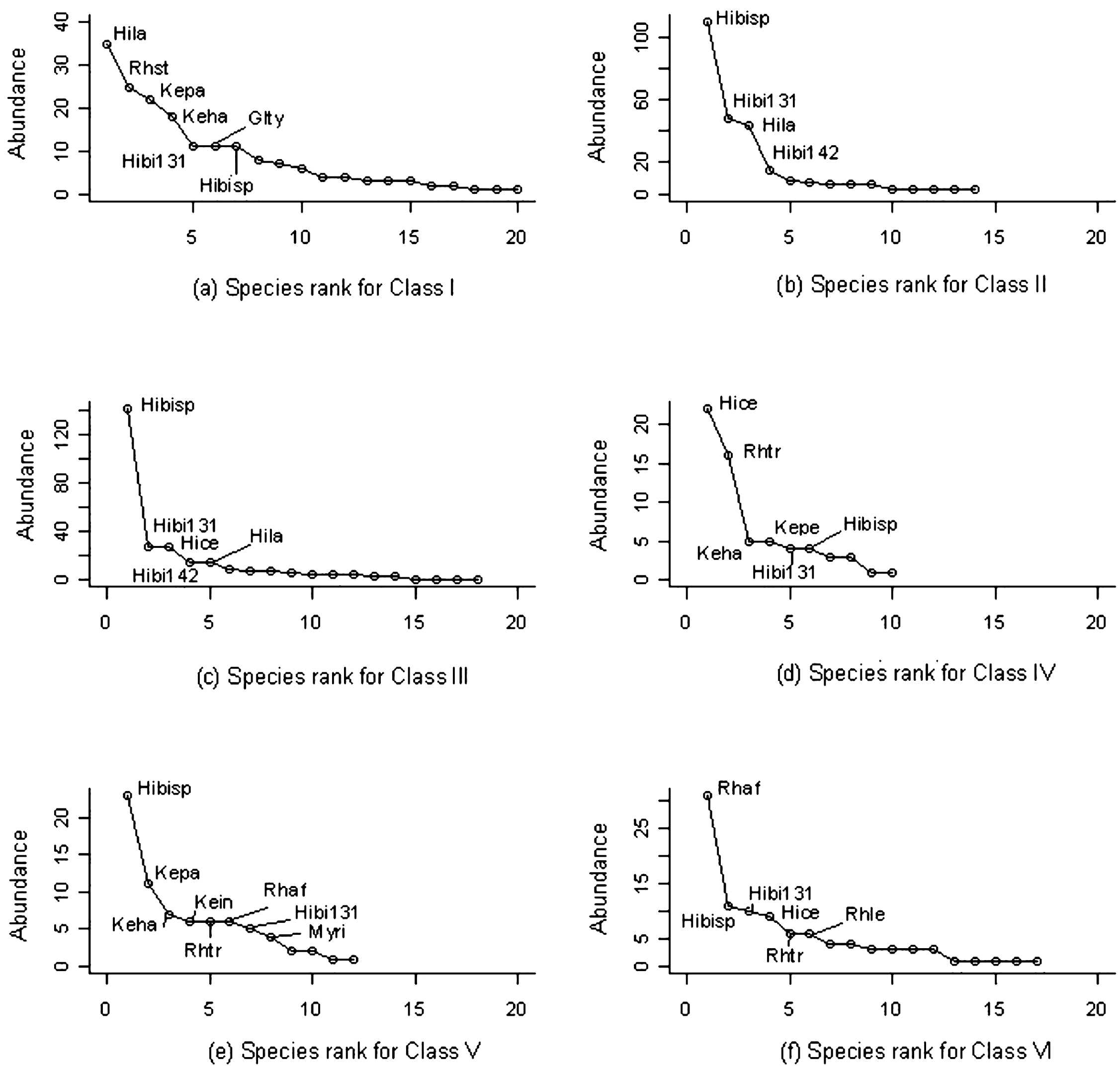

Figure 2 Species rank abundance curves with labels of species that had ≥ 5% of the population in the respective site (a) Class I Semangkok Forest Reserve (FR) (b) Class II Gunung Tebu FR (c) Class III Gunung Angsi FR (d) Class IV Ulu Gombak FR (e) Class V Kledang Saiong FR and (f) Class VI Berembun FR; species are written in codes, first two alphabets refer to the first two alphabets of the genus and second two alphabets refer to the first two alphabets of the species name; see Table 2 for full species names

suggested that species composition between interior VJR and the surrounding secondary forest was not significantly different, i.e. the hypothesis testing all pairwise combination had p value > 0.50 (Table 5). Distribution of dominant species explained by the cluster dendogram showed that clustering occurred mainly by site rather than VJR distances (Figure 3). This is further depicted in the NMDS ordination graph (Figure 4) which showed that transects from similar sites were closer together regardless of distance and that species closest to a site had higher abundance (Kindt & Coe 2005). This indicated that species composition was distributed according to site location rather than distances within a site. *Kerivoula pellucida* was closest to Class IV because it was present in high abundance (≥ 5 %) within the VJR and absent outside the VJR. *Rhinolophus lepidus* had only a small percentage caught in traps placed 200 m away from the VJR. However, there were species such as *Glischropus tylopus* that were not caught in traps > 600 m away from the VJRs. *Myotis ridleyi* was only captured within the VJR and appeared secluded in the graph because it was only captured at one site. Class II had similar distribution regardless of distances within or away from the VJR.

There was no significant difference in basal area ($p = 0.2266$, $r^2 = 0.0899$) and tree height ($p = 0.9647$, $r^2 = 0.0001$) between distances in the VJR (Table 4). The Mantel test also revealed that species composition was not significantly correlated with mean tree height ($p = 0.123$, $r = 0.1194$) and mean basal area ($p = 0.123$, $r = 0.111$) per plot. When analysed with dominant species (species contributing > 5% of the total bat capture), results showed that there was non-significant negative correlation with tree height ($r = -0.03384$, $p = 0.62$) and basal area ($r = -0.1188$, $p = 0.873$).

DISCUSSION

The results of this study did not support the hypothesis that bat abundance and species richness increased with increasing VJR size. However, they indicated that there were unique differences in the composition of insectivorous bats between different VJRs. Although there were significant differences in species richness between VJR size classes, bat abundance was not affected by the presence or size of VJR. Since the dissimilarity index revealed that bat species composition was not different at distances up to 600 m from the VJR, and that there was no significant difference between tree height and basal area within and outside the VJR, it seemed that the role of VJRs as reservoirs to restock the adjacent logged over forest had been fulfilled. Our results agreed with the report that restocking of a forest after logging was not done by immigrants from outside the area but by those moving out of forest pockets such as VJRs (Whitmore 1984). However, this was based on the assumption that species composition reflected in the VJR now was similar to the species composition before the surrounding forest was logged 30 to 40 years ago and that roosting ecology of insectivorous bats influenced spatial distribution of a species at the local level (Kingston 2001).

This study deliberately standardised the sampling effort regardless of VJR size. Even so, Chao's estimated total species richness showed that the largest VJR Berembun FR (Class VI) was sampled adequately but Gunung Angsi

Table 4 Bat abundance and species richness in each VJR class according to distance: Semangkok Forest Reserve (FR) (Class 1), Gunung Tebu FR (Class II), Gunung Angsi FR (Class III), Ulu Gombak FR (Class IV), Kledang Saiong FR (Class V) and Berembun FR (Class VI)

VJR size class	Bat abundance			Bat species richness			Mean basal area (m^2 ha^{-1})			Mean height (m)		
	Within	> 200 m	> 600 m	Within	> 200 m	> 600 m	Within	> 200 m	> 600 m	Within	> 200 m	> 600 m
Class 1	48	44	86	21	21	28	19.6	16.8	11.3	11.7	10.4	12.5
Class II	90	114	53	14	25	19	16.0	26.1	18.5	13.1	15.7	12.7
Class III	61	174	45	21	24	22	28.6	16.8	14.1	13.2	12.7	12.0
Class IV	13	17	34	7	10	11	15.1	21.7	18.9	11.1	15.0	12.4
Class V	14	33	27	8	15	11	21.4	16.9	14.6	13.9	13.6	13.2
Class VI	58	24	15	21	11	12	12.8	10.8	16.0	13.0	12.9	13.4

Table 5 Block multiple response permutation procedure for comparison between species composition within and distances away from the VJR

Distances within VJR size compared	A[1]	P
Within vs 200 m away	0.0072	0.8095
Within vs > 600 m away	0.0086	0.9039
200 m away vs > 600 m away	-0.0025	0.5002

[1]Chance-corrected within-group agreement (A) describes within-group homogeneity; all observed items are identical within groups, A = 1, which is the highest possible value; there is less agreement within groups than expected by chance, $A < 0$; the higher the A value the more identical the sites are in terms of bat communities; $p > 0.05$ indicates that the pair is dissimilar

FR (Class III) and Ulu Gombak FR (Class IV) were undersampled. One explanation of undersampling could be that these two VJRs were hosting a number of rare species that had low detection rate and thus not adequately captured in this study. This was evident as many rare species were captured in all other VJRs except Gunung Angsi FR and Ulu Gombak FR. On the other hand, lack of trapping effort or type of sampling technique administered might have also affected species detection (Kingston et al. 2000).

Although the results of this study might seem to suggest that smaller fragments had more substantial value for bat conservation than larger fragments, it should be noted that the results were heavily influenced by two very closely related species, i.e. *H. bicolor* 131 and *H. bicolor* sp.. Most bat species were too scarce (sample size too small) to detect species-specific impacts. Some species might benefit and some might suffer from logging (Laidlaw 1996a), leaving an overall impression of no change.

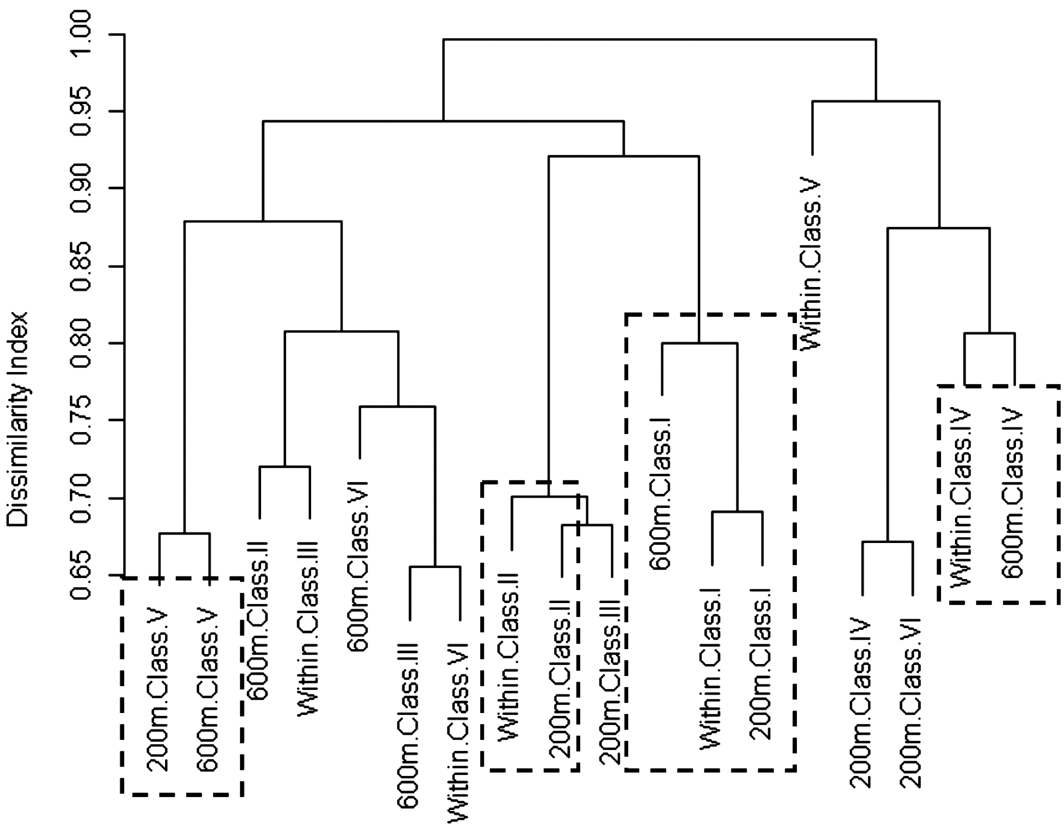

Figure 3 Cluster dendogram using Steinhaus dissimilarity index of dominant species proportion within the VJR (within), 200 m away from the VJR (200m) and > 600 m away from the VJR (600m); Class I Semangkok Forest Reserve (FR), Class 1I Gunung Tebu FR, Class III Gunung Angsi FR, Class IV Ulu Gombak FR, Class V Kledang Saiong FR and Class VI Berembun FR; dotted rectangular indicates clustering of transects in similar sites

The value and importance of larger fragments were evident in Class IV and Class VI, where there was higher abundance of tree- or foliage-roosting species compared with other size classes. Bigger areas of undisturbed forest are more likely to contain critical habitat features for each one of the many bat species occurring in the forest and therefore are more likely to encompass viable population sizes than small areas. Species that are of greatest concern are near threatened (NT) species such as *Hipposideros doriae, Rhinolophus sedulus, K. pellucida, K. intermedia, Phoniscus atrox, M. ridleyi* and *Nycteris tragata*, and vulnerable (VU) species such as *Murina rozendaali*. They were not only low in abundance but also were mostly recorded in only one of the six study sites. Other species such as *G. tylopus* and *M. ridleyi* concentrated in the forest interior of smaller size VJR. These tree- or foliage-roosting species depend largely on vegetation, thus, restricting their occurrences around viable roosting habitat (Struebig et al. 2009) and will inevitably increase their vulnerability to human activities (Sheema 2006). Therefore, old growth forests such as VJRs are especially important because they offer critical roosting habitat (Thomas 1992). For example, *R. sedulus* prefers roosting in hollows of trees with dbh of 55 cm and above, which incidentally

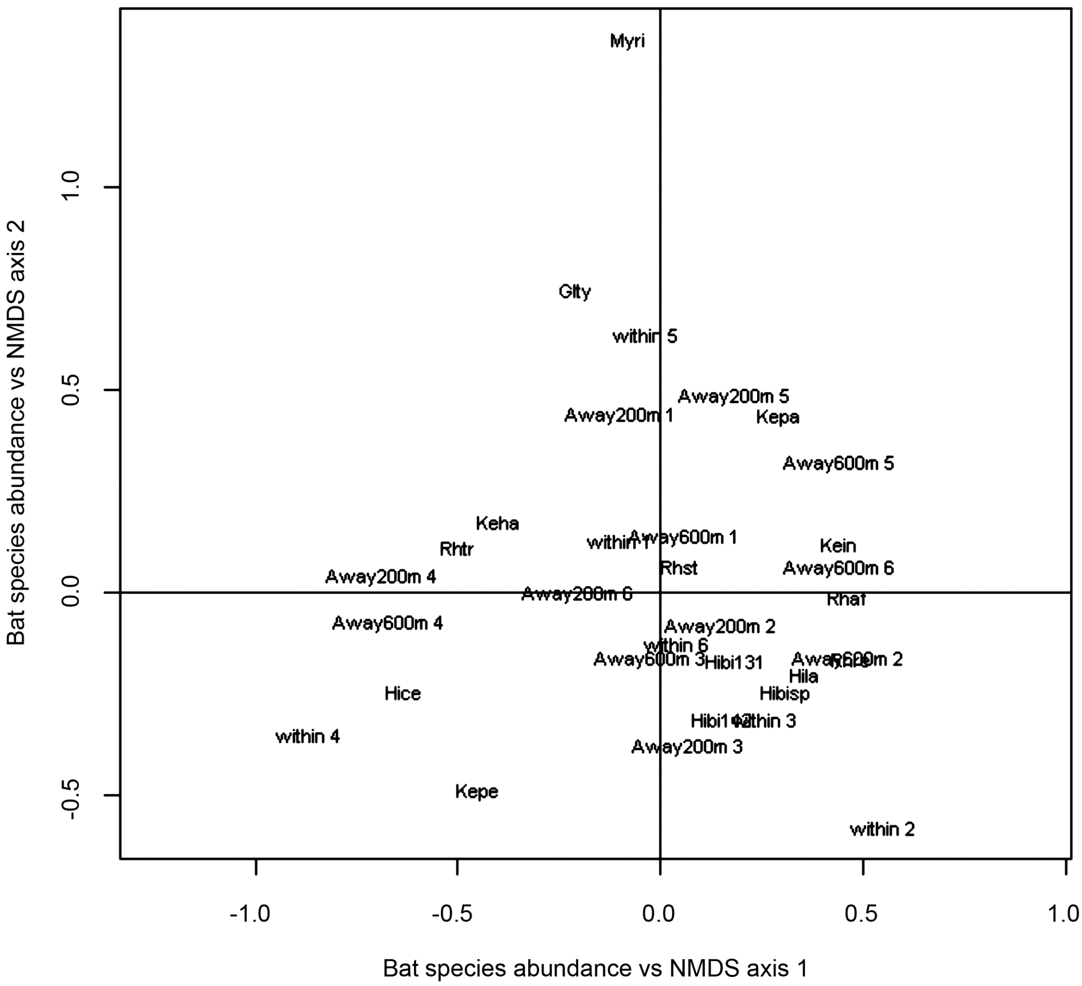

Figure 4 Non-metric multidimensional scaling (NMDS) of bat species abundance (of species ≥ 5 % of the population) and sites categorised as 'within' for within virgin jungle reserve (VJR), 'Away200m' and 'Away 600m' for traps at 200 m and > 600 m away from VJR respectively; numbers (1–6) indicate the size clases (Class I–Class VI respectively); distances between sampling sites on the ordination reflect dissimilarity in bat species composition using Bray–Curtis coefficients; species are written in codes, first two alphabets refer to the first two alphabets of the genus and second two alphabets refer to the first two alphabets of the species name, see Table 2 for full species names

falls above the minimum cutting limit of the Selective Management System (SMS) felling (Fletcher 2006).

Most sites in this study were dominated by common species that have larger home-range (i.e. cave/boulder dwelling bats). Hipposideridae was the dominant family with *H. bicolor* 131 and *H. bicolor* sp. each representing ≥ 5 % of the total population in all six sites, and together make up 16 to 66% of the total bat population. This is expected because they are found in various habitats (Douangboubpha et al. 2010) due to their gregarious roosting habits and high versatility (Struebig et al. 2009), making them theoretically less vulnerable to anthropogenically-induced habitat changes (Sheema 2006). By way of contrast, a forest specialist *R. trifoliatus* was present in many sites and in higher abundance in larger sized VJRs, echoing findings from a similar study conducted in Pahang (Struebig et al. 2008). Further studies on *R. trifoliatus* is needed to better understand how this species have adapted and flourished despite disturbances caused by logging.

There may be other confounding factors such as habitat quality that are affecting species abundance and composition in each site (Laidlaw 1996b, Laurance 2002). Some species may not flourish in fragmented habitats that are of low quality, namely, those surrounded by urban development, as opposed to high quality of a continuous forest (Henry et al. 2007). For instance, Ulu Gombak FR which has the lowest abundance and species richness is bordering one of the major highways in the country. Although topography was considered in the sampling design, it was eventually disregarded as no significant difference was detected between ridge, slope and valley. Another possibility that may be influencing the species composition in each forest reserve is the presence/absence of caves within or beyond the forest reserve (Struebig et al. 2009) and the availability of species-specific roosting sites (i.e. number of boulders, hollow trees, fallen trees) (Kingston 2001). However, both of these factors were not observed in this study.

Today, the conservation of bats in ever changing forest landscapes is even more crucial because of the intricate interdependency between the two. It involves several variables not easily quantifiable such as roost and food availability, or factors for which there are no available information such as population sizes (Bernard & Fenton 2007). Conservation should focus on bridging the gap between knowledge (research) and action (implementation) because as new species are being discovered, so is the impending destruction of their habitat. Further research on patterns of habitat use for each bat species will help provide more in-depth analysis for specific species rather than general information on multiple species (Miller et al. 2003, Patriquin & Barclay 2003). This will hopefully increase our understanding on population density and habitat requirements for sound conservation management practices (Francis 1990). The result of this study showed that the establishment of VJRs in production forest helped restock the surrounding forest and retained the population of habitat-sensitive species. VJR proved to be an essential forest management strategy for the conservation of insectivorous bats, especially foliage- or tree-roosting bats.

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