Bat diversity in two lowland forests of Brunei Darussalam

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Abstract

The forests of Brunei Darussalam harbour rich bat assemblages. In this study we update current knowledge of the abundance and distribution of bats in Brunei by comparing bat diversity between two lowland forest sites: Temburong and Tasek Merimbun. We recorded 27 bat species with three new locality records for each of the two sites surveyed. Temburong had higher bat diversity than Tasek Merimbun, suggesting that it has more diverse habitat types. This study highlights the need for further bat surveys as full inventories of bat communities have not yet been reached and little is known about the ecology and conservation status of bat populations.

Index Terms: Chiroptera; Conservation; Range extension; Tasek Merimbun; Temburong

1. Introduction

Bats have their highest diversity in the tropics where more than 60 species can be found at a single locality.[1,2] Bat populations have recently been declining due to factors such as global climate change, habitat disturbance, water pollution, environmental toxins, overhunting, and the spread of diseases.[3]

Bats play key roles in many ecosystems as pollinators, seed dispersers, and insect eaters. They are the primary pollinator for important agricultural plants such as bananas, durian, and mango.[4] Currently, approximately 250 genera of plants are known to rely on bats for pollination.[5] In addition, they play a role in restoring rainforests that have been cleared or damaged due to forest fires by dispersing the pollen or seeds.[6] They also provide many ecosystem services[7], for example by controlling insect pests on farmland.[8]

Bats can be used as bio-indicators to assess the health of an ecosystem because they are relatively easy to identify and most species have been described.[3] In addition, they are widely distributed and the effects of short and long-term forest disturbance on their populations can be monitored with relative ease.

The tropical rainforests of Brunei Darussalam have high levels of biodiversity and endemism.[9] Struebig et al.[10,11] reported 36 bat species from eight families surveyed at seven Bruneian study sites. The communities were dominated by forest-insectivorous species, including *Kerivoula papillosa*, *K. minuta* and *K. intermedia*. The highest number of species was found in Temburong and Andulau. By contrast, Merimbun had the fewest species.

In this study, bat diversity was resampled in two forests: Ulu Temburong National Park, Temburong and Tasek Merimbun Heritage Park, Tutong as part of a long-term monitoring program.

The objective of this study was to re-assess bat species richness and abundance in two lowland mixed-dipterocarp rainforests in Brunei separated

by only 50 km. However, long-term studies are needed to provide full inventories of bat communities and information on conservation status, rarity, threats and population trends of bat populations.

Based on previous surveys by Streubig et al.[10], we hypothesised that bat diversity would be higher in the never-logged Ulu Temburong forest because of the higher mosaic of microhabitats there. Furthermore, we hypothesised that that the composition of bat species differs between the two sites depending on the foraging strategies/roosting ecology of the affected species Finally, we expected to find additional bat species at these two sites as bat inventories in the tropics are notoriously incomplete.

2. Experimental approach

Bat diversity was sampled in two forests in Brunei Darussalam: Ulu Temburong National Park (N 4° 31', E 115° 08') and Tasek Merimbun Heritage Park (N 4° 34', E 114° 38'). Sampling in Temburong was done behind the Kuala Belalong Field Studies Centre, specifically along the Ashton trail. No logging activity has taken place in this forest. Sampling in Tasek Merimbun took place in the C2 sector of the forest, which has been subject to selective logging.

Both Ulu Temburong and Tasek Merimbun are categorised as mixed-dipterocarp rainforests. However, their forest structure is significantly different, leading Anderson & Marsden[12] to place them in two different subcategories (***Figure 1***). The sampling area in Ulu Temburong has dense, uneven canopy that is primarily made up of large crowns. By contrast, Tasek Merimbun has an uneven or moderately open canopy, with some medium and large emergents. Tasek Merimbun is also surrounded by padang forest and land under urban and industrial use.

Bat surveys in Temburong were caried out in 2015 during four periods: 8-21 March, 13-26 May, 8-12 July, and 20-23 September. Sampling in Tasek Merimbun was conducted from 2-12 October 2015. Bats were captured and collected in the early morning from 6-7am, and at night between 7-10pm.

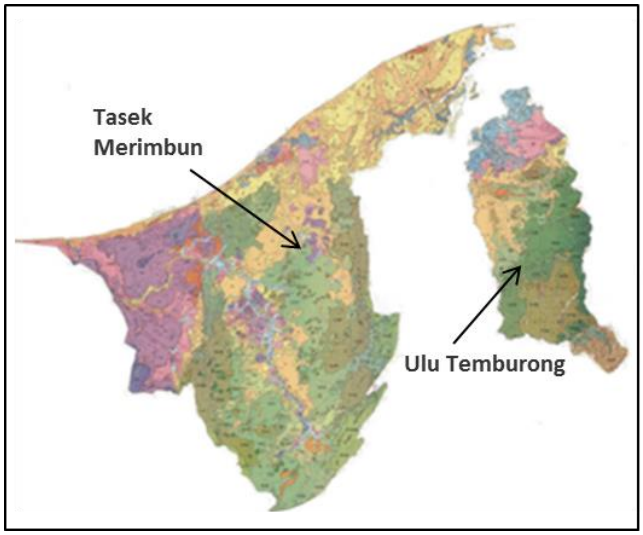

Figure 1. Forest map of Brunei Darussalam modified from Anderson & Marsden[11]. Different forest types are coded by colour: shades of green for mixed-dipterocarp forest, orange for Kerangas, purple for peat swamp, blue for mangrove or fresh water swamp, yellow for secondary forest, and ochre for urban or cleared land.

Bats were captured using harp traps placed perpendicular to established forest trails, preferably with overhanging tree branches to increase the probability of the bats being captured. This method was chosen because many bat species use established trails to move between roost sites and foraging sites. Harp traps were chosen over mist nets as they have been shown to be more effective in catching bats.[10,13,14] In addition, they cause less distress to the bats and need to be checked less frequently[14]. Bats fly against the strings and fall into cloth bags attached beneath the trap where they can be collected easily and without harming the animals.

Between 2-4 traps were moved between sites on forest trails each day to increase trapping efficacy for species that might be spatially limited to staying nearby a certain resource and to prevent capture rate from decreasing due to bats learning to avoid traps.[13] Bags were only attached to the aluminum frame of the trap in the late afternoon to prevent bats or non-target species from being trapped in the daytime. The traps were checked

twice a day, at 6-9 am and 7-10 pm. Each day, the traps were transferred approximately 50-150 m along the trail from the previous location.

Captured bats were processed and identified *in situ* according to unpublished keys by Matthew J. Streubig based on Payne and Francis.[15] As a precaution to protect against bites lightweight leather gloves were used while handling the bats.

Forearm length was measured using calipers to help identify the bat species.[16] Other measurements such as the length of tibia, tail, ear and tragus were also taken. Body mass was measured using a Pesola spring balance and the gender and reproductive condition was noted.

Catch rates were calculated by determining the mean number of bats captured per trap night. We controlled for recaptures by punching a small hole into the wing membrane of each captured bat. A trap night was defined as a single trap/night. We used the open access statistical software R with Vegan package and Fossil package to analyse the data. The Fossil package was used to calculate Simpson's index, abundance based estimators (Chao 1 and abundance based coverage (ACE)), Morisita-Horn index and the rarefied species accumulation curves.

The rarefaction method was used to standardise the sampling effort, since the sample size in Temburong was higher than in Tasek Merimbun. We used the Simpson's index to compare the diversity of the two study sites since it is less sensitive to small sample sizes than the Shannon-Wiener index.

The Simpson's index was calculated by measuring the probability that two individuals randomly selected from a sample belonged to the same species. Therefore, when the value is higher, diversity is lower.[17] Simpsons's measure of evenness was used to determine assemblage evenness. A high value means even species abundance regardless of the number of species.[9]

We also calculated the abundance-based estimators Chao 1 and the abundance-based coverage estimator (ACE). Chao 1 estimates the total number of species present in a community based on the number of rare classes. ACE uses abundance data sets to estimate the total number of species.

Chi-square tests were conducted to test for significant differences in foraging strategy and roosting ecology of bats among the two sample sites. Yates' correction was applied to roosting ecology to improve the accuracy of the test since it only has one degree of freedom.

The Morisita-Horn index was used to determine beta diversity, i.e. the spatial turnover of bat communities in the landscape.[18]

3. Results and Discussion

A total of 27 species were identified from both study sites. From 81 trap nights and a total of 189 individuals, 144 individuals belonging to 24 species were caught in Temburong. Another, 45 individuals of 18 species were caught in Tasek Merimbun over 35 nights (***Table 1***). Catch rates in Temburong were similar to those in Tasek Merimbun. However, the total number of species was higher in Temburong.

Table 1. Number of trap nights, number of bats captured, catch rates, and total number of species for both Ulu Temburong (UTNP) and Tasek Merimbun (TMHP) study sites

Site	Trap nights	Number of bats captured	Catch rate	Species richness
UTNP	81	144	1.78	24
TMHP	35	45	1.28	18

Members of the subfamily Kervoulinae and the family Hipposideridae were commonly found in both Temburong and Tasek Merimbun (***Figure 2***). The most abundant species at both sites, *Kerivoula papillosa*, accounted for 25.7% and 17.8% of all individuals captured in Temburong and Tasek Merimbun, respectively. Other dominant species from Temburong were *Hipposideros ater, Kerivoula lenis and Kerivoula minuta.* In Tasek Merimbun, *Hipposideros ridleyi* was the second most dominant species.

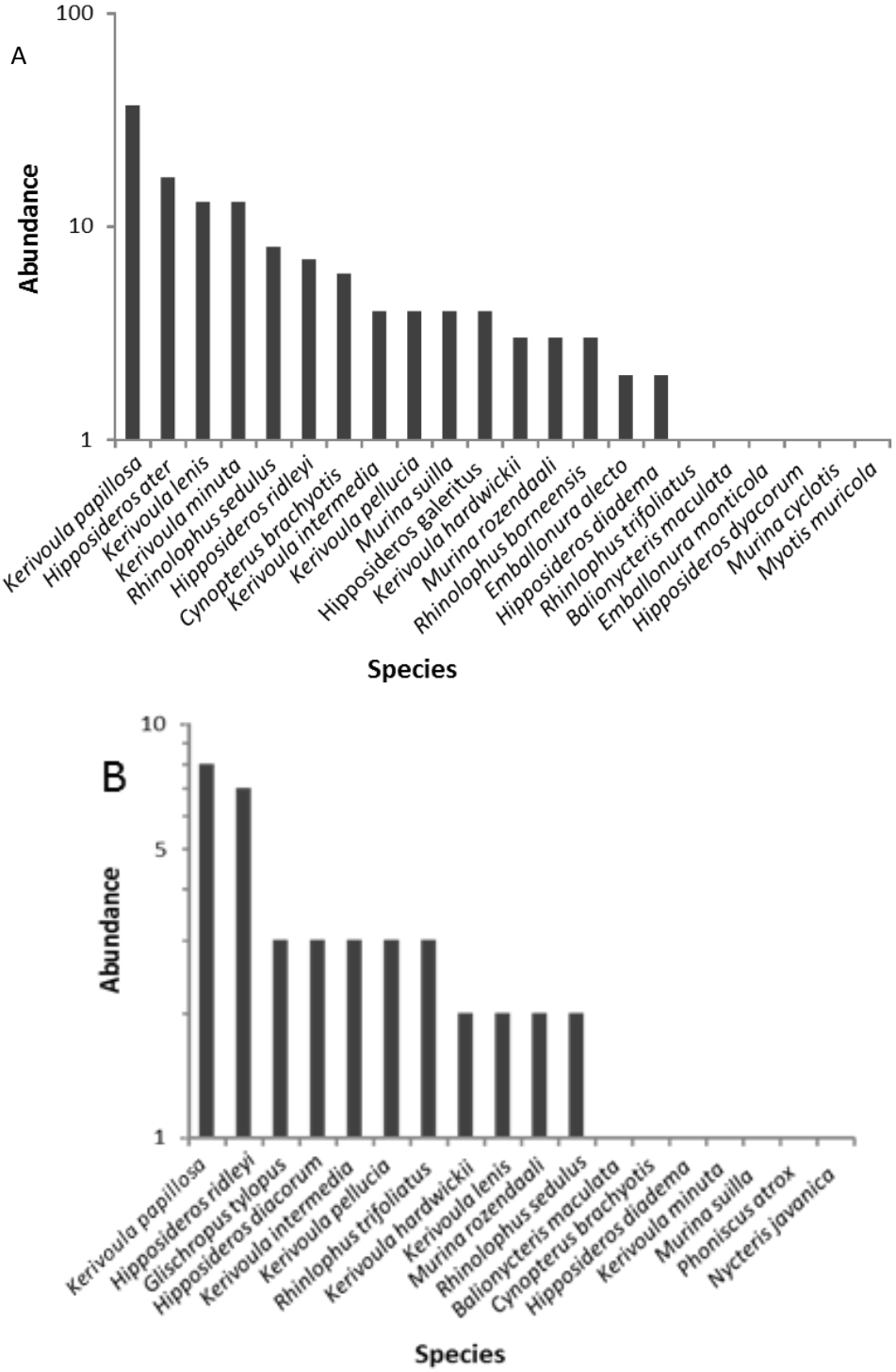

Figure 2. Rank abundance (log-scaled) of bat species found in Temburong (A) and Tasek Merimbun (B).

Six apparently rare species (singletons) sighted in Temburong were *Balionycteris maculata, Emballonura monticola, Hipposideros dyacorum, Macroglossus minimus, Murina cyclotis and Myotis muricola*. Three species were new records for Ulu Temburong National Park: *Cynopterus brachyotis, Hipposideros galeritus,* and *Murina rozendaali.* In Tasek Merimbun, seven species were found only once: *Balionycteris maculata, Cynopterus brachyotis, Hipposideros diadema, Kerivoula minuta, Murina suilla, Phoniscus atrox and Nycteris javanica*. Of particular interest were *G. tylopus, M. rozendaali* and *P. atrox* as they

were not recorded as being present at Tasek Merimbun in a previous survey by Struebig et al.[10]

The species accumulation curves suggest that sampling was far from complete (***Figure 3***). The diversity estimators Chao 1 and ACE suggest that the true number of species would be between 26-30 and 21-24 species in Temburong and Tasek Merimbun, respectively (***Figure 3***). The Chao 1 index indicated a greater number of bat species predicted than the actual number of species obtained.

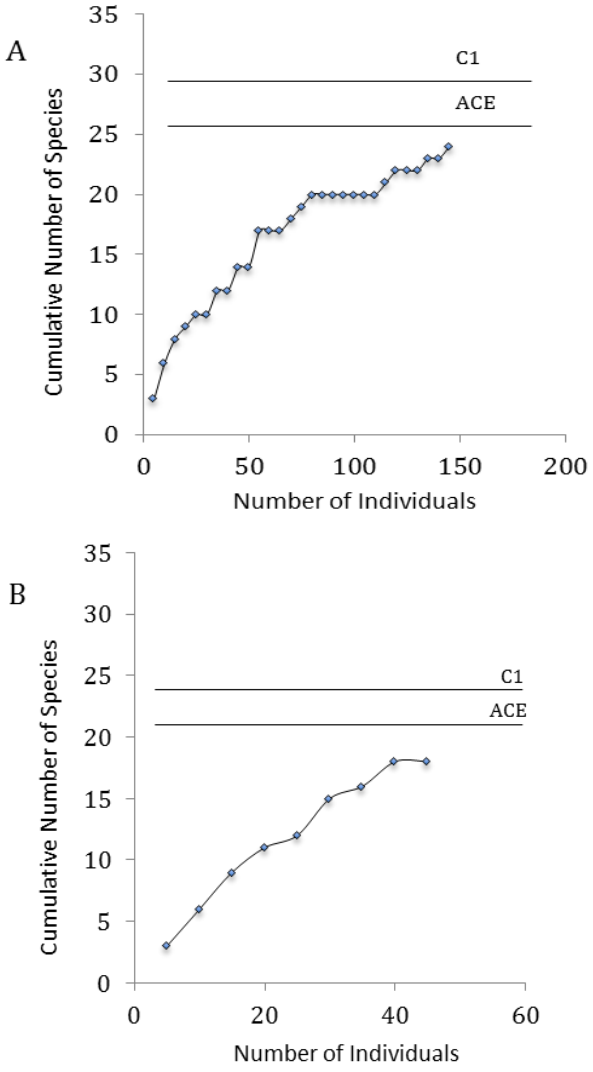

Figure 3. Species accumulation curves of bats species found in Temburong (A) and Tasek Merimbun (B). The straight lines above the curve indicate the diversity estimators C1 = Chao 1 & ACE = the abundance-based coverage estimator.

The species accumulation curve derived from sample-based rarefaction shows that Tasek Merimbun had higher species richness than Temburong (***Figure 4***). The rarefied values for Temburong and Tasek Merimbun, with the sample size standardised to 45 individuals, were 16 and 18 species, respectively. However, since the rarefaction curve for the Tasek Merimbun assemblage falls within the 95% confidence interval of the Temburong assemblage, species richness between the two sites was not significantly different.[19]

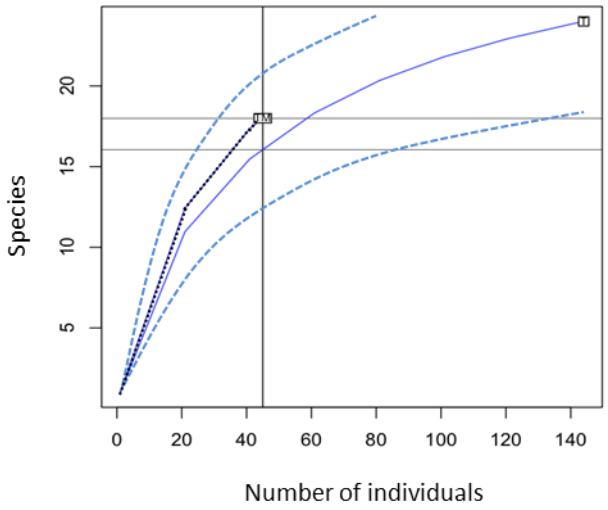

Figure 4. Sample-based rarefied species accumulation curve for Temburong and Tasek Merimbun. At 45 individuals species counts were 16 and 18 in Temburong (grey) and Tasek Merimbun (dotted black), respectively. Dashed grey lines are the 95% confidence intervals for Temburong.

The Simpson's index indicated that there might be higher bat diversity in Temburong (***Table 2***). Furthermore, Simpson's measures of evenness ($E_{1/D}$) were: 0.07 for Temburong and 0.06 for Tasek Merimbun. Thus, both of the sites had a similar degree of evenness.

Table 2. Simpson's index (D) and Simpson's measure of evenness ($E_{1/D}$) for Temburong (UTNP) and Tasek Merimbun (TMHP)

Site	D	$E_{1/D}$
UTNP	0.89	0.07
TMHP	0.91	0.06

The Morisita-Horn index was 0.704 suggesting that the two communities were quite dissimilar in composition. Insectivorous bats dominated the assemblage, with Kervoulinae and Hipposideridae being the most abundant taxa in both study sites.

Most of the bats in both study sites typically forage in narrow spaces or clutter inside the forest (Ni) (***Figure 5***)[2]. There were no frugivorous or insectivorous bats that forage in open areas and over large distances (Of and Oi) in either study site. There was no significant difference in the foraging strategy of bats between Temburong and Tasek Merimbun ($\chi^2 = 3.1841$; df = 2; p = 0.204).

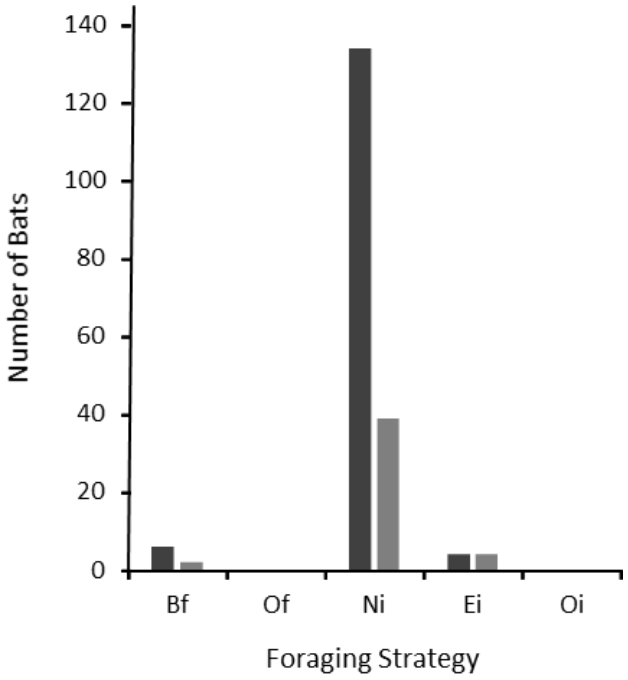

Figure 5. Foraging strategy of bats based on wing morphology captured in Temburong (black bars) and Tasek Merimbun (grey bars) following Streubig et al.[12]. Bf, frugivorous or nectarivorous species that forage in clutter within the forest; Of, frugivorous or nectarivorous species that forage in open areas over large distances; Ni, forest-interior insectivorous species that typically forage in narrow spaces; Ei, insectivorous species that forage in clutter within the forest; Oi, insectivorous species that forage in open areas and over large distances.

Most individual bats (81%) found at the two study sites are known to predominantly roost in trees, hollows or other foliage. The remainder were classified as roosting in caves or under boulders. There was a significant difference in roosting ecology between the two sites with Temburong having proportionally more cave/boulder-dwelling bats than Tasek Merimbun ($\chi^2 = 4.9586$; df = 1; p = 0.026).

A total of 27 bat species were recorded from the two study sites. We recorded three new records for each of the two sites Ulu Temburong and Tasek Merimbun, bringing the total number of bat species recorded from this and previous studies for these localities to 42 and 28, respectively.[10] The Brunei bat list contains 64 species out of 93 known to occur on Borneo.[10,11,20,21]

Our study, although small in scale and with unequal sampling effort between sites, indicates that the coastal, nutrient-poor forest at Merimbun has a more depauperate bat fauna than Ulu Temburong.[10] Although the rarefied species estimates at a sample size of 45 were not significantly different for the two forests, the species accumulation curve for Tasek Merimbun is likely to level off much faster than in Temburong as shown in the more extensive study by Struebig et al.[10] Clearly, a larger sampling effort for Tasek Merimbun would be most revealing.

Both sites had similar bat diversity as indicated by the Simpson's index. Likewise, Simpson's measure of evenness showed that both sites had similar evenness. However, unequal distributions of species among subfamilies and families in the two communities translated into a relatively low Morisita-Horn value suggesting that the two bat communities were dissimilar in composition.

This study has shown that Temburong and Tasek Merimbun have dissimilar bat assemblages. Although both are lowland mixed-dipterocarp rainforests, they are of different subtypes, with Temburong having much higher canopy than Tasek Merimbun.[12] In addition, the sites in Merimbun have experienced selective logging and are in close proximity to major economic activities such as rice and rubber plantations.[22] Fukuda et al.[23] observed low bat diversity in disturbed forests on Borneo. Moreover, canopy height and

tree-cavity availability, both of which are associated with minimally-disturbed old-growth forests, were recently identified as predictors of interior-forest bat assemblage composition.[24]

About 96% of the bats sampled in Temburong and Tasek Merimbun were insectivorous. Struebig et al.[10] also recorded mostly insectivorous bats (27 out of 35 species) across six sites in Brunei using harp traps set along forest interior trails. Frugivorous bats tend to move seasonally to disturbed habitat to find food[25] and are often found in higher numbers in disturbed forests.[26] The abundance of frugivorous bats was higher in Tasek Merimbun, suggesting a greater availability of flowering and fruiting plants; possibly locally-cultivated ones such as *Durio spp*.[22]

The woolly bat, *K. papillosa*, was the dominant species in both study sites, suggesting that both forests experience only low levels of disturbance.[10] *K. papillosa* is a forest specialist that can inhabit primary forests of different altitudes.[27] They also prefer to roost in hollows of small standing trees less than 20m in height.[28] They are dependent on the forest, restricting their range to forest-interior areas near their roosts.[29] Habitat disturbances such as logging are a threat to *Kerivoula*, and to other forest-specialist species. This sensitivity, combined with their relative abundance, makes *K. papillosa* a useful indicator of forest disturbance.[30]

Our study was biased towards capturing forest-interior insectivorous bats within the families/sub-families Hipposideridae, Kervoulinae, and Murininae as they are more susceptible to capture in harp traps than other species.[2] Genera such as *Tylonycteris*, *Hesperoptenus*, and *Pipistrellus* are not well represented in bat surveys that use harp traps because they forage around edges, above forest canopies, and open spaces.[10] A comprehensive survey of bat communities would thus require the use of multiple trap types such as mist nets, harp traps, and canopy nets as well as bioacoustic methods.

Some of the vulnerable and near threatened species listed by the IUCN[31] were captured in relatively high numbers, such as *Murina rozendaali, Hipposideros ridleyi, Rhinolophus sedulus, Kerivoula intermedia, K. minuta* and *K. pellucida*, suggesting that the forests surveyed are highly suitable for these species and thus should be protected.

This study also informs on the turnover of diversity across the landscape or beta diversity. Struebig et al.[10] found low bat landscape-level beta diversity across a spatial scale of 500km in northwestern Borneo. Low beta diversity, due to homogeneity of bat species across sites, indicates that biogeographical processes are likely to be irrelevant in shaping community structure at this scale. The distinct differences in community composition between Temburong and Tasek Merimbun, indicated in this study, however, suggests that bat communities across northwestern Borneo might be less homogeneous than previously thought. Less well studied forest types such as peatswamp forests or heath forests are likely to contain specialised forest-interior species, such as *Murina rozendaali* that may play key ecological roles in these habitats.

The availability and type of roosting sites can influence bat community composition and structure.[26] The difference in species composition between sites is commonly driven by the presence or absence of cave-roosting species. A higher proportion of cave-roosting bats (Hipposideridae and Rhinolophidae) were found in Temburong than in Tasek Merimbun. This is probably due to the higher availability of boulders in Temburong under which bats can roost in a cave-like manner[9].

Out of the 27 species recorded in this study, the majority were insectivorous bats that forage in the forest interior. These species were described by Kingston et al.[2] as intolerant to habitat disturbance. Frugivorous bats were not well represented in this study because they mostly forage at canopy level and shift their activity patterns in response to tree fruiting and flowering.[25,32]

The presence of six apparently rare species in Temburong and seven apparently rare species in

Tasek Merimbun shows that these sites should receive high conservation priority. Further research on bat roosting sites, foraging behaviour, and diets should be conducted to better understand bat abundance and distribution. Moreover, multiple sites across the landscape need protection to ensure that not only high biodiversity sites are protected but also areas with complementary fauna.

4. Conclusion

Our survey adds new records of bats to two rainforest sites in Brunei (Temburong and Tasek Merimbun) and shows high and complementary diversity. This leads us to the conclusion that both sites are of significant conservation value. Differences in bat community composition are likely to be driven by variation in canopy height and tree-cavity availability.

Acknowledgements

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