SPECIES LEVEL HABITAT ASSOCIATION OF NON-VOLANT SMALL MAMMALS IN FOUR HABITAT TYPES OF CAMERON HIGHLANDS, MALAYSIA

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(Received 24th Jun 2024; accepted 2nd Jun 2025)

Abstract. This study aimed to assess the impact of deforestation on non-volant small mammals in the Cameron Highlands, Malaysia, focusing on four habitat types: restoration areas, boundary, disturbed, and undisturbed forests. Fieldwork was conducted from August 2020 to January 2021, using 80 live traps and 10 camera traps at three study sites: Terla A, Bertam, and Bukit Bujang Forest Reserve. A total of 23 species of non-volant small mammals from six orders and nine families were recorded by live trapping and camera trapping at the three study sites of Terla A, Bertam and Bukit Bujang Forest Reserve. The findings revealed that species diversity (*H'*) was highest at Terla A (*H'* = 2.274), with lower diversity in disturbed and boundary areas. Restoration areas had the lowest species diversity. *Berylmys bowersi* (Bower's Rat) was the most frequently captured species from trappings and *Lariscus insignis* (Three-striped Ground Squirrel) was the most frequently recorded species from camera trappings for all study sites. The Chao-1 species richness estimator showed the boundary area to have the highest species richness (13 species), while the restoration area had the lowest (four species). Additionally, most species preferred areas with 75-95% herbaceous cover and 5-25% grass coverage. A significant correlation was found between vegetation cover and small mammal abundance ($p = 0.03 < 0.05$). These results emphasize the importance of preserving undisturbed forests and regularly monitoring restoration areas to ensure the continued survival of these species. The study highlights the role of habitat composition over diversity, suggesting that habitat changes significantly affect small mammal populations.
Keywords: *forest reserve, inventory, richness, Rodentia, species indicator*

Introduction

Malaysia is one of the biodiversity hotspots in the tropical region of Southeast Asia with a high faunal diversity including small mammals and is ranked 12th in the world as indicated by the National Biodiversity Index (MyBIS, 2015). The diversity of mammals within the Malaysian territory is quite significant with at least 440 species of mammals recorded (DWNP, 2016), of which 15% (66 species) are endemic to Malaysia (Dee et al.,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_86918709

2019). Small mammals are described as any mammals that weigh less than 5 kg (Lim and Pacheco, 2016; Fauzi et al., 2021) are highly diverse and have a range of tolerance to habitat disturbance (Munian et al., 2020).

Small mammals have small sizes which make them difficult to locate. Most of them are active at night (nocturnal) and choose to hide in the ground or the tree during the day (Mohd Taib et al., 2018). Their roles as seed dispersers, pollinators and seed predators are important to help balance the environment (Ruxton and Schaefer, 2012; Zwolak, 2018; Llanos-Guerrero et al., 2024). Moreover, small mammals are important as a food supply to birds, reptiles and other carnivorous mammals (Stephen et al., 2019; Llanos-Guerrero et al., 2024). In other words, they serve as a link between the primary producers and the secondary consumers in the food chain. Therefore, a decrease in the abundance of small mammals will result in the extinction of some species and the local extinction phenomenon.

Cameron Highlands is ecologically and environmentally benefitting to the natural ecosystems. The biodiversity of its forest acts as climate control, green lungs, water catchment, shelters for flora and fauna, home to indigenous people, and defence towards natural disaster (eg: flood). The Forestry Department Peninsular Malaysia has taken an effort to conduct a “Restoration, Rehabilitation, and Reclamation of Degraded Forests (3RSM)” programme under RMK-11. The purpose of this effort was to rehabilitate the destroyed areas and to prevent landslides especially areas with slopes. The restoration programme includes degraded forests in Peninsular Malaysia such as Cameron Highlands, Janda Baik, and Lembangan Sungai Kelantan with the engagement from the schoolchildren, university students, and several corporate bodies (Forestry Department Peninsular Malaysia, 2020).

Numerous researchers have little or no interest in non-protected areas due to the general assumption that anthropogenic activities and the loss of natural habitats influenced the carrying capacity, hence diminishing the biodiversity of affected areas. Consequently, the distribution and diversity of non-volant small mammal species in different habitat types are often overlooked, hindering the understanding of urban species and the potential for new discoveries. The main purpose of this study is to determine species diversity and distribution of non–volant small mammals in different habitats representing restoration or rehabilitated, edge or boundary, disturbed forest and undisturbed forest area.

Materials and method

Study site

Sampling of non-volant small mammals in Cameron Highlands was conducted in two phases of sampling from August 2020 to January 2021. The sampling period included the dry season (August to October) and the wet season (November and February) for Cameron Highlands (Meteorology Department, 2020). According to the Meteorology Department (2020), rainfall is common all year round in Cameron Highlands, although the Northeast monsoon season between November and February contributes to high rainfall which associates with the wet season. Each phase of the study conducted for was five days and four nights for one study site.

This study was conducted in Terla A Forest Reserve (04°35’36.6” N, 101°22’54.7” E) with an elevation of 1300-1500 m (*Fig. 1*). Genus *Casuarina* (Rhu Bukit) dominated the restoration area. The average diameter and plant height in the restoration area were 10 mm

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and 0.90 m respectively. Flowering plants such as genus *Passiflora foetida* (Running pop), wild orchids, *Lagenaria siceraria* (bottle guard) and genus *Nepenthes* (pitcher plant) were seen growing wildly near the hill boundaries. The forest is overgrown with Dipterocarp trees, grasses and herbaceous plants. Minimal human disturbance was observed with the presence of a piping line that provide water source to the agricultural farm nearby. The distance from the restoration area and forest area were approximately 5 m apart.

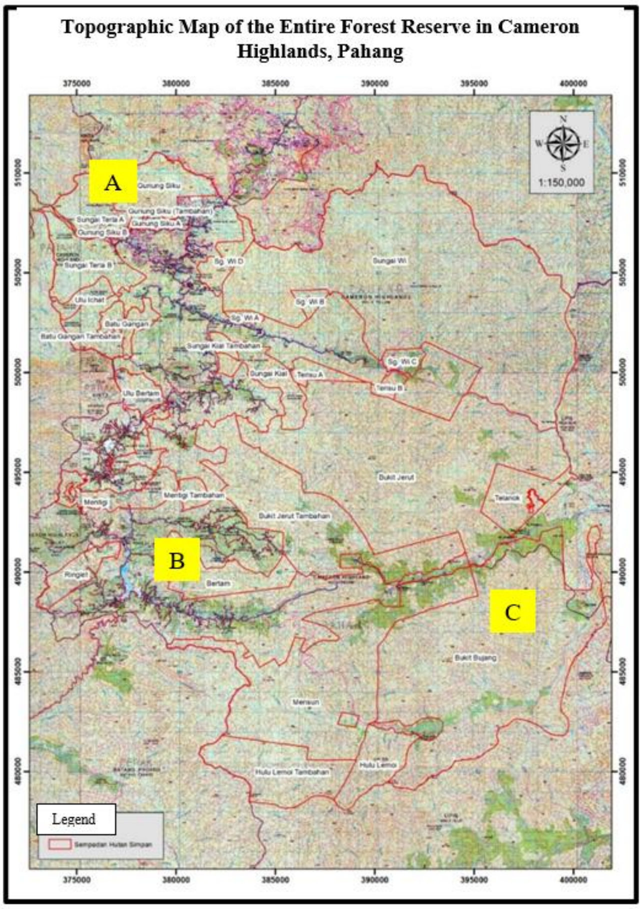

Figure 1. *Location of (A) Terla FR A-1 (04°35’36.6” N, 101°22’54.7” E), (B) Bertam FR (04º25’15.0” N, 101º26’41.4”E) and (C) Bukit Bujang FR (04º24’07.06”N, 101º35’37.28”E) Cameron Highlands, Pahang (Adapted from Forestry Department of Peninsular Malaysia, 2021)*

Bertam Forest Reserve (04º25′ 15.0″ N, 101º26′ 41.4″ E) has an elevation of 1200-1300 m in Cameron Highlands, Pahang (*Fig. 1*). The restoration trees were dominated by genus *Casuarina* (Rhu Bukit). Flowering plants such as, *Morus* (Mulberry tree), *Mentha* (Mint plant) and *Bambusa* (Bamboo tree) were seen growing wildly near the hill boundaries. The average diameter and plant height in the restoration area were 10 mm and 0.90 m respectively. The forest area has a small river as a source of water and is dominated by *Eugeissona* (Bertam) and *Musa balbisiana* (Sweet wild banana).

The study was also conducted at Bukit Bujang Forest Reserve (04º24′ 07.06″ N, 101º35′37.28″ E) (*Fig. 1*) which has an elevation of 400-500 m to compare the state of

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the diversity of non-volant small mammals undisturbed Forest Area. Vegetation for Bukit Bujang Reserve Forest has been dominated by trees of 5-10 m high. Different type of trees such as genus *Eugeissona* (Bertam), genus *Calamus* (Rotan), genus *Licuala* (Palas) and genus *Oncosperma* (Bayas) dominated this forest. This area has sufficient water source from rivers such as the Lemoi River.

Terla A and Bertam Forest Reserved are restoration areas listed under "Restoration, Rehabilitation, and Reclamation (3RSM)" programme in Cameron Highlands. Cameron Highlands is one of the areas affected by floods in 2014. Therefore, Forestry Department of Peninsular Malaysia initiated a restoration programme in the Eleventh Malaysia Plan (2016-2020) with an estimated area of 1640 ha in works. Almost all the undisturbed forests nearby in Cameron Highlands are located at low altitudes (Forestry Department of Peninsular Malaysia, 2020).

Restoration is defined as any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state (Stanturf, 2005). Restoration efforts should be planned at the landscape level with the aim of re-establishing ecological integrity and supporting human well-being (Janishevski et al., 2015). Forest boundaries were defined as the line formed by trees with a diameter of at least 5 cm at breast height (Hoover and Smith, 2020). Then, Esseens et al. (2006) also define boundary is the vertical projection of the crowns is the forest boundary that is relatively easy to determine from aerial photographs or the connecting line between the stems at the forest edge that is easily be done in the field. In forest ecology, disturbances refer to events of tree damage and mortality, which release growing space and resources, and change micro-climate (Kuuluvainen et al., 2021). Undisturbed forest is defined essentially undisturbed in the sense there is no known significant human intervention and where the past human intervention did occur it was such as to have allowed the endemic species and forest processes to be maintained or restored (Mackey et al., 2021).

Sampling method

In this study, two methods were used i.e. live trapping and camera trapping that target the more typical terrestrial non-volant small mammals. Advancements in camera-trapping technology have led to the widespread use of this survey method in the study of terrestrial mammals (Wearn and Glover-Kapfer, 2017; Haysom et al., 2021). The two methods were used for a more comprehensive inventory documentation of species such as using camera traps for the documentation of less trappable species (De Bondi et al., 2010; Thomas et al., 2020).

A distribution of 80 units of wire mesh live traps; 50 units of small traps measuring 25 cm X 11 cm X 12 cm and 30 units of medium traps measuring 81 cm x 38 cm x 25 cm were deployed along the transect line in each study site based on ecological conditions and topography of the surrounding areas. Live traps were also placed on dead logs, semi-open areas that resemble animal trails, near thistle plants and branches of trees (Zakaria et al., 2001; Norfahiah et al., 2012; Munian et al., 2020; Baharudin et al., 2022) to increase trapping success. Traps were arranged at 50 m span points with inter-trap distances of 10 m between each trap. The surface of the traps was covered with forest litter to provide thermal insulation for the captured sample and also acts as camouflage (Rychlik et al., 2012).

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Habitat structures

This habitat structure approach is primarily intended to provide general information for assessing non-volant small mammal's habitat conditions and quality (Bernard, 2004; Munian et al., 2020). According to Munian et al. (2020) an overview of habitat background features for the entire study area and each study area is essential to help clarify the interaction between habitat and small mammal species in all study areas. The suitability of a particular habitat to support wildlife is dependent not only upon the availability of the basic life requirements (food, cover, water, and space), but also upon other qualitative habitat factors Therefore, evaluation of vegetation and other related factors were conducted to answer this question.

Vegetation assessment

Small mammals play diverse roles in ecosystem, as seed and vegetation consumers (Bergstrom, 2013), prey, ecosystem engineers, and promoters of nutrient cy-cling (Happold, 2001), as well as acting as biological indicators (Avenant, 2007; Hurst et al., 2014). There are many biophysical attributes that can be measured as indicators of vegetation condition. It is expected that differences in vegetation characteristics in each area can be demonstrated using only a simple vegetation assessment method, based on vegetation structure (Rochefort et al., 2013). The assessment is divided into two parts:

I. Identify the background of the habitat of Terla A, Bertam and Bukit Bujang Forest Reserved.

II. Identify the habitat background of restoration area, boundary area, disturbed forest area and undisturbed forest area.

According to Bethany et al. (2009) study areas, vegetation plot design and data collection was described in detail. Habitat assessment were sampled along a 50 m long transect for each live trap. Sampling was performed on a selected point area with a radius of 5 m (*Fig. 2*). Selection of a radius of 5 m to fit the live trap area is found to reflect the background of the habitat within the study because, it covers almost part of the overall area of the study site. According to the topographic profiles of each transect, the plots was classified into three habitats: plots of the restoration area, boundary area, and disturbed forest area. The different habitats (the bottom and upper transect sections) were compared based on vegetation and microclimatic parameters during subsequent analyses.

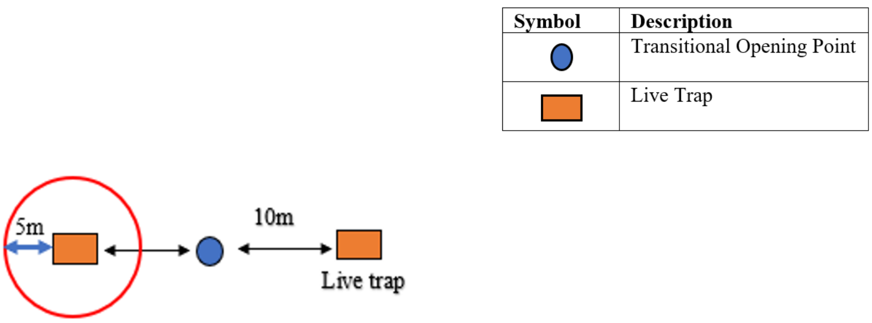

***Figure 2.** Schematic diagram of vegetation assessment was performed on a selected point area with a radius of 5 m*

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Data analysis

The Shannon-Wiener Index (*H'*) measures species diversity by accounting for both the number of species (richness) and how evenly individuals are distributed among them (evenness), providing insights into community structure; higher values indicate more diverse and balanced ecosystems (Lidicker et al., 2011). The Chao-1 estimator complements this by estimating total species richness, including undetected species, which is particularly useful for uncovering the biodiversity potential in under-sampled habitats (Chao and Chiu, 2019). According to Guo et al. (2023), Principal Component Analysis (PCA), a statistical method, simplifies complex species data by identifying patterns of variation, highlighting differences or similarities in species composition across habitats. Together, these tools illuminate how habitats like restoration areas, disturbed forests, and undisturbed forests support biodiversity, offering critical insights into ecosystem health and conservation priorities (Chao et al., 2019).

According to Mishra et al. (2019), One-way ANOVA is a statistical technique extended from an independent t-test to compare the mean for more than three groups of an independent variable. Therefore, One-way ANOVA was used to analyse the influence of different habitats on the number of individuals. Moreover, all the variables are considered as significantly different at $p < 0.05$ (Mishra et al., 2019).

Results

Live trap

Diversity indices and relative abundance for live trap method

A total of 39 individuals of non-volant small mammals were captured using the live trap method (*Table 1*). The restoration areas yielded five (5) individuals, with four (4) recorded in Terla A Forest Reserve and one (1) in Bertam Forest Reserve. In the boundary areas, 11 individuals were recorded, comprising six (6) from Terla A Forest Reserve and five (5) from Bertam Forest Reserve. The disturbed forest areas contributed 12 individuals, evenly split between Terla A and Bertam Forest Reserves.

Species diversity, as measured by the Shannon-Wiener index (*H'*), was highest in the boundary (*H'* = 2.025) and disturbed forest areas (*H'* = 1.992), both recording an equal number of species (*S* = 8) (*Table 2*). In contrast, the restoration area recorded the lowest diversity (*S* = 3, *H'* = 0.950). Evenness values were highest in the undisturbed forest (*E* = 0.930), followed closely by the boundary area (*E* = 0.947). The Chao-1 estimator identified the boundary area as the richest habitat, with 13 estimated species, while the restoration area was the least diverse, with four species.

Habitat selection analysis, using the Morisita Similarity Index, identified two main clusters of habitats (*Fig. 3*). The first cluster grouped the disturbed forest and restoration areas, while the second grouped the boundary and undisturbed habitats. The highest similarity (55.1%) was observed between the boundary and undisturbed habitats, suggesting shared microhabitat features, whereas the disturbed and restoration areas exhibited a similarity of 47.1%.

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Table 1. *Species abundance of non-volant small mammals recorded by using live traps*

Family Species	**Common Name**	**Terla A Forest Reserve**			**Bertam Forest Reserved**			**Bukit Bujang Forest Reserved**	**Relative Abundance (%)**
		Restoration	**Boundary**	**Disturbed Forest**	**Restoration**	**Boundary**	**Disturbed Forest**	**Undisturbed Forest**	
Insectivora									
Hylomys suillus	Short-tailed Gymnure	-	1	-	-	-	-	-	2.56
Muridae									
Berylmys bowersi	Bower's Rat	2	-	1	1	1	2	-	17.95
Leopoldamys sabanus	Long-tailed Giant Rat	-	-	-	-	1	1	2	10.26
Maxomys whiteheadi	Whitehead's Maxomys	-	1	-	-	1	-	3	12.83
Niviventer cameroni	Cameron Highlands Niviventer	-	-	1	-	-	-	-	2.56
Niviventer cremoriventer	Dark-tailed Niviventer	-	-	-	-	-	1	2	7.69
Niviventer fulvescens	Indomalayan Niviventer	-	1	-	-	-	-	-	2.56
Rattus exulans	Pacific Rat	-	1	-	-	-	-	-	2.56
Rattus norvegicus	Norway Rat	-	-	-	-	-	-	1	2.56
Rattus rattus	House Rat	1	-	-	-	-	-	-	2.56
Rattus tiomanicus	Malaysia Wood Rat	1	-	-	-	-	-	-	2.56
Sundamys muelleri	Muller's Rat	-	1	1	-	1	1	2	15.38
Sciuridae									
Callosciurus caniceps	Grey-bellied Squirrel	-	-	1	-	-	-	-	2.56
Dremomys rufigenis	Red-Cheeked Squirrel	-	1	2	-	-	-	-	7.69
Tupaiidae									
Tupaia glis	Common Treeshrew	-	-	-	-	1	-	-	2.56
Viverridae									
Paguma larvata	Masked Palm Civet	-	-	-	-	-	-	1	2.56
Paradoxurus musangus	Common Palm Civet	-	-	-	-	-	1	-	2.56
Total individual recorded		4	6	6	1	5	6	11	

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Table 2. *Species abundance, richness and diversity values estimated for each study habitat by using live trap method*

Study habitat	Taxa (S)	Individuals	Simpson Dominance Index (D)	Shannon (H')	Evenness (E)	Chao -1
Restoration	3	5	0.560	0.950	0.862	4
Boundary	8	10	0.860	2.025	0.947	13
Disturbed Forest	8	13	0.852	1.992	0.916	9.5
Undisturbed Forest	6	11	0.809	1.720	0.931	6.25

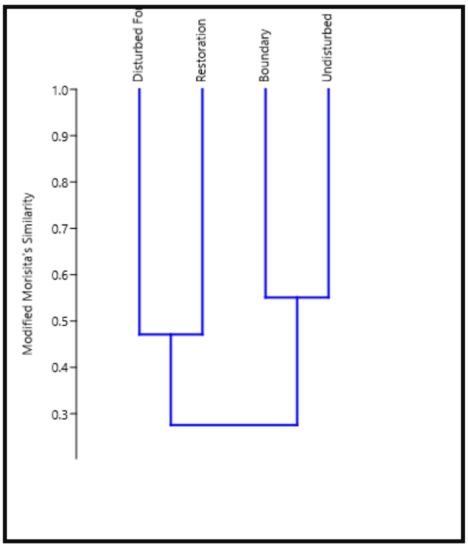

Figure 3. *Cluster analysis dendrogram of non-volant small mammals in all habitat types using the Modified Morisita Similarity Index. Percentage form (Example: 25%); represented as a decimal (i.e. 0.25)*

Vegetation preferences

Live trap vegetation percentage cover (Table 3)

Rarefaction curve

Rarefaction analysis indicated that the species accumulation curves for all habitats did not reach an asymptote, signifying sampling incompleteness (*Fig. 4*). This was most pronounced in the disturbed forest area, which showed a steep curve, suggesting additional species may be discovered with further sampling effort.

The relationship between four habitats and non-volant small mammals' abundance is shown in *Figure 5* from the PCA analyses, the first two PCA axes explained 75.37% of the habitat data variation: 37.935% for the first and 37.436% for the second axis. The results show that the first axis was related to variables that characterize habitat types of restoration and disturbed forest area. Non-volant small mammals that contributed most to this axis were *Dremomys rufigenis* (r = 0.482) and *Berylmys bowersi* (r = 1.599). The second axis was more related to boundary and undisturbed forest area. Non-volant small mammals that contributed most to this axis were *Niviventer cremoriventer* (r = 0.819), *Sundamys muelleri* (r = 2.114) and *Maxomys whiteheadi* (r = 1.440).

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Table 3. *Total individuals recorded by live trap at vegetation covers in the (A) restoration, (B) boundary, (C) disturbed and (D) undisturbed forest area*

(A) Restoration

Species	Ferns (0-5%)	Ferns (5-25%)	Ferns (25-50%)
Berylmys bowersi	1	1	1
Rattus tanezumi	0	1	0
Rattus tiomanicus	1	0	0

(B) Boundary

Species	Ferns (0-5%)	Ferns (50-75%)	Shrubs (0-5%)	Shrub (50-75%)	Shrubs (95-100%)	Herbs (50-75%)	Moss (25-50%)
Maxomys whiteheadi	2	0	0	0	0	0	0
Berylmys bowersi	0	1	0	0	0	0	0
Sundamys muelleri	0	1	0	0	0	1	0
Niviventer fulvescens	1	0	0	0	0	0	0
Rattus exulans	0	0	1	0	0	0	0
Dremomys rufigenis	0	0	0	0	1	0	0
Tupaia glis	0	0	0	1	0	0	0
Hylomys suillus	0	0	0	0	0	0	1

(C) Disturbed Forest

Species	Ferns (5-25%)	Herbs (0-5%)	Ferns (25-50%)	Ferns (95-100%)	Ferns (0-5%)	Ferns (50-75%)
Berylmys bowersi	2	0	1	0	0	0
Sundamys muelleri	0	1	0	0	0	0
Niviventer cameroni	0	0	0	1	0	0
Niviventer cremoriventer	0	0	0	0	1	0
Leopoldamys sabanus	0	0	0	0	0	2
Dremomys rufigenis	0	1	1	0	0	0
Callosciurus canicep	0	0	0	1	0	0
Paradoxurus musangus	0	0	0	0	1	0

(D) Undisturbed Forest

Species	Shrubs (0-5%)	Shrubs (75-95%)	Ferns (0-5%)	Fern (75-95%)	Herbs (0-5%)	Herbs (95-100%)	Leaf litter (5-25%)
Maxomys whiteheadi	0	2	0	1	0	0	0
Sundamys muelleri	0	0	0	0	1	1	0
Niviventer cremoriventer	0	0	0	0	0	1	1
Rattus norvegicus	1	0	0	0	0	0	0
Leopoldamys sabanus	0	0	2	0	0	0	0
Paguma larvata	0	0	0	0	1	0	0

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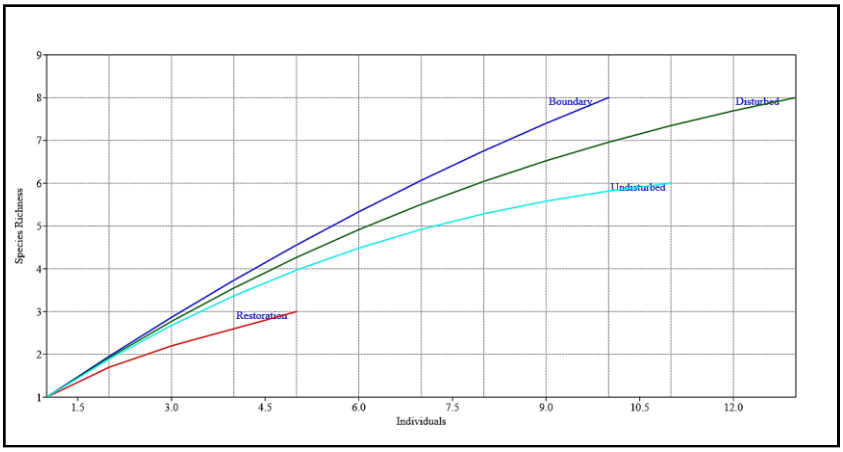

Figure 4. *Individual-based rarefaction curve of non-volant small mammals in four habitats at Terla A-1 FR, Bertam FR and Bukit Bujang FR, Cameron Highlands*

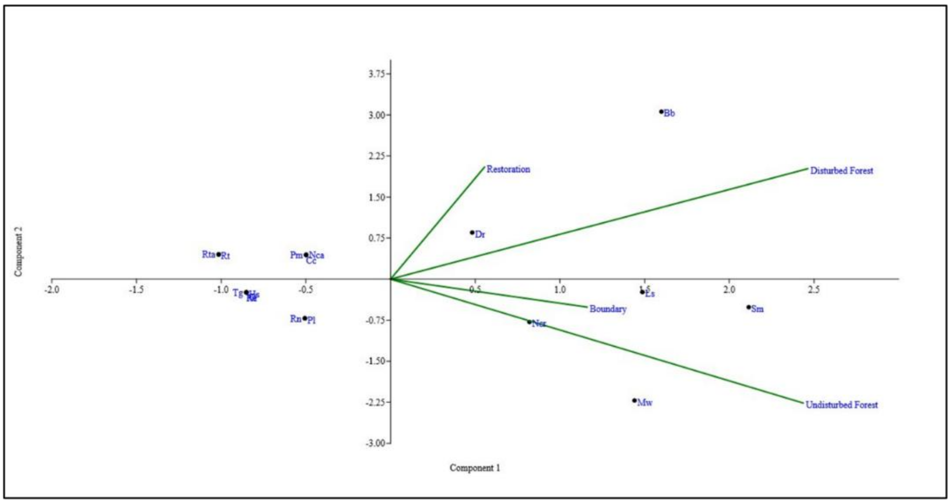

Figure 5. *PCA of different habitat types with non-volant small mammals species*

The analysis shows *B. bowersi* (Bb) was strongly associated with restoration and disturbed forest area. *Dremomys rufigenis* (Dr) was seen positively preferred boundary and disturbed forest area. However, other non-volant small mammals species; *Rattus tanezumi* (Rta), *R. tiomanicus* (Rt), *R. norvegicus* (RN), *Tupaia glis* (Tg), *Hylomys suilus* (Hs), *N. fulvescen* (Nf), *N. cameroni* (NC), *Callosciurus caniceps* (CC) and *Paguma larvata* (PL) does not associate with any habitat types.

Camera trap

Diversity indices and relative abundance for camera trap method

From the 94 positive sighting images, 12 species of non-volant of small mammals have been captured as shown in a summary in *Table 4*. Sixteen images are Three-striped Ground Squirrel (*Lariscus insignis*), 14 *Sciurus* sp. and *Rattus* sp., 12 lesser mouse deer (*Tragulus kanchil*), 10 Grey-bellied Squirrel (*Callosciurus canicep*), eight Crab-eating Mongoose (*Urva urva*) and Long-tailed Giant Rat (*Leopoldamys sabanus*), five Bower's

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Rat (*Berylmys bowersi*), three Common Treehrew (*Tupaia glis*), and one Masked Palm Civet (*Paguma larvata*), Banded Linsang (*Prionodon linsang*), Leopard Cat (*Prionailurus bengalensis*) and Sunda Pangolin (*Manis javanica*).

Table 4. *Species abundance of non-volant small mammals captured by camera traps*

Order	Family	Species	Local Name	Numbers of Photo Captured			N
				Terla A	Bertam	Bukit Bujang	
Rodentia	Muridae	*Rattus* sp.	-	1	12	1	14
		Berylmys bowersi	Bower's Rat	5	-	-	5
		Sundamys muelleri	Muller's Rat	-	-	-	0
		Leopoldamys sabanus	Long-tailed Giant Rat	-	6	2	8
	Sciuridae	*Lariscus insignis*	Three-striped Ground Squirrel	3	4	9	16
		Callosciurus canicep	Grey-bellied Squirrel	9	-	1	10
		Sciurus sp.	-	2	12	-	14
Scandetia	Tupaiidae	*Tupaia glis*	Common Treehrew	-	3	-	3
Carnivora	Viverridae	*Paguma larvata*	Masked Palm Civet	-	1	-	1
		Prionodon linsang	Banded Linsang	-	-	1	1
	Herpestidae	*Urva urva*	Crab-eating Mongoose	-	8	-	8
	Felidae	*Prionailurus bengalensis*	Leopard Cat	1	-	-	1
Artiodactyla	Tragulidae	*Tragulus kanchil*	Lesser Mousedeer	1	0	11	12
Pholidota	Manidae	*Manis javanica*	Sunda Pangolin	-	-	1	1
Total numbers of captured photos				**22**	**46**	**26**	**94**

Bertam Forest Reserve exhibited the highest Shannon-Wiener diversity index (H' = 1.745) and species evenness (E = 0.818), followed by Terla A and Bukit Bujang Forest Reserves (*Table 5*). Vegetation preferences varied by species and site. For example, *Callosciurus caniceps* in Terla A Forest Reserve preferred 0-25% herbaceous cover, while *Tragulus kanchil* in Bukit Bujang Forest Reserve was associated with 5-50% shrub coverage (*Table 6*).

Table 5. *Diversity indices that were recorded on non-volant small mammals at three (3) forest reserves in Terla A FR, Bertam FR and Bukit Bujang FR*

Study habitat	Taxa (S)	Photos Captured (n)	Simpson Dominance Index(D)	Shanon (H')	Evenness (E)	Chao -1
Terla A FR	7	22	0.252	1.614	0.717	8.5
Bertam FR	7	46	0.196	1.745	0.818	7.0
Bukit Bujang FR	7	26	0.311	1.430	0.597	10.0

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Table 6. *Total individuals recorded by camera trap at vegetation covers in the Terla A, Bertam and Bukit Bujang Forest Reserve*

Terla A Forest Reserve

Species	Herbs (0-5%)	Herbs (5-25%)	Shrubs (25-50%)	Shrubs (75-95%)	Shrubs (95-100%)	Ferns (25-50%)	Ferns (50-75%)	Leaf litter (25-50%)
Callosciurus caniceps	3	3	2	0	0	1	0	0
Prionailurus bengalensis	0	0	0	1	0	0	0	0
Lariscus insignis	0	0	0	0	0	0	1	2
Berylmys bowersi	0	0	2	0	0	0	0	0
Tragulus kanchil	0	0	0	0	1	0	0	0
Rattus sp.	0	0	1	0	0	0	0	0
Sciurus sp.	0	2	0	0	0	0	0	0

Bertam Forest Reserve

Species	Herbs (5-25%)	Herbs (25-50%)	Herbs (75-95%)	Ferns (0-5%)	Ferns (5-25%)	Shrubs (0-5%)	Shrubs (5-25%)	Shrubs (25-50%)	Shrubs (50-75%)	Shrubs (75-95%)	Leaf Litter (5-25%)	Bare ground (5-25%)
Rattus sp.	0	0	0	2	0	0	0	0	4	3	0	0
Sciurus sp.	0	3	0	0	0	0	4	2	0	0	0	3
Urva urva	0	0	0	0	0	3	3	0	0	0	2	0
Paguma larvata	0	0	1	0	0	0	0	0	0	0	0	0
Tupaia glis	3	0	0	0	0	0	0	0	0	0	0	0
Lariscus insignis	0	0	0	0	1	0	0	0	0	0	2	1
Leopoldamys sabanus	1	0	0	1	1	0	0	1	0	0	0	0

Bukit Bujang Forest Reserve

Species	Herbs (0-5%)	Ferns (0-5%)	Shrubs (5-25%)	Herbs (5-25%)	Shrubs (25-50%)	Ferns (25-50%)	Shrubs (50-75%)	Shrubs (75-95%)	Herbs (95-100%)
Rattus sp.	0	0	0	0	0	1	0	0	0
Lariscus insignis	0	4	3	2	0	0	0	0	0
Manis javanica	0	0	0	0	0	0	0	1	0
Leopoldamys sabanus	0	0	0	0	0	0	2	0	0
Prionodon linsang	1	0	0	0	0	0	0	0	0
Callosciurus canicep	0	0	0	0	0	0	0	0	1
Tragulus kanchil	0	0	1	0	1	0	0	0	0

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Bertam Forest Reserve exhibited the highest Shannon-Wiener diversity index (*H'* = 1.745) and species evenness (*E* = 0.818), followed by Terla A and Bukit Bujang Forest Reserves (*Table 5*).

Camera trap vegetation percentage cover

Vegetation preferences varied by species and site. For example, *Callosciurus caniceps* in Terla A Forest Reserve preferred 0-25% herbaceous cover, while *Tragulus kanchil* in Bukit Bujang Forest Reserve was associated with 5-50% shrub coverage (*Table 6*).

Discussion

This study highlights the critical role of habitat structure and diversity in shaping the distribution and abundance of non-volant small mammals. Restoration areas, characterized by limited canopy cover and vegetation complexity, recorded the lowest species diversity. This can be attributed to the lack of essential resources such as food and shelter, a finding consistent with previous studies by Yaap et al. (2010) and Zakaria et al. (2001), which emphasized the significance of habitat complexity for mammalian diversity.

The highest diversity observed in boundary habitats mirrors findings by Yaap et al. (2010) and Zakaria et al. (2001), who reported that transitional habitats serve as biodiversity hotspots, supporting species from both disturbed and undisturbed areas. The low diversity in restoration areas reflects the limited canopy cover and resource availability, as noted in studies on early successional habitats (Cusack et al., 2014; Munian et al., 2020). Interestingly, while altitude and vegetation type have long been known to shape small mammal communities (Butler, 2019), this study further elucidates the microhabitat preferences of key species, such as the association of *Berylmys bowersi* with fern-dominated areas and *Tupaia glis* with herbaceous cover, confirming ecological adaptations reported by Lee et al. (2019) and Thaweepworadej and Evans (2022). Additionally, the overlap in species composition between boundary and undisturbed forests highlights habitat connectivity's importance, as similarly observed by Hayes and Castillo (2017). Unlike many earlier studies focusing primarily on protected areas, this work underscores the conservation value of non-protected fragmented habitats, contributing novel insights into their ecological significance and the need for targeted management strategies to support small mammal biodiversity.

The lack of a clear association between habitat type and rodent diversity observed in this study is intriguing and highlights the complex dynamics shaping small mammal communities in fragmented ecosystems. Traditional ecological theory often predicts that habitat diversity drives species diversity, with more complex habitats supporting a broader range of niches and thus higher biodiversity (MacArthur and MacArthur, 1961). However, the results challenge this expectation, suggesting that factors other than habitat type, such as interspecies interactions, resource availability, and disturbance regimes, may play more dominant roles in shaping rodent diversity.

This finding contrasts with studies like those of Munian et al. (2020), which demonstrated significant habitat-specific diversity patterns in tropical forests. It also diverges from the predictions of the intermediate disturbance hypothesis, which suggests that moderately disturbed habitats (e.g., boundaries) should show the highest diversity due to a mix of disturbance-tolerant and specialist species. Instead, the data here indicate that while individual species exhibit clear preferences for specific microhabitats (e.g.,

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Berylmys bowersi favoring ferns), the overall rodent community remains relatively stable across habitats in terms of diversity.

The findings underscore the importance of preserving a mosaic of habitat types, not just for maintaining diversity but also for supporting ecological processes that benefit the broader ecosystem. They also emphasize the need for more targeted research into the specific ecological roles and interactions of rodent species within fragmented landscapes to better inform conservation strategies.

Boundary areas demonstrated the highest diversity and richness, likely due to their transitional nature, allowing species from both disturbed and undisturbed habitats to coexist. The Shannon-Wiener diversity index and evenness values further underscore the ecological importance of boundary habitats as biodiversity hotspots.

Environmental factors, such as altitude and vegetation types, significantly influenced species distribution. Cold temperatures and limited food availability at higher altitudes may have contributed to lower diversity, as noted by Butler (2019). Additionally, human disturbances were shown to affect species distribution, corroborating findings by Mulungu et al. (2008).

Sampling constraints, including the COVID-19 pandemic and adverse weather conditions, restricted the duration of fieldwork, leading to incomplete species accumulation curves. Achieving sampling completeness would require extended surveys and broader spatial coverage, as suggested by Gotelli and Colwell (2001). Despite these limitations, the findings provide valuable insights into the biodiversity of small mammals in the Cameron Highlands.

Vegetation structure played a pivotal role in habitat preference. Species such as *Berylmys bowersi* and *Sundamys muelleri* exhibited specific preferences for vegetation types, including ferns and herbaceous plants, which provide critical resources. For example, *Hylomys suillus* favored mossy habitats, as also observed by Lee et al. (2019), highlighting the ecological significance of such microhabitats. Similarly, *Niviventer cremoriventer* and *Tupaia glis* displayed distinct preferences for fern and herbaceous cover, reflecting their ecological adaptations and resource requirements.

In the restoration habitat (*Table 3(A)*), three (3) species; *Berylmys bowersi*, *Rattus tanezumi* and *R. tiomanicus* tend to choose 5-25% of fern coverage. There is no individual species in restoration area with any coverage of 50-100%, this is possible because, in the restoration site, the trees considerably not high to provide a canopy shade to the ground.

In the boundary habitat (*Table 3(B)*), *Sundamys muellerri* tend to choose 50-75% of herbaceous and fern coverage. *Maxomys whiteheadi* tended to select 0-5% of fern coverage in boundary area which may be related to its behavioural adaptation where showed significant preference to disturbed microhabitats (Cusack et al., 2014). This study also recorded that *Hylomys suilus* selected 25-50% of moss, was supported by a study by Lee et al. (2019) where this species inhabits a habitat with moss that potentially provides the habitat of the gymnure is now restricted to the moss forests covering the rocks near the boundary, and the gymnure is more widespread at lower altitudes. In the mountains where the gymnure does not occur, *H. suitlus* may live both in lower and higher montane rainforests. A habitat with 50-75% of herbaceous coverage was preferred by *Tupaia glis*. This may explain *T. glis* was considered as an insectivore and although invertebrates were the main animal component, small vertebrates may also be taken into account (Selig et al., 2019). Generally, beetles (Carabidae) and centipedes were found near the area. Sulaiman et al. (2016) found that 90 percent of the diet of *T. glis* consisted of insects and another 10 percent are fruits.

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In disturbed forest area (*Table 3(C)*), the association of *Berylmys bowersi* with 5-50% of ferns, showed lower habitat specificity and were found both in forested areas and in crops area. Four species; *Sundamys muelleri*, *Niviventer cremoriventer*, *Dremomys rufigenis* and *Paradoxurus musangus* tended to select 0-5% of ferns and herbaceous coverage may be related due to their preferences for settlements and agricultural environments (McFarlane et al., 2012). A habitat with 95-100% of herbaceous and ferns coverage were preferred by *N. cameroni*, *D. rufigenis* and *Callosciurus caniceps* may explained these species differ in their response to habitat fragmentation in terms of presence/absence or abundance (Thaweepworadej and Evans, 2022).

While in undisturbed forest area (*Table 3(D)*), four (4) species were trapped; *Sundamys muelleri*, *Rattus norvegicus*, *Leopoldamys sabanus* and *Paguma larvata* with 0-5% of shrub, herbaceous and ferns coverage. Only one (1) individual of *Niviventer cremoriventer* were caught on leaf litter with 5-25% may explained *N. cremoriventer* used both habitats intensively, and most of the species recorded in the canopy were also trapped on the ground (Wells et al., 2004). This study also recorded three (3) individuals of *Maxomys whiteheadi* at 75-95% of shrubs and ferns coverage. This may be related that their main habitat is primary and secondary forests, although they are occasionally found in rice fields, gardens or tree plantations, especially those adjacent to forests (Nakagawa et al., 2007).

Non-volant small mammals, such as rodents and shrews, are the most common and widespread species that play a significant role in many ecosystems worldwide, including tropical rainforests. These mammals can influence tree recruitment through selective foraging on seeds and seedlings (Zwolak et al., 2018).

Habitat selection analysis revealed two distinct clusters, with higher microhabitat sharing observed between boundary and undisturbed habitats. This finding is supported by Hayes and Castillo (2017), who noted that habitat overlaps exceeding 54% indicate competitive interactions.

Finally, the rarefaction analysis highlighted sampling limitations but also suggested the potential for additional species discoveries, particularly in disturbed forest areas. Prolonged and more intensive sampling efforts are recommended for future studies to capture a more comprehensive representation of non-volant small mammals in tropical forest ecosystems.

Conclusion

Twenty-three non-volant small mammals species were recorded in this study. Overall, Terla A Forest Reserved recorded the highest diversity of non-volant small mammals with 14 species. Although the restoration habitat differed greatly from the boundary, disturbed and undisturbed forest area in terms of species richness, it still appears to have an important role in providing habitat for highly adaptable species. Therefore, it is crucial for the authorities to manage these non-protected areas properly as they continue to function as an ecosystem.

The environmental parameters are shown to have affected the abundance and species richness at restoration, boundary, undisturbed and disturbed forest habitat. From the study, it was revealed that non-volant small mammals preferred particular microhabitat in an area. As such, especially in a restoration area, non-volant small mammals were highly dependent fern and herbaceous coverage. Meanwhile, the non-volant small mammals were abundantly recorded in 75-95% of herbaceous coverage in all habitats.

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The results of this study show that habitat fragmentation does not impact the overall species richness of non-volant small mammals in the habitats investigated, but that each species responds differently to the habitat structure. Interestingly, our results show no association between habitat and rodent species diversity at the level of habitats, rather indicating that the changes in the composition of habitats.

Acknowledgements. We would like to thank the Forestry Department Peninsular Malaysia, Pahang State Forestry Department and Forestry Department Cameron Highlands District Office for granting permission to conduct the research and for the assistance provided during the data collection. We also thank all our friends and colleagues who were involved in this research. This research was funded by the Forestry Department Peninsular Malaysia's research grant for the Research and Development for Restoration, Rehabilitation and Reclaimation of Degraded Forests in Peninsular Malaysia (3RSM) (UPM Research Vot No. 6300880). Our research permits on the non-volant small mammals were approved by the Department of Wildlife and National Park (DWNP) JPHL&TN (IP):100-34/1.24 JId 16 (22).

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DOI: http://dx.doi.org/10.15666/aeer/2305_86918709