

RESPONSES OF BABBLERS (TIMALIIDAE) TO THE FOREST EDGE–INTERIOR GRADIENT IN AN ISOLATED TROPICAL RAINFOREST IN PENINSULAR MALAYSIA

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VARASTE H MORADI & MOHAMED Z. 2010. Responses of babblers (Timaliidae) to the forest edge–interior gradient in an isolated tropical rainforest in Peninsular Malaysia. The understanding of bird community responses, especially Timaliidae family, to tropical forest edge–interior gradient is limited. In this study, the point-count sampling method was used to determine community composition, abundance and density of babblers along the edge–interior gradient in Ayer Hitam Forest Reserve, Peninsular Malaysia. Environmental variables were measured within a 25 m radius of each point. Babbler species richness and diversity were positively correlated with humidity, distance from edge and the number of palm trees. There was a clear structured gradient in babbler species composition across edge–interior gradient and habitat variables, with abundant edge and interior specialist species. The interior specialist species were positively correlated with distance gradient, humidity, litter depth, canopy cover and the number of palm trees. In contrast, edge-tolerant species were positively correlated with ground cover, light intensity, shrub cover, and per cent of shrub cover between 0.5 and 2 m high but negatively correlated with distance from the forest edge. Changes in habitat structure at the edge of the isolated lowland rainforest may explain babbler species response to edge–interior gradient. From a conservation perspective, edge-avoider species should receive the most attention.

Keywords: Association, forest isolation, composition, density, diversity

VARASTE H MORADI & MOHAMED Z. 2010. Gerak balas burung rimba (Timaliidae) terhadap kecerunan pinggir dan kawasan dalaman suatu hutan hujan tropika terpencil di Semenanjung Malaysia. Pemahaman tentang gerak balas komuniti burung terutamanya daripada famili Timaliidae terhadap kecerunan pinggir dan kawasan dalaman hutan tropika adalah terhad. Dalam kajian ini, kaedah pensampelan kiraan pada pusat digunakan untuk menentukan komposisi komuniti, limpahan dan kepadatan burung rimba di sepanjang kecerunan pinggir dan kawasan dalaman Hutan Simpan Ayer Hitam, Semenanjung Malaysia. Pemboleh ubah persekitaran diukur di sekitar 25 m dari setiap pusat. Kekayaan spesies burung rimba dan kepelbagaianya berkorelasi secara positif dengan kelembapan persekitaran, jarak dari pinggir hutan dan bilangan pokok palma. Terdapat hubungan yang jelas antara komposisi spesies burung rimba di sepanjang kecerunan pinggir dan kawasan dalaman hutan dengan pemboleh ubah habitat—terdapat banyak spesies pengkhusus pinggir hutan dan pengkhusus pedalaman. Spesies pengkhusus pedalaman berkorelasi secara positif dengan cerun jarak, kelembapan, kedalaman sarap, litupan kanopi dan bilangan pokok palma. Sebaliknya, spesies pinggir hutan berkorelasi secara positif dengan litupan tanah, keamatan cahaya, litupan pokok renek dan peratusan litupan pokok renek berketegangan antara 0.5 m hingga 2 m tetapi berkorelasi secara negatif dengan jarak dari pinggir hutan. Perubahan dalam struktur habitat di pinggir hutan hujan tanah pamah terpencil mungkin dapat menjelaskan gerak balas spesies burung rimba terhadap kecerunan pinggir dan kawasan dalaman. Dari perspektif pemuliharaan, spesies yang menjauhi pinggir hutan patut mendapat perhatian yang lebih.

INTRODUCTION

Tropical rainforest is the most biologically diverse ecosystem. Degradation of tropical forests through logging, isolation and fragmentation is rampant. In most tropical regions, forest habitat is being isolated by rapid proliferation of small and large clearings. The impact of such disturbances on fauna and flora, especially birds, is poorly understood (Hill & Hamer 2004).

Forest fragmentation and isolation affect the distribution and abundance of organisms by reducing the amount and proximity of remnant patches of suitable habitat and increasing the amount of edges (Maina & Jackson 2003). Most studies on the effects of habitat loss or degradation of various South-East Asian biotas have focused on lowland rainforest habitat (Soh *et al.* 2005).

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Although many lowland species are prone to extinction due to intense logging, little attention has been focused on edge effect. Edges can alter abiotic processes such as microclimate, light intensity and hydrology (Sisk *et al.* 1997), and biotic factors such as habitat structure and food availability (Yahner 1988). Changes in conditions at edges can be associated with changes in abundance, density and diversity of birds due to changes in their demographic rates (Paton 1994, Donovan *et al.* 1997) or through behavioural avoidance of or attraction to the edge (Lidicker 1990).

Fragmentation generally increases the amount of edge per unit land area. Species that are adversely affected by edges can experience reductions in effective area of suitable habitat (Temple & Cary 1988), which can lead to high probability of extinction (Woodroffe & Ginsberg 1998). Avian species may respond to one or a combination of these changes in the landscape (Donovan *et al.* 1997).

Species that require forest interior may avoid edges due to altered microclimate or vegetation structure. The alteration is caused by variation of vegetation species composition and structure with distance from edge or high density of predators or brood parasites (Stephens *et al.* 2003).

Few studies have examined bird communities in South-East Asia forest isolates. Little is known about the direct effects of edge on tropical forest bird communities especially babbler species. Diet plays an important role in determining a species' response to disturbance. Babblers are

insectivorous and are most sensitive to forest disturbances (Fimbel *et al.* 2001). Generally, they are more specialised than other groups of insectivorous birds, therefore, more sensitive to edge effect (Varasteh Moradi *et al.* 2008). Food supply for babblers has been shown to vary with fragment size as a result of edge effects because invertebrates, especially surface dwellers, are prone to desiccation and may not survive well in edge habitat, which is often warmer and drier than the forest interior (Zannette *et al.* 2000).

The main objectives of this research were to: (1) study the effects of the edge–interior gradient on babbler community structure, composition and diversity, and (2) relate changes in babbler species composition and abundance to habitat variables along the edge–interior gradient.

MATERIALS AND METHODS

Study site

The study was conducted at Ayer Hitam Forest Reserve, Puchong, Selangor, Malaysia. The area is located at about 3° to 3° 2.2' N and 101° 37.9' to 101° 40.0' E, approximately 20 km southwest of Kuala Lumpur. The Ayer Hitam Forest Reserve is surrounded by development, making it an isolated patch of forest in the middle of the modern infrastructures and societies of Puchong, Kinrara, Seri Kembangan, Serdang and the Multimedia Super Corridor (Figure 1). The study area is an isolated lowland dipterocarp rainforest.

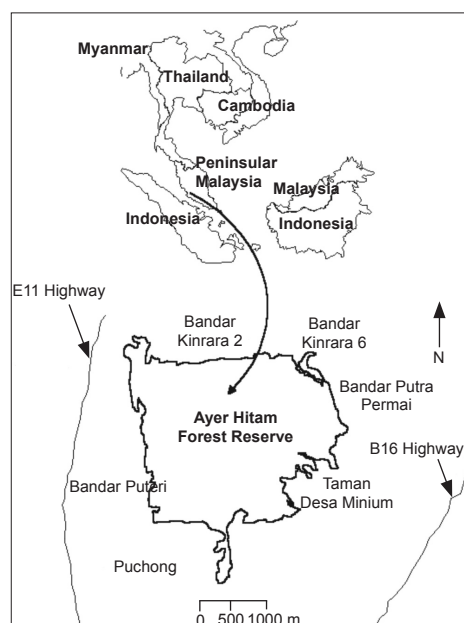


Figure 1 Map showing the position of Ayer Hitam Forest Reserve

This forest is affected by surrounding highways and housing areas. It was originally about 3500 ha in area. However in 1997, the forest on the eastern side of Puchong was excised for housing projects and highways, and the forest area was decreased to 1248 ha. This forest is the only lowland green lung left in Klang Valley, an area of 504 000 ha with 6 million people (Varasteh Moradi *et al.* 2008).

Bird surveys

The point-count sampling method (Bibby *et al.* 2000) was used to survey the abundance of babbler species at each of the 93 survey points. Ten visits were made at each point between April 2007 and July 2008. A total of 14 parallel transects were placed across the gradient of distance from the forest edge at 200 m intervals to minimise the risk of counting the same individual twice (Antongiovanni & Metzer 2005), beginning approximately 25 m from the forest edge. Data were collected at each of the 93 sampling points along the 14 transects. Distance 1 refers to the 14 points closest to the edge. Distances 2, 3 and 4, the next three sets of 14 sampling points 200, 400 and 600 m respectively away from the forest edge; Distance 5 refers to 13 sampling points 800 m away from the forest edge; Distance 6 refers to 11 sampling points 1000 m from the forest

edge and Distance 7 refers to 13 sampling points 1200 m from the forest edge. All sampling points were chosen randomly along each transect (Figure 2). To avoid time-of-day biases, the points were frequented in reverse order on different visits. Birds were counted at each census station point for a period of 10 min (Marsden *et al.* 2001). Birds occurring within 25 m fixed radius of each station were recorded because it was often not possible to identify species past this distance (Watson *et al.* 2004). Only species sighted within the point count area were recorded as present. Calls were used to locate birds and to aid identification. Bird surveys were carried out between 0730 and 1030 hours and only in the absence of rain or heavy mist. The census period was deemed as appropriate because bird activities tend to be high in the morning. All point counts were conducted by one observer to minimise observer effects.

Habitat surveys

Birds may respond to variation in microhabitat and microclimate structure. Therefore, 23 microhabitat and microclimate variables were recorded at each point to determine the effects of environmental variables on babblers. At each point, variables were measured within a 25 m radius (Castelletta *et al.* 2005). The variables

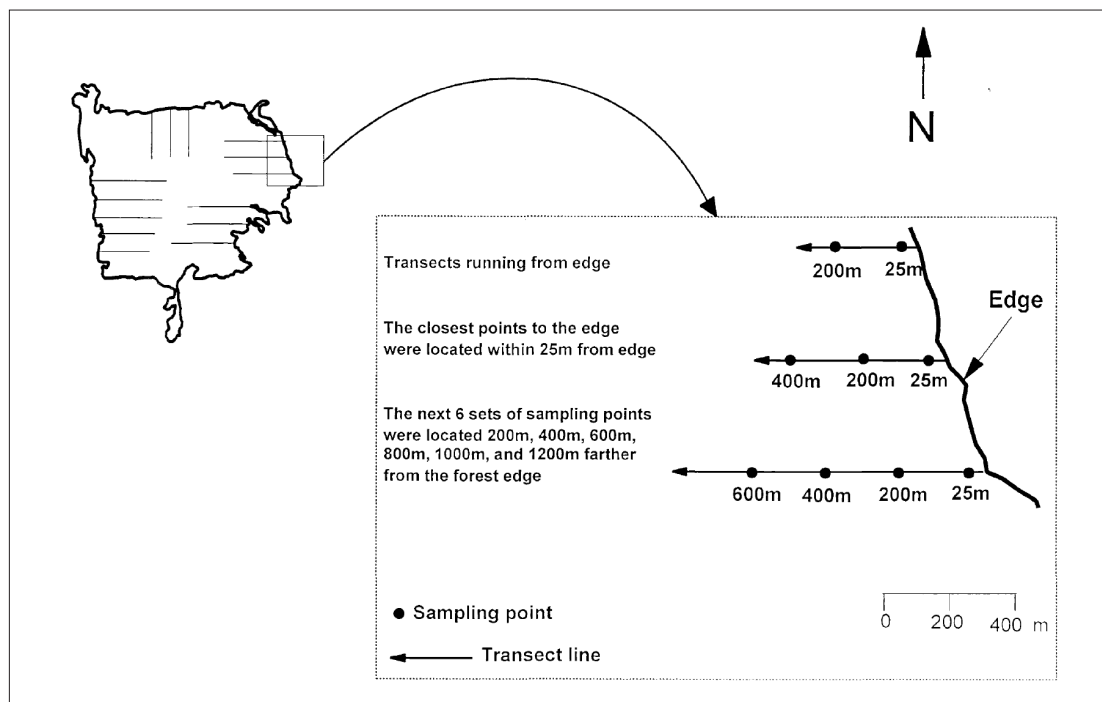


Figure 2 Map showing the position of sampling points

recorded were: distance from the forest edge (DIS), slope (SLO), temperature (TEM), humidity (HUM), light intensity (LUX), number (NDT) and dbh (DDT) of dead trees, number of palm trees (NPT), leaf litter depth (LDP), leaf litter per cent (LPC), basal area (BSL), canopy cover (CCV), ground cover (GCV), understorey shrub cover (SHC), per cent of shrub cover between 0.5 and 2 m height (PSH), number of trees higher than 10 m height (NT10), number of tree saplings with dbh less than 2 cm (NT2), number of tree species (NTS), number of tree with dbh 20–30 cm (NT20), number of tree with dbh 30–50 cm (NT30), number of tree with dbh more than 50 cm (NT50), number of *Melastoma malabathricum* shrubs (MM) and number of *Agrostistachys longifolia* trees (AL). The last two species were chosen because they were the most abundant tree and shrub at the Ayer Hitam Forest Reserve.

Data analysis

Prior to conducting statistical analyses, each variable was tested for deviations from the normal distribution using the Kolmogorov–Smirnov test for equality of variances. All variables were log-transformed in all analyses to normalise their distributions in order to meet this assumption of parametric statistics. Differences in total number of individuals, species and diversity per plot between the seven different distances from the forest edge were tested with General Linear Models (GLM) to compensate for differences in sample size. A *post-hoc* Tukey test was used to determine differences in edge–interior gradient types for the tested variables. When the data were not normally distributed, or standard deviations between factors differed too much to apply GLM, non-parametrical Kruskal–Wallis and Mann–Whitney U-test were used. These tests were also used to determine differences in habitat variables between different distances from the edge.

Using Canoco 4.5 software, the relationships were explored between babbler species abundances, babbler diversity and habitat variables. Before deciding whether to use the linear or unimodal type of ordination method, a detrended canonical correspondence analysis (DCCA) was performed. The gradient length measured by DCCA indicates the beta diversity in community composition along individual independent gradients. Since the beta gradient

was shorter than three, the linear constrained redundancy ordination (RDA) (Ter Braak & Smilauer 2002) was performed to detect babbler species responses to gradients in environmental variables. RDA is an extension of principal component analysis (PCA) that explicitly models response variables as a function of explanatory variables (Zuur *et al.* 2007). The default ‘by species’ scaling method was employed as the main interest was in the ordination of individual species with respect to one another and the environmental variables. The significance of the RDA was calculated using the Monte Carlo permutation tests with 499 permutations. To reduce the influence that the most abundant species might have on the ordination analysis, the abundance of each species was log-transformed (Jongman *et al.* 1995). To determine which explanatory variables are more important, RDA analysis using a forward selection procedure was applied. Also the default ‘attribute plots’ based on sample scores was used to display the variability in the species composition (diversity index values) related to explanatory variables.

All statistical tests were performed using Minitab 15 except for ordination analysis performed with Canoco 4.5. (Ter Braak & Smilauer 2002), diversity index values using Ecological Methodology software and density estimates using the DISTANCE 5.0 program. In the text and tables, values are means \pm SD. Statistical significance for all analyses was set at $\alpha = 0.05$.

RESULTS

Abundance and diversity

A total of 773 observations of 13 different babbler species were detected. Among the 13 babbler species, three showed significant difference in the numbers observed (Table 1). Two species, for which abundance was significantly high close to the edge, were striped tit-babbler (*Macronous gularis*) with the highest number of observations found at Distance 1 (25 m) (K–W, $H_{6,92} = 19.18$, $p = 0.00$) and fluffy-backed tit-babbler (*Macronous ptilosus*) with the highest number of observations at Distance 2 (200 m) (K–W, $H_{6,92} = 17.10$, $p = 0.01$). The only babbler species in which abundance increased significantly with increasing distance from edge was short-tailed babbler (*Malacocincla malaccensis*) (K–W, $H = 15.11$, $p = 0.02$). The Mann–Whitney U-test *post-hoc*

Table 1 Comparison of variables for babbler species in relation to edge–interior gradient

Parameter/ Bird	Distance from forest edge (m)							F, H	p
	25	200	400	600	800	1000	1200		
Shannon diversity index	1.21 ± 0.61 b	1.98 ± 0.32 a	1.73 ± 0.43 b	1.48 ± 0.47 b	1.50 ± 0.39 b	1.32 ± 0.34 b	1.52 ± 0.35 ab	2.63* GLM	0.03
Simpson evenness	0.55 ± 0.14 b	0.81 ± 0.12 a	0.70 ± 0.09 ab	0.67 ± 0.08 b	0.69 ± 0.16 ab	0.78 ± 0.10 a	0.66 ± 0.09 b	4.04* GLM	0.00
Simpson diversity index	0.46 ± 0.23 b	0.79 ± 0.09 a	0.68 ± 0.09 ab	0.61 ± 0.17 b	0.65 ± 0.15 ab	0.64 ± 0.08 b	0.63 ± 0.07 b	14.71* K–W	0.02
Number of babbler species	3.71 ± 1.11	3.00 ± 0.81	3.86 ± 1.06	4.57 ± 0.97	4.28 ± 1.38	3.71 ± 0.95	3.71 ± 1.25	8.40 K–W	0.21
Black-capped babbler	0.32 ± 0.08	0.32 ± 0.08	0.37 ± 0.17	0.32 ± 0.08	0.32 ± 0.08	0.35 ± 0.12	0.42 ± 0.19	5.90 K–W	0.43
Chestnut-winged babbler	0.44 ± 0.24	0.54 ± 0.26	0.51 ± 0.23	0.56 ± 0.27	0.52 ± 0.23	0.49 ± 0.24	0.41 ± 0.17	4.30 K–W	0.64
Fluffy-backed tit-babbler	0.40 ± 0.26 ab	0.58 ± 0.32 a	0.46 ± 0.28 ab	0.51 ± 0.31 ab	0.30 ± 0.00 b	0.30 ± 0.00 b	0.34 ± 0.13 b	17.10* K–W	0.01
Short-tailed babbler	0.49 ± 0.30 b	0.59 ± 0.27 b	0.74 ± 0.30 ab	0.64 ± 0.26 ab	0.71 ± 0.30 ab	0.85 ± 0.26 a	0.85 ± 0.25 a	15.11* K–W	0.02
Striped tit-babbler	1.21 ± 0.24 a	0.78 ± 0.27 b	0.90 ± 0.36 b	0.84 ± 0.37 b	0.82 ± 0.28 b	0.72 ± 0.83 b	0.83 ± 0.25 b	19.18* K–W	0.00
Brown fulvetta	0.32 ± 0.08	0.32 ± 0.08	0.30 ± 0.00	0.30 ± 0.00	0.32 ± 0.08	0.32 ± 0.08	0.35 ± 0.11	5.03 K–W	0.54
Moustached babbler	0.30 ± 0.00	0.32 ± 0.08	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	0.32 ± 0.08	0.35 ± 0.11	7.16 K–W	0.31
Scaly-crowned babbler	0.30 ± 0.00	0.30 ± 0.00	0.32 ± 0.08	0.34 ± 0.11	0.30 ± 0.00	0.33 ± 0.09	0.30 ± 0.00	6.63 K–W	0.36
Rufous-crowned babbler	0.32 ± 0.08	0.32 ± 0.08	0.36 ± 0.22	0.34 ± 0.11	0.32 ± 0.08	0.30 ± 0.00	0.35 ± 0.11	2.39 K–W	0.88
Black-throated babbler	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	0.36 ± 0.15	0.33 ± 0.09	0.32 ± 0.08	7.36 K–W	0.28
Grey-headed babbler	0.34 ± 0.16	0.30 ± 0.00	0.36 ± 0.14	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	8.15 K–W	0.22
White-bellied yuhina	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	0.30 ± 0.00	0.35 ± 0.11	0.36 ± 0.12	0.30 ± 0.00	12 K–W	0.06
Eyebrowed wren-babbler	0.32 ± 0.08	0.38 ± 0.15	0.32 ± 0.08	0.32 ± 0.08	0.32 ± 0.08	0.36 ± 0.12	0.30 ± 0.00	4.98 K–W	0.54

Means with different letters within the same column are significantly different; * significant at $\alpha = 0.05$; GLM = general linear models; K–W = Kruskal–Wallis test; F = test of parametric analysis of variances; H = test of non-parametric analysis of variances

revealed that this species had significantly higher number at Distances 6 (1000 m) and 7 (1200 m). There was also strong effect of distances from the forest edge on diversity indices. Shannon diversity index (GLM, $F = 2.63$, $p = 0.03$), Simpson diversity index (K–W, $H = 14.71$, $p = 0.02$) and Simpson evenness index (GLM, $F = 4.04$, $p = 0.00$) showed significant differences along edge–interior gradient (Table 1). The Mann–Whitney U-test *post-hoc* revealed that the three diversity indices had significantly higher value at Distance 2 (200 m from the forest edge).

Density estimates

Due to insufficient number of observation for all babbler species, density analyses were presented only for five babbler species (Table 2). Babbler species had different density response to the edge. Notable were high density estimates for striped tit-babbler (9.62 ± 3.23 individuals/ha at Distance 1 and 2.54 ± 0.87 individuals/ha at Distance 6), fluffy-backed tit-babbler (4.56 ± 2.07 individuals/ha at Distance 2 and 0, at Distances 5 and 6) and short-

Table 2 Density estimates (individuals per ha) for five babbler species in relation to different distances from the forest edge (using distance sampling method)

Bird	Distance from the forest edge (m)						
	25	200	400	600	800	1000	1200
Black-capped babbler <i>Pellorneum capistratum</i>	0.94 ± 0.94	0.94 ± 0.94	0.38 ± 0.25	0.94 ± 0.94	0.10 ± 0.10	0.24 ± 0.16	0.61 ± 0.28
Chestnut-winged babbler <i>Stachyris erythroptera</i>	0.50 ± 0.25	0.84 ± 0.28	0.67 ± 0.24	0.95 ± 0.33	0.72 ± 0.25	0.64 ± 0.28	0.30 ± 0.14
Fluffy-backed tit-babbler <i>Macronous ptilosus</i>	2.05 ± 1.49	4.56 ± 2.07	2.51 ± 1.76	3.42 ± 1.92	0.00	0.00	0.49 ± 0.51
Short-tailed babbler <i>Malacocincla malaccensis</i>	0.87 ± 0.44	1.05 ± 0.35	1.92 ± 0.48	1.34 ± 0.37	1.82 ± 0.56	2.52 ± 0.60	2.70 ± 0.58
Striped tit-babbler <i>Macronous gularis</i>	9.62 ± 3.23	3.90 ± 1.39	5.90 ± 1.98	5.08 ± 2.06	3.81 ± 1.23	2.54 ± 0.87	4.10 ± 1.23

tailed babbler (2.70 ± 0.58 individuals/ha at 1200 m from the edge and 0.87 ± 0.44 individuals/ha at 25 m from the edge).

Changes in habitat variables along forest edge–interior gradient

The abiotic variables (temperature, humidity, and light intensity) were significantly different between plots from different distances from the edge (Table 3). Distance 1 had the highest temperature and light intensity but lowest humidity compared with the other distances. Some biotic variables also differed significantly along the edge–interior gradient. Variables DDT (dbh of dead trees), LDP (leaf litter depth) and LPC (leaf litter per cent) increased significantly from the forest edge to the interior. Conversely, variables SHC (understorey shrub cover), GCV (ground cover) and MM (number of *M. malabathricum* shrubs) decreased significantly from the forest edge to the interior.

Association between environmental variables and babbler species composition

To describe how individual babbler species were distributed in the current study with regard to environmental variables (including distance from the forest edge), the RDA was performed. There was a strong relationship between environmental variables and the abundance of the babbler species. The total ordination of species along environmental variable gradients was significant ($p = 0.012$, Monte Carlo simulations at 499

permutations). The first two axes explained 49.9% of the variation in the species data which could be explained with the environmental explanatory variables. The first two axes explained 45% of this, which worked out as 22.45% of the babbler species variation, as explained by the first two axes. The species–environment correlations for the first two axes were 0.72 and 0.75 respectively. These elaborate correlations measured how well environmental variables explained the extracted variation in the composition of the community.

Environmental variables differed in their relation to the first and second axes of RDA ordination (Figure 3). The first axis represented the vegetation and distance gradient. The environmental variables which were significantly related to this axis were light intensity, shrub cover, percentage of shrub cover between 0.5 and 2 m in height, ground cover, basal area, number of *A. longifolia* trees, leaf litter per cent, slope, canopy cover, number of palm trees and distance from the forest edge. The second axis represented a microclimate gradient including humidity and temperature.

The first axis, which described vegetation and distance gradient, had successfully separated three edge specialist species, namely, striped tit-babbler, fluffy-backed tit-babbler and grey-headed babbler (*Stachyris poliocephala*) in the negative direction with distance from the forest edge at the right side of the ordination diagram (hereafter referred to as edge-tolerant) from seven interior specialist species, namely, short-tailed babbler, black-capped babbler (*Pellorneum capistratum*),

Table 3 Habitat variables measured along edge–interior gradient

Variable	Distance from the forest edge (m)							F, H	P
	25	200	400	600	800	1000	1200		
TEM	24.8 ± 1.3 a	24.5 ± 0.9 ab	24.2 ± 0.9 b	24.3 ± 1.1 b	24.2 ± 1.2 b	24.3 ± 1.3 b	24.5 ± 1.5 ab	4.32* GLM	0.00
HUM	96.1 ± 4.4 b	96.9 ± 3.6 ab	97.6 ± 2.7 a	97.2 ± 3.3 ab	97.5 ± 3.0 a	97.2 ± 3.4 ab	96.8 ± 3.7 ab	2.78* GLM	0.01
LUX	117 ± 113 a	24.3 ± 18.6 b	23.5 ± 17.03 b	24.9 ± 11.6 b	21.1 ± 13 b	23.7 ± 9.5 b	40.1 ± 37.8 b	19.96* K–W	0.00
SLO	3.87 ± 2.83	4.46 ± 1.36	4.93 ± 2.91	4.54 ± 2.25	4.51 ± 2.49	4.00 ± 3.82	3.85 ± 2.59	0.32 GLM	0.93
BSL	0.38 ± 0.47	0.18 ± 0.18	0.22 ± 0.36	0.32 ± 0.34	0.25 ± 0.14	0.19 ± 0.13	0.21 ± 0.19	4.42 K–W	0.62
NT10	2.24 ± 1.29	2.79 ± 0.77	2.69 ± 1.04	2.94 ± 0.30	3.03 ± 0.21	2.94 ± 0.23	2.83 ± 0.78	3.22 K–W	0.78
NT2	2.90 ± 1.14	3.07 ± 0.92	2.76 ± 1.11	3.12 ± 0.25	3.28 ± 0.32	2.99 ± 0.93	2.88 ± 0.91	3.65 K–W	0.72
NT20	0.40 ± 0.16	0.51 ± 0.20	0.36 ± 0.12	0.48 ± 0.19	0.58 ± 0.22	0.50 ± 0.19	0.53 ± 0.24	10.93 K–W	0.09
NT30	0.46 ± 0.21	0.38 ± 0.15	0.44 ± 0.17	0.43 ± 0.19	0.45 ± 0.17	0.40 ± 0.17	0.51 ± 0.22	3.79 K–W	0.70
NT50	0.44 ± 0.17	0.34 ± 0.10	0.34 ± 0.10	0.39 ± 0.16	0.35 ± 0.11	0.35 ± 0.12	0.34 ± 0.13	6.98 K–W	0.32
NPT	2.41 ± 1.17	2.63 ± 1.02	2.44 ± 1.16	2.51 ± 1.00	2.57 ± 1.03	2.79 ± 0.85	2.66 ± 0.74	2.36 K–W	0.88
NDT	1.87 ± 1.23	2.31 ± 1.13	2.56 ± 0.67	2.05 ± 1.17	1.64 ± 1.30	2.64 ± 0.24	1.55 ± 1.21	8.13 K–W	0.23
DDT	1.12 ± 0.65 b	1.20 ± 0.52 b	1.36 ± 0.39 ab	1.06 ± 0.55 ab	0.91 ± 0.61 ab	1.61 ± 0.25 a	0.89 ± 0.63 ab	13.09* K–W	0.04
SHC	2.72 ± 1.08 a	1.21 ± 1.28 b	1.36 ± 1.29 b	0.85 ± 1.10 b	0.86 ± 1.05 b	1.22 ± 1.28 b	1.01 ± 1.12 b	23.47* K–W	0.00
LDP	0.85 ± 0.92 b	1.08 ± 1.26 a	1.07 ± 1.36 a	1.03 ± 1.41 ab	1.12 ± 1.30 a	0.96 ± 1.29 ab	1.11 ± 1.32 a	14.07* K–W	0.03
LPC	1.88 ± 0.35 b	2.18 ± 0.15 b	2.03 ± 0.32 ab	2.06 ± 0.35 ab	2.24 ± 0.10 a	2.15 ± 0.15 ab	2.16 ± 0.15 ab	18.93* K–W	0.00
CCV	1.84 ± 0.36	2.08 ± 0.12	2.06 ± 0.17	2.00 ± 0.16	2.11 ± 0.14	2.10 ± 0.12	2.04 ± 0.21	9.17 K–W	0.16
GCV	1.92 ± 0.34 a	1.36 ± 0.38 b	1.33 ± 0.52 b	1.31 ± 0.44 b	1.23 ± 0.23 b	1.27 ± 0.37 b	1.44 ± 0.44 b	21.87* K–W	0.00
PSH	2.01 ± 0.30	1.99 ± 0.13	1.91 ± 0.47	1.93 ± 0.29	1.98 ± 0.13	1.92 ± 0.16	1.86 ± 0.31	6.27 K–W	0.39
NTS	1.74 ± 0.14	1.74 ± 0.16	1.65 ± 0.23	1.59 ± 0.26	1.72 ± 0.12	1.62 ± 0.21	1.62 ± 0.21	6.23 K–W	0.39
MM	0.76 ± 0.51 a	0.43 ± 0.32 ab	0.47 ± 0.30 ab	0.36 ± 0.17 b	0.32 ± 0.08 b	0.42 ± 0.27 ab	0.39 ± 0.18 ab	13.68* K–W	0.03
AL	0.59 ± 0.37	0.83 ± 0.48	0.71 ± 0.45	0.82 ± 0.51	0.81 ± 0.41	0.87 ± 0.58	0.69 ± 0.54	3.55 K–W	0.74

TEM = temperature, HUM = humidity, LUX = light intensity, SLO = slope, BSL = basal area, NT10 = number of trees higher than 10 m height, NT2 = number of tree saplings with dbh less than 2 cm, NT20 = number of trees with dbh 20–30 cm, NT30 = number of trees with dbh 30–50 cm, NT50 = number of trees with dbh more than 50 cm, NPT = number of palm trees, NDT = number of dead trees, DDT = dbh of dead trees, SHC = understory shrub cover, LDP = leaf litter depth, LPC = leaf litter per cent, CCV = canopy cover, GCV = ground cover, PSH = per cent of shrub cover between 0.5 and 2 m height, NTS = number of tree species, MM = number of *Melastoma malabathricum* shrubs, AL = number of *Agrostistachys longifolia* trees
Means with different letters are significantly different; * significant at $\alpha = 0.05$; GLM = general linear models; K–W = Kruskal–Wallis test; F = test of parametric analysis of variances; H = test of non-parametric analysis of variances

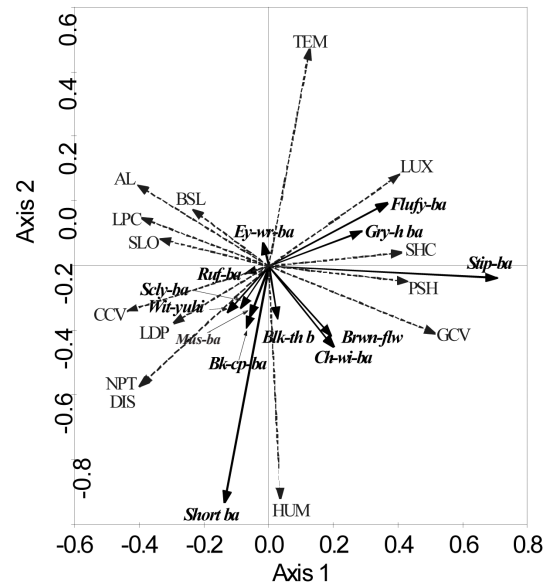


Figure 3 Ordination diagram of the first two axes of RDA for babbler species and all environmental variables in Ayer Hitam Forest Reserve. Axes 1 and 2 accounted for 18.21 and 4.24% of the variance in the species data. Arrows represent directions of greatest change of variables. Environmental variables: LUX = light intensity, TEM = temperature, SHC = shrub cover, PSH = per cent of shrub cover between 0.5 and 2 m height, GCV = ground cover, HUM = humidity, DIS = distance from the forest edge, NPT = number of palm trees, LDP = leaf litter depth, CCV = canopy cover, SLO = slope, LPC = leaf litter per cent, AL = number of *Agrostistachys longifolia* trees, BSL = basal area. Babbler species: Strip-ba = striped tit-babbler, Gry-h ba = grey-headed babbler, Fluffy-ba = fluffy-backed tit-babbler, Ey-wr-ba = eyebrowed wren-babbler, Ruf-ba = rufous-crowned babbler, Scly-ba = scaly-crowned babbler, Wit-yuhi = white-bellied yuhina, Mus-ba = moustached babbler, Bk-cp-ba = black-capped babbler, Short ba = short-tailed babbler, Blk-th b = black-throated babbler, Ch-wi-ba = chestnut-winged babbler, Brwn-flw = brown fulvetta.

black-throated babbler (*Stachyris nigricollis*), moustached babbler (*Malacopteron magnirostre*), scaly-crowned babbler (*Malacopteron cinereum*), rufous-crowned babbler (*Malacopteron magnum*), and white-bellied yuhina (*Yuhina zantholeuca*) in the positive direction with distance from the forest edge at the left side of the ordination diagram (hereafter referred to as edge-avoider). Three species, namely, eyebrowed wren-babbler (*Napothera epilepidota*), brown fulvetta (*Alcippe brunneicauda*) and chestnut-winged babbler (*Stachyris erythroptera*) showed no significant bias towards or against distance gradient (hereafter referred to as edge-indifferent). The RDA ordination biplot (Figure 3) indicated that edge-avoider species were positively correlated with distance gradient, humidity, litter depth, canopy cover and number of palm trees. In contrast, edge-tolerant species were positively correlated with ground cover, light intensity, shrub cover, and per cent of shrub cover between 0.5 and 2 m height.

To determine which explanatory variables were most important, a forward selection procedure was applied (Figure 4). The forward selection procedure indicated that ground cover, per cent of shrub cover between 0.5 and 2 m height, humidity, distance from the forest edge, the number of *A. longifolia* trees and the number of palm trees were the most important explanatory variables describing babbler species composition.

To display the variability in the babbler species composition (diversity index values) related to explanatory variables along edge-interior gradient, the biplot diagrams with the most important environmental variables and plots with the size symbols corresponding to species diversity indices were plotted (Figure 5). The Simpson and Shannon–Wiener diversity indices were positively correlated with humidity, distance from edge and the number of palm trees but negatively correlated with number of *A. longifolia* trees (Figures 5a and b). The Simpson evenness index did not show any clear pattern

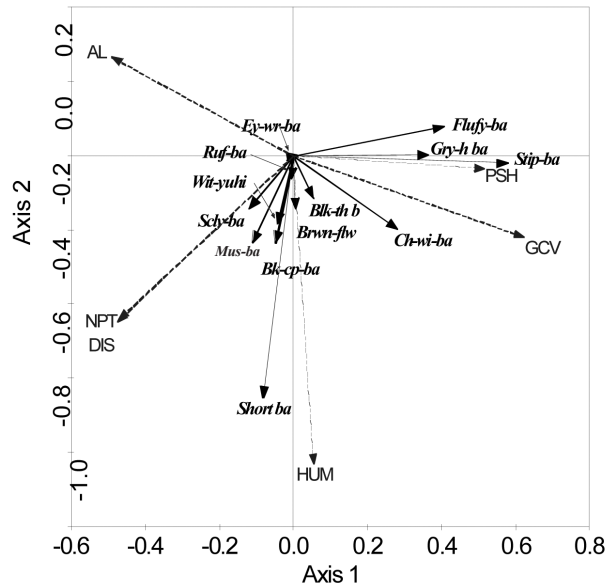


Figure 4 Ordination diagram of the first two axes of RDA for babbler species and the most important environmental variables in Ayer Hitam Forest Reserve. Axes 1 and 2 accounted for 8.1 and 2.1% of the variance in the species data. Arrows represent directions of greatest change of variables. Environmental variables: PSH = per cent of shrub cover between 0.5 and 2 m height, GCV = ground cover, HUM = humidity, DIS = distance from the forest edge, NPT = number of palm trees, AL = number of *Agrostistachys longifolia* trees. Babbler species: Strip-ba = striped tit-babbler, Gry-h ba = grey-headed babbler, Flufy-ba = fluffy-backed tit-babbler, Ey-wr-ba = eyebrowed wren-babbler, Ruf-ba = rufous-crowned babbler, Scly-ba = scaly-crowned babbler, Wit-yuhi = white-bellied yuhina, Mus-ba = moustached babbler, Bk-cp-ba = black-capped babbler, Short ba = short-tailed babbler, Blk-th b = black-throated babbler, Ch-wi-ba = chestnut-winged babbler, Brwn-flw = brown fulvetta.

corresponding to environmental variables along edge–interior gradient (Figure 5c).

DISCUSSION

The lowland rainforests contain a distinctive forest bird assemblage but are threatened by deforestation, fragmentation and degradation. Edge effects are a key component in understanding how landscape structure influences habitat quality (Ries *et al.* 2004). Species are affected in a major or minor way by their surrounding environment depending on the way they use it. Identifying the variables that affect the presence of babbler species in a given habitat is imperative in order to determine the threats that these species might be exposed to along the edge–interior gradient. This will allow for the creation of robust tools for the conservation and management of species in isolated tropical forest.

Among the 13 babbler species in Ayer Hitam Forest Reserve, three were strongly influenced

by edge–interior gradient. Striped tit-babbler and fluffy-backed tit-babbler showed a strong tendency to the edge. Previous study by Fimbel *et al.* (2001) also yielded the same pattern, i.e. some species such as tit babblers (*Macronous* spp.) had increased in response to the edge and disturbance. On the other hand, the increase in the abundance and density of the short-tailed babbler from the forest edge to the interior seemed to be related to their specialisation in food preferences and/or foraging techniques (Marra & Remsen 1997). This insectivorous species may depend on specific substrates in the forest interior, particularly environmental conditions such as leaf litter depth, humidity, number of tall trees and canopy cover of the understorey forest. There was also strong effect of distances from the forest edge on diversity indices. Shannon diversity index and Simpson diversity index showed significant differences along edge–interior gradient. Forest interior habitat exhibited higher babbler species diversity

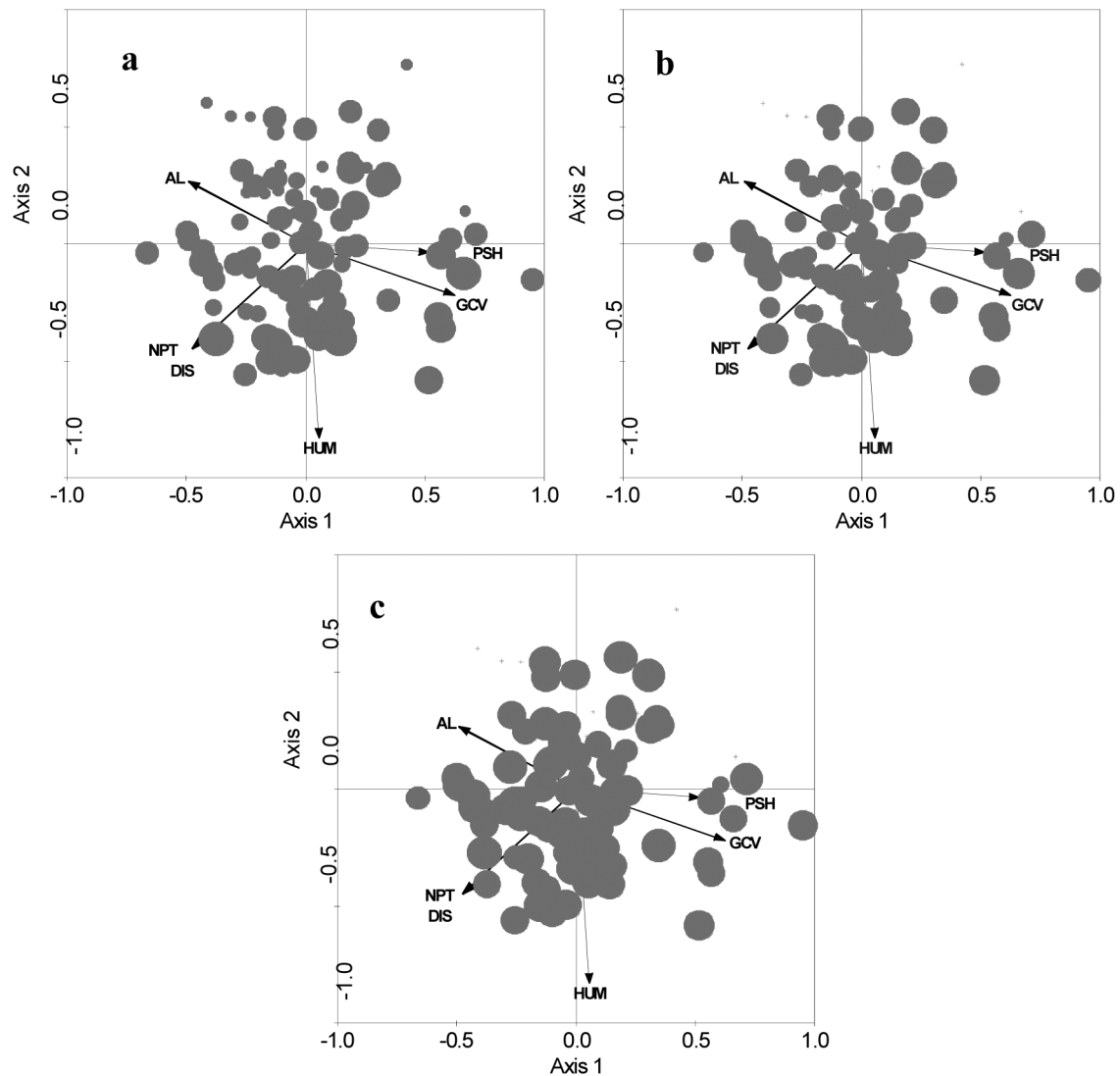


Figure 5 The biplot diagrams with the most important environmental variables and plots, plotted in the RDA ordination diagram (a) Simpson diversity index, (b) Shannon–Wiener diversity index, (c) Simpson evenness index. The size of the symbols corresponds to the magnitude of species diversity indices in individual samples. AL = number of *Agrostistachys longifolia* trees, NPT = number of palm trees, DIS = distance from the forest edge, HUM = humidity, GCV = ground cover, PSH = percentage of shrub cover between 0.5 and 2 m height.

indices than forest edge. The high values of species diversity indices of forest interior were mainly a result of a combination of some habitat variables such as humidity and number of palm trees. The forest understorey birds can decline when their habitat becomes fragmented (Bierregaard & Stouffer 1997, Lens *et al.* 2002). The decline in understorey babbler species has been reported in Costa Rica (Sigel *et al.* 2006), the Amazon Basin (Stratford & Stouffer 1999, Stouffer & Bierregaard 1995a, b) and Panama (Robinson 1999); these findings are consistent with that found for the Ayer Hitam Forest

Reserve in this study. Many rare species such as black-capped babbler, black-throated babbler and white-bellied yuhina were never detected at the forest edge.

In this study, habitat quality along the edge–interior gradient, which was defined as a complex function of the 23 environmental variables that influenced babbler species abundance and diversity (through RDA ordination) was measured. Edge effects for babblers were an indirect response to a cascade of effects that involved environmental variables of the microclimate and microhabitat. In Ayer

Hitam Forest Reserve, the air temperature and light intensity tend to diminish from the forest edge to the interior, while relative humidity tends to increase. These changes in the abiotic environmental factors were found to be consistent with results gathered in other tropical rainforest around the world. For example, Turton and Freiburger (1997) reported that the abiotic changes accrued near the forest edge include reduced humidity availability, increased temperature and more intensity of light compared with the forest interior. According to them, abiotic changes tend to decline from the edge to the forest interior, considering the fact that the gradient of these changes is due to the combination of age and geographic direction of an edge. It was also reported that in the tropical rainforests, abiotic changes could not be detected beyond 15–60 m from the forest edge (Laurance 1997). Moreover, shrub cover, ground cover and the number of *M. malabathricum* shrubs were found to significantly decrease from the forest edge to the forest interior. These pioneer species at the Ayer Hitam Forest Reserve tend to grow better in a habitat with high light intensity and temperature close to the forest edge. The positive effect of the edge on pioneer species was consistent with the findings by Camargo and Kapos (1995), and Williams-Linera (1990). They found that the edge habitat could result in speeding up of succession of some pioneer vegetation. Patterns of some microhabitat variables were also related to proximity to the forest edge. According to RDA ordination, the number of palm trees, leaf litter depth and canopy cover were positively correlated with distance from the forest edge.

The RDA ordination separated three groups of babbler species. The first (edge-avoider) consists of species that occurred more abundantly in the forest interior. These species are known to be especially abundant in the forest interior with high value of humidity, litter depth, canopy cover and number of palm trees. These species have been suggested to be the most adversely affected when their habitats are altered (Varasteh Moradi *et al.* 2008). They are thought to be intolerant to high temperature or high light intensity (Zakaria *et al.* 2002). This shade-preferring group of babblers (Varasteh Moradi *et al.* 2008) tend to occupy the special microhabitat with high humidity, deep leaf litter depth and dense canopy cover. Furthermore, they may avoid the edge as they tend to have narrow diets, narrow ranges

of tolerable environmental conditions and use specialised microhabitats that are not available at the forest edge (Lindell *et al.* 2004). One reason for edge avoidance could be the loss of sheltered understorey habitat in the large sections of the forest edge, which could affect food resources for these birds. Many understorey insectivores are reluctant to enter open habitats (Borges & Stouffer 1999, Develey & Stouffer 2001). It seems that the increased canopy openness close to the edge (Barlow *et al.* 2002, Haugaasen *et al.* 2003) is sufficient to limit the movement and dispersal of this group of birds associated with the forest interior. At the Ayer Hitam Forest Reserve, the affinity of the interior-specialist species to the micro-environment factors conformed to other studies conducted in tropical forests (Johns 1991, Thiollay 1992, Lindell *et al.* 2004).

The second group (edge-tolerant) were positively correlated with ground cover, light intensity, shrub cover, and per cent of shrub cover between 0.5 and 2 m height. This group was negatively correlated with distance from the forest edge. Among foliage-gleaning babblers, some species have been reported to increase in response to the edge and disturbance, such as the tit babblers (Lambert 1992, Fimbel *et al.* 2001). They adapt to the microclimatic changes associated with the disturbance of the forest structure because they forage in the understorey shrubs and trees (Johns 1991). At the forest edge, the understorey vegetation and shrub can grow denser and faster due to fluctuations in the light intensity (close to the gaps), temperature and humidity. Consequently, the edge habitat will provide a suitable feeding substrate for leaf-gleaning babblers. This guild was reported to be dependent on the size of trees (height and diameter) and the degree of human disturbance in its habitat (Arriaga-Weiss *et al.* 2008). The occurrence of foliage-gleaning insectivores was significantly related to the low level of human disturbance and lower height of trees. In fact, shorter trees provide a good feeding substrate for this particular group of birds. They glean and search for insects on the understorey tree leaves. At the same time, their abundance also generally reflects the amount of understorey vegetation and its associated insects as well as the microclimatic conditions (Johns 1991).

The third group (edge-indifferent) showed no significant bias towards or against distance gradient. Proximal explanations for edge-

avoidance vary across system and species (Watson *et al.* 2004). For instance, habitat structure and composition may be different on the edge and microclimatic changes near the edge can make the edge unsuitable for some babbler species. In this study, the edge habitat had significantly ($p < 0.05$) more shrub cover, ground cover, light intensity, temperature, and less litter depth and humidity than the core habitat (Table 3). Therefore, for seven edge-avoider babbler species, it is possible that the cause of their edge-sensitivity be due to a lack of high humidity and deep litter depth at the edge. It should be noted, however, that there was no evidence of an edge effect due to changed forest structure for three edge-indifferent species, as these species did not have their variance explained by habitat variables at either edge or core sites. One reason for this may be the rareness and low detection rate of birds. Another possible reason for this is that they have been found to be influenced by unmeasured resources such as food and other microhabitat factors.

CONCLUSIONS

The results of this study supported the hypotheses that microclimatic and microhabitat factors could affect the composition, abundance, density and diversity of the babblers across an edge–interior gradient. Babblers showed different species-specific responses to edge effects from the viewpoint of abundance, distribution, density, and diversity. The findings indicate that a fair proportion of edge-sensitive babbler species (7 species out of 13) were affected by changes to microhabitat structure. These species reflect the habitat quality of the forest interior and their disappearance may be an indication of habitat degradation within an isolated forest, or a fragmented and isolated forest is not large enough to exclude edge effects. The difficulty in finding fragments with good habitat quality further restricts the distribution of birds exclusive to the interior. This makes the creation of lowland conservation areas even more urgent. Our findings can assist wildlife managers in the selection of forest fragments appropriate for the preservation of bird species. By way of example, maintaining forest microhabitat with a deep leaf litter cover and dense canopy cover can support more babbler species with high sensitivity to the forest edge. From a conservation perspective, it would be argued that the edge-avoider species

should receive the most attention. It is also recommended that conservation strategies be applied to ensure that lowland rainforest remnants have a high area/perimeter ratio (to reduce edge effect) and to limit the destruction and degradation within the core of these larger remnants.

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