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Research Article

Bat (Mammalia: Chiroptera) Diversity of the Taliwas River Conservation Area, Lahad Datu, Sabah

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ABSTRACT

Understanding species diversity and distribution is essential for informing conservation strategies, particularly in lesser-explored forest habitats. This study provides the first species checklist of bats in the Taliwas River Conservation Area (TRCA), a forest reserve adjacent to the Danum Valley Conservation Area (DVCA) in Sabah, Malaysia. A four-night bat survey was conducted from June 8–11, 2022, using mist nets and harp traps placed along three forest interior trails. A total of 16 bat species comprising 61 individuals were recorded across four families: Pteropodidae (4 spp.), Rhinolophidae (6 spp.), Hipposideridae (3 spp.), and Vespertilionidae (3 spp.). The insectivorous *Hipposideros* cf. *saevus* (formerly *Hipposideros ater*) was the most frequently captured species (21 individuals), while *Pteropus vampyrus* (n = 4) was visually observed feeding on *Octomeles sumatrana* (Binuang) nectar near the main camp. Two species of high conservation concern were recorded: the Endangered *P. vampyrus* and the Vulnerable *Hipposideros ridleyi*. The detection of multiple forest-interior species, including individuals showing reproductive signs, suggests that the TRCA provides suitable habitat for both foraging and roosting. These results highlight the conservation relevance of the TRCA as a complementary area to the broader DVCA landscape. Future studies incorporating long-term monitoring, acoustic detection, and habitat quality comparisons between protected and adjacent modified landscapes are recommended to inform site-based conservation management.

Keywords: Bat assemblage; forest understorey; harp trapping; species richness; Southeast Asian biodiversity.

INTRODUCTION

As the second largest order, Chiroptera includes diverse species with significant importance especially in the forest ecosystem (Simmons & Cirranello, 2018; Soliman & Emam, 2022). Bats are one of the more extensively dispersed taxa, and they occupy a wide range of feeding niches in forests, including their interiors, edges, and open areas above or outside of the forest (Soliman & Emam, 2022; Law et al., 2015). The bat assemblages are influenced by different factors: roost site availability, the presence of suitable foraging habitats, and food supply (Froidevaux et al., 2021; Kaňuch & Krištín, 2005). In Borneo, bat assemblages are facing structural changes as the result of habitat degradation (Furey et al., 2010). Most forest specialist bats are in threat of extinction as the effect of forest fragmentation (Struebig et al., 2008, 2011) and land conversion (Phommexay et al., 2011). Therefore, bat assemblages are well-suited to serve as bioindicators for forest landscapes in the Paleotropics and Borneo, where they are structured over a forested landscape. Many species of bats combine a variety of traits that enable them to provide essential ecological services, particularly in tropical habitats, such as pollination, seed dispersal, and arthropod population control (Ramírez-Fráncel et al., 2021, Aziz et al., 2021).

Nearly a third of Sabah's overall forest cover and a comparable percentage of the commercially permitted (Class II) forest reserves are contained inside the Yayasan Sabah Forest Management Area (YSFMA) (Reynolds et al., 2011). The YSFMA also involves substantial and quickly growing plantation interests as well as numerous massive forest restoration initiatives (Reynolds et al., 2011). Three of Southeast Asia's largest and most significant protected primary forests, the Danum Valley Conservation Area (DVCA), Maliau Basin Conservation Area (MBCA), and Imbak Canyon Conservation Area (ICCA), are included in the YSFMA (Reynolds et al., 2011; Conservation & Environmental Management - Yayasan Sabah Group, 2022). The DVCA and MBCA remnants were not the only remaining areas of primary forest; very little of the YSFMA had been logged more than once by the end of the 1990s (Reynolds et al., 2011). These important conservation areas are part of the Heart of Borneo and provide significant landscape for conservation, supporting megadiversity, and important ecological processes (Sloan et al., 2019).

The bat assemblages within the YSFMA have not yet been fully uncovered. Given that the YSFMA still contains substantial portions of primary forest and old-growth secondary forest bordered by other landscapes like oil palm plantations (Conservation & Environmental Management - Yayasan Sabah Group, 2022), these places could potentially host a variety of bat species as well as new species discoveries. Bat checklists were recorded in the ICCA (Bunya et al., 2012, Bansa et al., 2020, Senawi et al., 2020), the MBCA (Shukor et al., 2010; Mahyudin et al., 2010; Turner, 2011; Hemprich-Bennett et al., 2021) and the DVCA (Struebig et al., 2008; Roslan, 2018; Hemprich-Bennett et al., 2021), where the latter includes the Taliwas River Conservation Area (TRCA), Silam Coast Conservation Area (SCCA) and INFAPRO (Conservation & Environmental Management - Yayasan Sabah Group, 2022). The checklist of bats is still far from complete for DVCA, especially in the TRCA. Therefore, this study aims (1) to document a bat species checklist within the TRCA, Sabah; (2) to assess the composition and diversity of bat assemblages in the TRCA as baseline data for monitoring impacts of habitat degradation and fragmentation; and (3) to evaluate the conservation value of the TRCA by identifying species associated with primary forest habitats and highlighting priorities for future conservation and management efforts.

METHODOLOGY

Study area

The Taliwas River Conservation Area (TRCA) 4° 59′ 32.72″ N 118° 4′ 16.06″ E is located about 36 km from Lahad Datu town, 24 km to the west of Silam and about 45 km east of the Danum Valley Conservation Area (DVCA) (Taliwas River Conservation Area, 2022). This area is approximately 29.5 km away from the DVCA Field Centre. About 9,546 hectares of lowland forest are covered by TRCA, with some areas having been treated with agroforestry techniques and silvicultural treatments through girdling and enrichment planting by the Sabah Forestry Department from 1970 to 1980 (Taliwas River Conservation Area, 2022). The TRCA was then elevated to a Class 1 (Protection) Forest Reserve in 2012 (Taliwas River Conservation Area, 2022). These areas are rich in dipterocarps and the oldest silvicultural forest that was designed for research, teaching, training, and ecotourism (Taliwas River Conservation Area, 2022).

Field methods

A bat survey was conducted in the TRCA from June 8th to 11th, 2022, covering three sites, namely the Vanilla Trail (VT), the Gading Trail (GT), and the Arboretum Trail (AT) (Fig. 1).

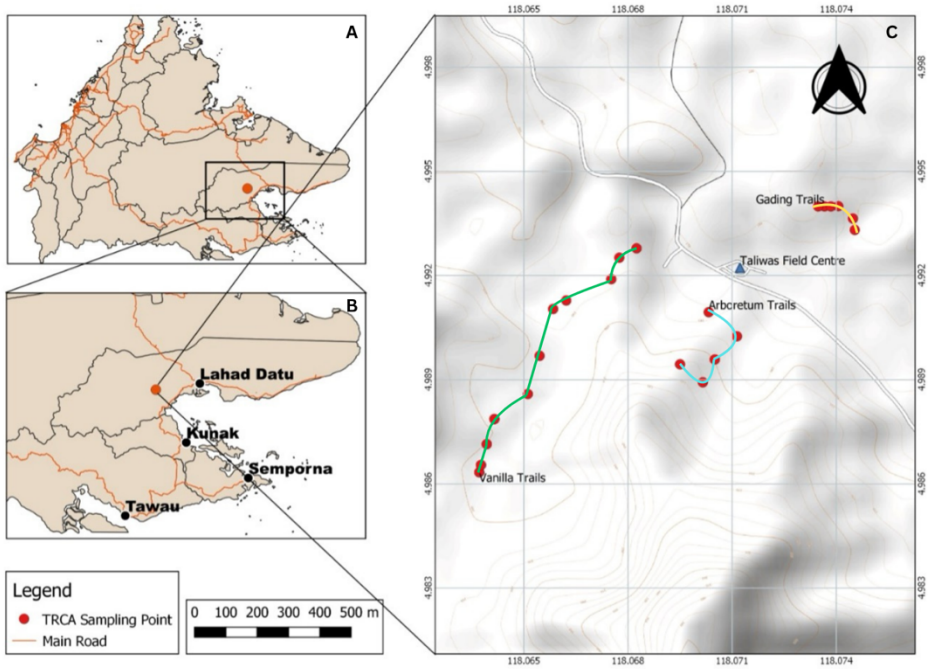

Figure 1: A. Map of Sabah, Malaysia in the northern region of Borneo. **B.** The location of the Taliwas River Conservation Area, in Lahad Datu, Sabah. **C.** Sampling locations indicate the trapping points in the Taliwas River Conservation Area, which includes 3 trails: the Vanilla Trail (green), Gading Trail (yellow), and Arboretum Trail (blue).

Four trapping nights were used to conduct the survey utilising 10 conventional mist-nets (13–15 mm) and three sets of four-bank harp traps (5×6 ft, lined with 0.18 mm/6 lb string and 10 mm gap between the line) (Kunz & Kurta, 1988; Francis, 1989). The nets and traps were set up along the routes, in the narrow pathways of the forest understorey, and across small streams. This deployment was designed to catch the forest understorey bats. Both nets and traps were checked frequently (every 15–30 minutes) from 1900 hrs and 2200 hrs and finally at 0600 hrs

(Kingston et al., 2003). The total survey effort was 208 trap hours (mist nets: 10 × 4 hours/night × 4 nights = 160 net-hours; harp trap – 3 × 4 hours/night × 4 nights = 48 trap hours).

Bat identification, samples processing and preservation

Captured bats were held in individual cloth bags and identified following Payne & Francis (1985) and Phillips & Phillips (2016) and taxonomic nomenclature following Simmons & Cirranello (2018). Their maturity was determined by the amount of diaphyseal fusion on the third, fourth and fifth metacarpals (Kunz & Anthony, 1982). For all individuals, sex is identified by the presence of a prominent penis for males, and the nipples on both sides for females. Three individuals per species were taken as voucher specimens. The standard morphological measurements were taken, namely, the forearm (FA), ears (E), tibia length (TB), hind foot (HF), head body (HB) and tail to ventral (TVL) by using a digital calliper (Mitutoyo) and weighed by using a spring balance (Pesola) (Hall et al*.,* 2004). The bats were photographed for identification records and future reference and released within 12 hours.

Selected bats individuals were euthanised by using isopropene in accordance to approval by the Animal Ethics Committee, UMS (AEC-0005/2020). Liver and muscle tissue were minced and preserved into lysis buffer for further molecular work (Longmire et al., 1997). The whole specimen was preserved in 70% ethanol as voucher specimens and deposited in the BORNEENSIS Wet Collection of the Institute for Tropical Biology and Conservations, UMS.

Species composition and diversity of bat assemblages

Species abundance matrix (species × site) was compiled, and the following diversity indices were calculated using the vegan package in R (Oksanen et al., 2022): species richness (S), Shannon diversity index (H'), Simpson's diversity index (D) and Evenness (J'). Higher values for H' indicate greater species diversity and evenness (Shannon, 1948); value closer to 1 in D indicate higher diversity while close to 0 indicates dominance by a few species (Simpson, 1949); while value close to 1 in J' indicates even species distribution while otherwise indicates dominance (Pielou, 1966).

Sampling completeness was evaluated using species accumulation curves (`specaccum( )` from the vegan package) and individual-based rarefaction curves (iNEXT package; Hsieh et al., 2016) to determine whether sampling effort was adequate for characterizing species richness. Principal Coordinates Analysis (PCoA) was performed based on the Bray-Curtis dissimilarity matric to visualise community composition. Ordination was conducted using `cmdscale( )` and species scores were overlaid using `wascores( )` to display species associations with particular sites. This method was chosen due to its effectiveness in handling abundant data and visualising similarities in community structure (Cisneros et al., 2015; Struebig et al., 2008). The closer two sites or species in the plot, the more similar their species assemblages are.

Species conservation statuses and ecology

The IUCN Red List status of each recorded species was obtained from the online database (International Union for Conservation of Nature, 2025). Species were categorised as Least Concern (LC), Near Threatened (NT), Vulnerable (VU), or Endangered (EN). The number of species within each category was summarised and visualised using a bar chart. Species accounts are provided for species with NT, VU and EN statuses, and the three most abundant species with the following information: Family name, species, relevant remarks, general body measurements (forearm length in mm) and a short note on each species occurrence and ecology. Foraging strategy of each species was also included to reflect species ecological role based on

their echolocation calls as published in previous studies (Kingston et al., 1999; Delaval & Charles-Dominique, 2006; Sedlock, 2001).

RESULTS

A total of 65 bat individuals representing 16 species were recorded through traps or observation from the TRCA. These were represented by four families namely, Pteropodidae (three genera, four species), Hipposideridae (one genus, three species), Rhinolophidae (one genus, six species), and Vespertilionidae (one genus, three species). From the survey, *Hipposideros* cf. *saevus* (formerly *Hipposideros ater*) recorded the highest relative abundance with 21 individuals (32.3%), followed by *Rhinolophus trifoliatus* with nine individuals (13.8%), and *Cynopterus minutus* with eight individuals (12.3%) (Table 1, Fig. 2 and Fig. 3).

Less than five individuals were recorded for the rest, namely *Pteropus vampyrus* (the only species recorded through observation) and *Rhinolophus sedulus* with four individuals (6.2%) each; and four species with two individuals (3.1%) each, namely *Macroglossus minimus*, *Rhinolophus acuminatus*, *Rhinolophus borneensis*, and *Rhinolophus creaghi*. Five species were recorded as singletons (1.5%), namely *Cynopterus brachyotis*, *Hipposideros ridleyi, Kerivoula intermedia, Kerivoula lenis,* and *Kerivoula papillosa*.

Table 1: List of bat species, conservation status, relative abundance and foraging strategy of bats recorded based on four nights bat surveys at the Taliwas River Conservation Area. The three most abundant bat species are highlighted in bold. Bat species with important and critical conservation status based on the IUCN Red List are marked with an asterisk (*).

Family	Species	Common name	Relative abundance (%)	Conservation status (IUCN Red list)	References (IUCN)	Foraging strategy
Pteropodidae	*Cynopterus brachyotis*	Lesser short-nosed fruit bat	1.5	LC	Csorba et al., 2019	Uf
	Cynopterus minutus	Minute fruit bat	12.3	LC	Ruedas & Suyanto, 2019	Uf
	Macroglossus minimus	Long-tongued nectar bat	3.1	LC	Waldien et al., 2021	Uf
	Pteropus vampyrus	Large flying fox	6.2	EN*	Mildenstein et al., 2022	Cf
Hipposideridae	***Hipposideros* cf. *saevus*** **(**formerly *Hipposideros ater*)	Dusky leaf-nosed bat	32.3	LC	Armstrong, 2021	Ni
	Hipposideros diadema	Diadem Leaf-nosed Bat	4.6	LC	Aguilar & Waldien, 2021	Ni
	Hipposideros ridleyi	Ridley's Leaf-nosed Bat	1.5	VU*	Khan et al., 2020	Ni
Rhinolophidae	*Rhinolophus acuminatus*	Acuminate Horseshoe Bat	3.1	LC	Thong et al., 2019	Ni

	Rhinolophus borneensis	Bornean Horseshoe Bat	3.1	LC	Jayaraj, 2020	Ni
	Rhinolophus creaghi	Creagh's Horseshoe Bat	3.1	LC	Jayaraj, 2020	Ni
	Rhinolophus luctus	Greater Wooly Horseshoe Bat	4.6	LC	Thong et al., 2019	Ni
	Rhinolophus sedulus	Lesser Wooly Horseshoe Bat	6.2	NT*	Jayaraj, 2020	Ni
	Rhinolophus trifoliatus	*Trefoil Horseshoe Bat*	13.8	NT*	Huang, 2020	Ni
Vespertilionidae	*Kerivoula intermedia*	Small Woolly Bat	1.5	NT*	Nor Zalipah, 2020	Ni
	Kerivoula lenis	Lenis Woolly Bat	1.5	LC	Srinivasulu & Srinivasulu, 2019	Ni
	Kerivoula papillosa	Papillose Woolly Bat	1.5	LC	Hutson & Kingston, 2021	Ni
	Total number of individuals		11			
	Total number of families		4			
	Total number of species		16			

*na-Data not available;
[a]LC=Least Concern, NT=Near Threatened, VU=Vulnerable, EN = Endangered;
[b]Cf- Canopy frugivore; Uf – understorey frugivore; Ni – narrow-space insectivore

Diversity indices indicated a moderately high species richness and evenness (H'=2.45) with high diversity and no single species being overly dominant (1-D = 0.89; E = 0.88) (Table 2). The species accumulation graph for four nights of survey at three sites showed increasing number of species accumulated throughout the trapping nights and did not reach asymptote (Fig. 4). Rarefaction curves showed that the Vanilla Trail (sampling night = 1) has the highest species richness or better sampling efficiency, while the Arboretum Trail (sampling night = 2) and the Gading Trail (sampling night = 1) each showed moderate and low species richness, respectively. It also indicates incomplete sampling for all trails.

Table 2: Diversity indices of bat species in the Taliwas River Conservation Area indicates high taxonomic diversity and well-distributed community without single species dominance.

Metric	Value
Species Richness	16.0000000
Shannon Index (H')	2.4534145
Simpson Index (1-D)	0.8906250
Evenness (E)	0.8848822

Figure 2: Chiroptera species recorded from the Taliwas River Conservation Area. Family Pteropodidae **A.** *Cynopterus brachyotis.* **B.** *Macroglossus minimus;* Family Hipposideridae. **C.** *Hipposideros diadema.* **D.** *Hipposideros ridleyi.* **E.** *Hipposideros ater (Hipposideros* cf. *saevus);* Family Rhinolophidae **F.** *Rhinolophus borneensis,* **G.** *Rhinolophus creaghi.* **H.** *Rhinolophus acuminatus.* **I.** *Rhinolophus luctus.* **J.** *Rhinolophus trifoliatus;* and Family Vespertilionidae **K.** *Kerivoula papillosa.* **L.** *Kerivoula lenis.*

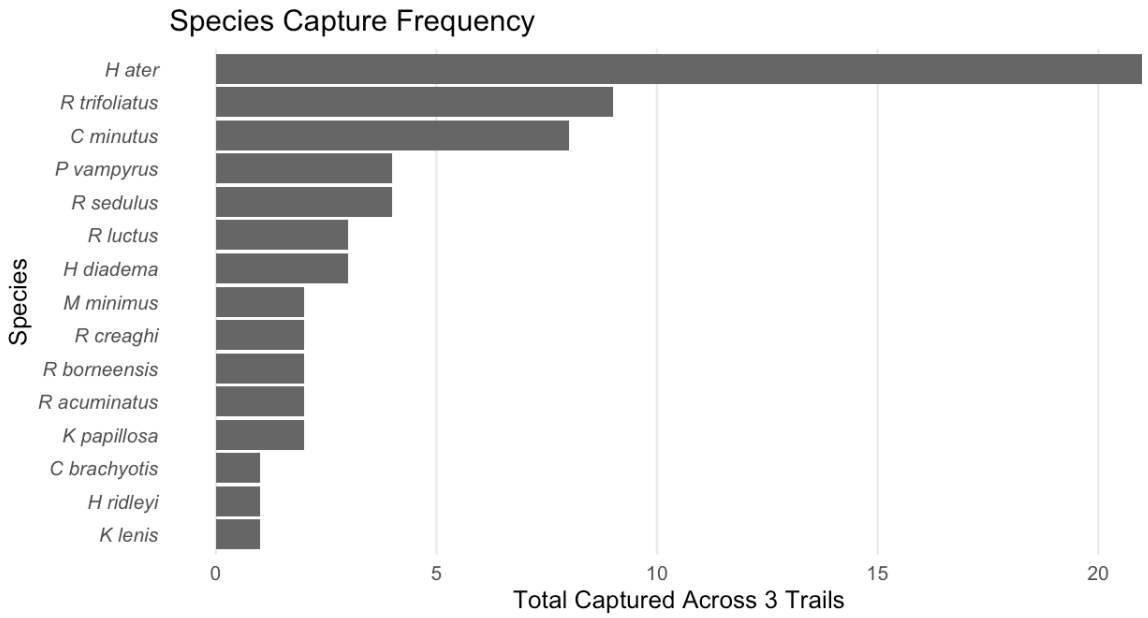

Figure 3: Species capture frequency recorded during the surveys across the 3 trails in the Taliwas River Conservation Area, with more common species recorded on the top, and rarer towards the bottom.

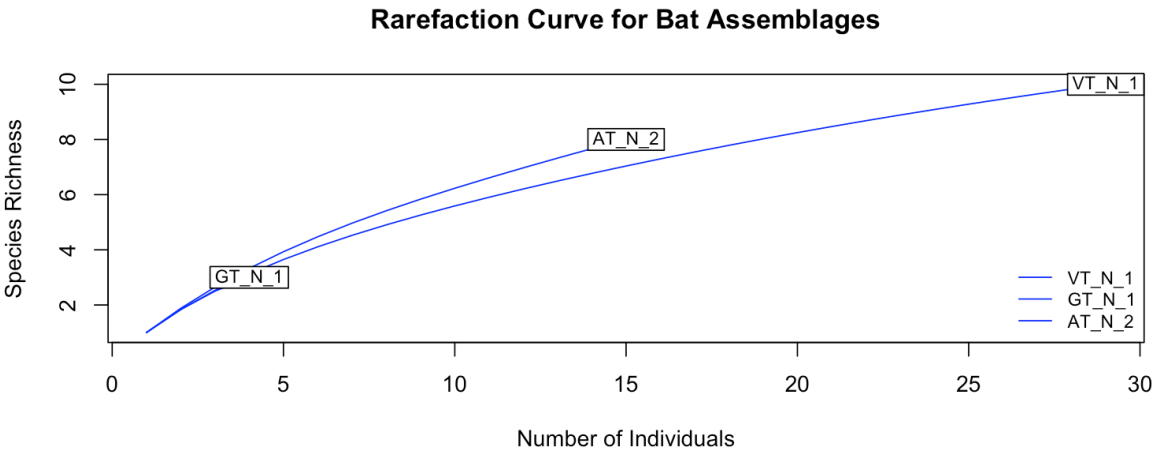

Figure 4: Rarefaction curve for bat assemblages in the Taliwas River Conservation Area showed the still rising curve indicating incomplete sampling from the area. Vanilla Trail (VT_N_1) showed the highest species richness (sampling night = 1), followed by Arboretum Trail (AT_N_2) (sampling night = 2) and Gading Trail (GT_N_1) (sampling night = 1) with moderate and lowest species richness, respectively.

The PCoA plot indicated a homogenous bat assemblage across all sites, with the Arboretum Trail (AT) and the Vanilla Trail (VT) showing close species clustering in ordination spaces, suggesting species such as *R. luctus, R. trifoliatus, R. borneensis* was more frequently captured or consistently present in both trails (Fig. 5). The Gading Trail was slightly separated with minor variation in species, such as *M. minimus* and *R. sedulus,* that is indicative of less widespread or site-specific occurrence across the sites.

According to the IUCN Red List, this survey identified five bat species of conservation concern, namely the large flying fox*, P. vampyrus* (Pteropodidae), listed as Endangered (EN),

and the Ridley's leaf-nosed bat, *H. ridleyi* (Hipposideridae), listed as Vulnerable (VU) (Fig. 6). *Rhinolophus sedulus*, *R. trifoliatus*, (Rhinolophidae) and *K. intermedia* (Vespertilionidae) are three of the known species that are designated as Near Threatened (NT), and 11 other species are listed as Least Concern (LC) (Fig. 6).

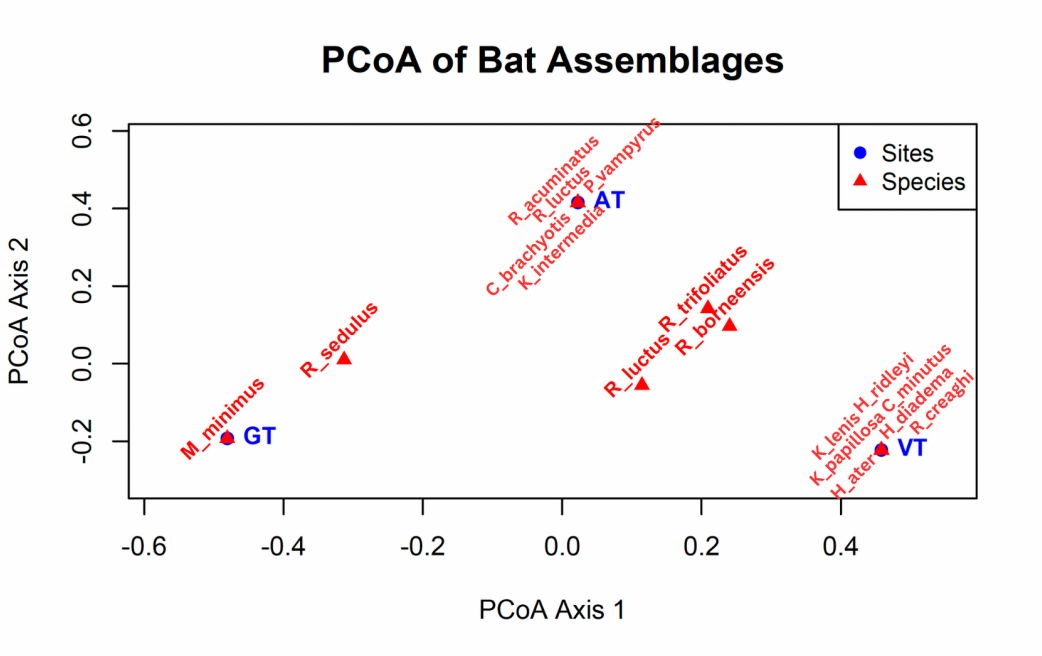

Figure 5: Principle Coordinates Analysis plot showing the community composition of bats in the Taliwas River Conservation Area across three trails, Vanilla Trail (VT), Arboretum Trail (AT), Gading Trail (GT).

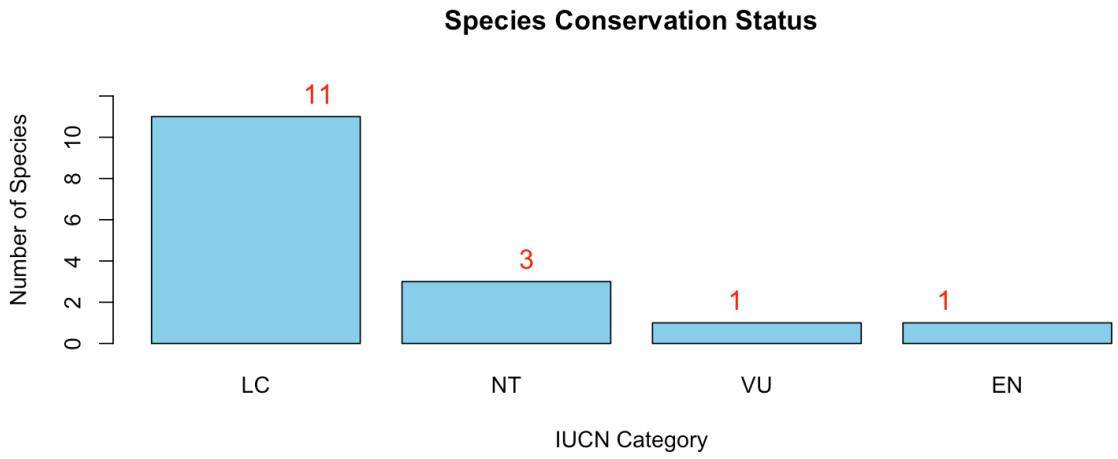

Figure 6: Summary of the IUCN Red List conservation statuses of bat species from the Taliwas River Conservation Area. LC: Least Concern, NT: Near Threatened, VU: Vulnerable, E: Endangered.

Species account

Family Pteropodidae.

Cynopterus minutus (Miller, 1906)

Collected voucher specimen – 1 (BOR MAL10677); Forearm (mm): 53.67–58.52

Two individuals of *Cynopterus minutus* were recorded during this survey along the Vanilla Trail, captured using mist nets deployed along the trail. Typically found in primary forests, *C. minutus* has also been recorded in villages and disturbed habitats (Ruedas & Suyanto, 2019), reflecting its adaptability to a range of habitat conditions. Its presence in the TRCA, particularly within intact forest, may reflect a preference for semi-closed canopy areas. This frugivorous species likely contributes to short-distance seed dispersal, particularly for understorey plants and shrubs (Sheherazade et al., 2017). In Borneo, it has been observed roosting in banana leaves, palms, and low foliage, indicating its reliance on lower strata vegetation for roosting (Payne & Francis, 1985). The species is currently listed as Least Concern on the IUCN Red List (Ruedas & Suyanto, 2019). Individuals encountered in this study frequently exhibited a pale-yellow fur collar around the neck. In contrast to *C. brachyotis*, where bright yellow to orange collars is commonly documented in adult males, the markings in *C. minutus* were subtler but observed in both males and females. This characteristic, along with a noticeably calmer disposition when handled (except for pregnant female), may aid in field identification and species differentiation.

Pteropus vampyrus (Linnaeus, 1758)

Remarks – 4 individuals observed

Four individuals of the large flying fox (*Pteropus vampyrus*) were observed feeding on Binuang (*Octomeles sumatrana*) nectar near the main camp of TRCA. This migratory species is listed as Endangered on the IUCN Red List due to significant population declines across its range (Mildenstein et al., 2022). While *P. vampyrus* forages in both forested and agricultural landscapes, it prefers undisturbed native forests, particularly mangroves, peat swamps, and freshwater swamps for roosting (Lim, 1966; Payne & Francis, 1985; Mildenstein et al., 2005, 2022). Major threats include habitat loss, overhunting, roost site disturbance, and conflict with fruit producers (Mildenstein et al., 2022). As one of Southeast Asia's largest fruit bats, *P. vampyrus* serves as a vital pollinator and seed disperser for large-canopy forest trees (Nakamoto et al., 2009; Aziz et al., 2017). Its presence in the TRCA reinforces the importance of protecting mature fruiting trees that support these ecological services. Observations of this species feeding on Binuang nectar have also been reported from other forested sites such as the Maliau Basin Conservation Area. The repeated observation of *P. vampyrus* in the TRCA suggests that the area may function as part of a broader foraging corridor (Epstein et al., 2009). Conservation of such sites is particularly important as suitable roosting habitats continue to decline.

Family Hipposideridae.

Hipposideros cf. *saevus* (Templeton, 1848)

Collected voucher specimens – 3 (BOR MAL10670, MAL10669, MAL10674); Forearm (mm): 39.30–43.73

A total of 21 individuals of *Hipposideros* cf. *saevus* (formerly *Hipposideros ater*) were captured at the Vanilla and Gading trails. This species is known to roost in caves and man-made structures such as tunnels, often forming colonies of up to several hundred individuals (Payne & Francis, 1985; Sedlock, 2001). It is currently listed as Least Concern on the IUCN Red List (Armstrong, 2021). The high number of captures suggests it may be among the more commonly encountered insectivores in the area. Its frequent detection using harp traps aligns with its low, manoeuvrable flight and clutter-adapted foraging behaviour (Pavey, 2021). As a

small constant-frequency echolocator, *H.* cf. *saevus* likely plays an important role in insect population regulation within forest understorey environments (Schnitzler & Kalko, 2001). Wongwaiyut et al. (2023) proposed reclassification of this taxon as *Hipposideros* cf. *saevus*, highlighting the need for detailed morphological comparisons—particularly of the internarial septum and noseleaf base—with other similar species. Genetic and morphometric assessments are recommended to confirm the identity of Bornean populations.

Hipposideros ridleyi (Robinson and Kloss, 1911)
Remarks – 1 individual (Released); Forearm (mm): 48.88
A single female *Hipposideros ridleyi* was captured in a harp trap at the Vanilla Trail, showing clear signs of post-lactation. This species is listed as Vulnerable on the IUCN Red List due to population declines across its range (Khan et al., 2020). It has been reported from lowland dipterocarp and Kerangas forests (Payne & Francis, 1985) and has been recorded roosting in culverts and drainpipes rather than caves (Mohd-Ridwan et al., 2011). The capture occurred along a shaded, interior trail consistent with its narrow-space foraging ecology. Although only a single record, the observation of a post-lactating individual may indicate the presence of suitable breeding conditions in the TRCA.

Family Rhinolophidae.
Rhinolophus sedulus (K. Andersen, 1905)
Collected voucher specimens – 3 (BOR MAL10672, MAL10665, MAL10676); Forearm (mm): 49.06–51.11
Four individuals of *Rhinolophus sedulus* were captured using harp traps across all three trails, including one post-lactating female. This species is generally associated with primary lowland forests, where it forages in the dense understorey (Payne & Francis, 1985; Corbet & Hill, 1992; Jayaraj, 2020). It is currently listed as Near Threatened due to suspected population declines driven by forest loss (Jayaraj, 2020). Its detection in multiple locations, including a breeding female, suggests that parts of the TRCA may still offer adequate foraging and roosting conditions.

Rhinolophus trifoliatus (Temminck, 1834)
Collected voucher specimens – 2 (BOR MAL10668, MAL10680); Forearm (mm): 50.2–51.47
Nine individuals of *Rhinolophus trifoliatus* were recorded, making it one of the more frequently captured species during this survey. A solitary-roosting species, *R. trifoliatus* is typically found beneath palm, rattan, or other large leaves in the understorey (Kingston et al., 2006; Francis, 2008). It is known to occupy a variety of habitats, including primary and secondary forests as well as mangroves (Phillipps & Phillipps, 2018). Although currently listed as Near Threatened due to habitat fragmentation (Huang, 2020), its consistent detection in protected areas across Sabah suggests a wider ecological tolerance. The relatively high number of individuals captured suggests that suitable microhabitats for this species are available within the TRCA.

Family Vespertilionidae.
Kerivoula intermedia (Hill and Francis, 1984)
Remarks – 1 individual (Released)
A single individual of *Kerivoula intermedia* was captured in a harp trap along the Arboretum Trail. This species is typically associated with forest understorey habitats, where it roosts in foliage or tree cavities (Payne & Francis, 1985). Although infrequently encountered in surveys, it has been documented in multiple forest reserves across Sabah. It is currently listed as Near Threatened, with population declines linked to logging, forest fires, and plantation expansion (Nor Zalipah, 2020). Its detection in this study contributes to the understanding of its local

distribution and indicates that suitable forest structure persists in some parts of the TRCA. Continued protection of vegetation complexity and understorey conditions may benefit this and other similar forest-dependent species.

DISCUSSION

TRCA as a conservation site for threatened and forest-specialist bats

This study represents the first documentation of bat diversity within the Taliwas River Conservation Area (TRCA), providing baseline data on species composition and community structure. A total of 16 species were recorded over 70 trap hours—a moderately diverse assemblage when compared to the Danum Valley Conservation Area (DVCA), which has previously reported 35 species over 1341 trap hours (Kingston et al., 1995; Hazebroek et al., 2004). Although direct comparisons are limited due to data availability, the diversity observed in TRCA supports its value as a forest site of conservation significance. More species are likely to be recorded with extended sampling across multiple seasons.

The habitats within TRCA—including primary lowland rainforest, streamside vegetation, and dipterocarp-enriched silvicultural zones—provide structurally diverse environments that support a variety of bat guilds. In this survey, insectivorous species were more numerous than frugivores and nectarivores, likely due to both their greater reliance on intact forest structure for roosting and the effectiveness of harp traps in targeting forest-interior gleaners. For example, *Hipposideros* cf. *saevus (*formerly *H. ater*) and *Rhinolophus trifoliatus*—both gleaning insectivores active in the forest understorey—were the most frequently captured species. The detection of these species reinforces the importance of intact understorey conditions for supporting forest-specialist bats (Kingston, 2013; Struebig et al., 2008, 2012).

Notably, several Near Threatened and Vulnerable species were recorded, including *Kerivoula intermedia*, *Rhinolophus sedulus*, *R. trifoliatus*, and the Endangered *Pteropus vampyrus*. These species are known forest specialists and are highly sensitive to habitat degradation and fragmentation (Struebig et al., 2008, 2011; Kingston, 2013; Jayaraj, 2020; Huang, 2020). The observation of a post-lactating *Hipposideros ridleyi* (Vulnerable) further suggests that TRCA may support breeding populations of rare species, strengthening the case for its conservation priority.

Ecological and cultural importance of *Pteropus vampyrus*

The repeated presence of *P. vampyrus* feeding on *Octomeles sumatrana* (Binuang) trees near the TRCA camp highlights the site's importance as a foraging ground for this wide-ranging keystone species. In addition to its ecological roles in pollination and seed dispersal, *P. vampyrus* is facing population declines due to overharvesting and habitat loss (Lane et al., 2006; Bates et al., 2008). Although it is protected under wildlife laws in parts of Malaysia, hunting is still permitted under license in Sabah, where the species is consumed for its perceived medicinal properties (Mildenstein et al., 2022; Mohd-Azlan et al., 2022). Observations from this study support the need to protect nectar-producing trees and their surrounding habitats to ensure continued ecosystem services are provided by this species.

TRCA and the role of bats as bioindicators

Bats are increasingly recognized as useful bioindicators due to their ecological diversity, sensitivity to environmental changes, and wide geographic distribution (Jones et al., 2009; Pulscher et al., 2020). However, effective use of bats as indicators requires accurate and

localized species inventories. This study contributes to filling that gap for TRCA and complements existing data from DVCA and other forest reserves in Sabah. The presence of forest-interior specialists such as *K. papillosa* and *K. intermedia*, as well as wide-ranging species like *P. vampyrus*, suggests that TRCA retains a relatively intact forest structure capable of supporting diverse bat guilds.

A recent study on tropical birds noted that protected areas are particularly effective in conserving forest-dependent, locally endemic, and threatened species (Cazalis et al., 2020). The bat community in the TRCA reflects this pattern, with the detection of multiple forest specialists and Near Threatened species that rely on the availability of continuous canopy cover, intact roosting sites, and a functional understorey. *K. papillosa* and *K. intermedia*, for instance, are known to be vulnerable to changes in their habitat, while *R. sedulus* and *R. trifoliatus* have been reported to roost solitarily or in shared sites within the forest understorey (Corbet & Hill, 1992; Payne & Francis, 1985).

Caveats and limitations

While this study provides valuable baseline data, several caveats should be noted. First, the sampling effort was limited in duration and scope, representing only a short-term, single-season survey, as this factor is known to have a negative impact on capture rates (Yoh et al., 2020; Meyer, 2015). Some species may have been missed due to seasonal variation of bat species composition, especially among frugivores and nectarivores. Additionally, the survey covered only three trails within the conservation area, which may not fully reflect the spatial heterogeneity of the TRCA.

Second, the reliance on harp traps without concurrent acoustic monitoring likely biased the results toward low-flying, forest-interior insectivores, underrepresenting high-flying or edge-adapted species such as *Taphozous* or *Miniopterus*. Third, while species identifications were based on morphological characteristics, some taxa—notably within *Hipposideros* and *Kerivoula*—may represent cryptic species complexes that require genetic confirmation (Khan et al., 2010).

Lastly, while comparisons were made to other conservation areas, such as the DVCA, inconsistencies in sampling design, effort, and available species lists limit the strength of such comparisons. Despite these limitations, the findings from the TRCA still offer meaningful insights into the area's conservation value and can serve as a foundation for future, more comprehensive surveys.

Implications for conservation and future monitoring

The presence of sensitive and threatened bat species within the TRCA highlights its value as a key conservation area within the larger Yayasan Sabah Forest Management Area. The diversity recorded suggests that the TRCA still maintains good forest quality. However, to better understand seasonal and long-term trends in bat diversity and abundance, future surveys should incorporate acoustic monitoring, stratified sampling across forest strata, and longer-term trapping efforts. These efforts will strengthen the baseline and enable more informed management decisions.

In summary, the findings from this study not only provide the first detailed bat inventory for the TRCA but also demonstrate the area's ecological importance in supporting a diverse and conservation-relevant bat community. This supports the case for the continued protection and integration of TRCA into Sabah's wider conservation planning framework.

CONCLUSIONS

This study presents the first detailed assessment of bat diversity in the TRCA, highlighting its ecological value as a primary lowland forest that supports a diverse bat community. With 16 species recorded in a relatively short sampling effort—including several forest-interior specialists and threatened taxa—the TRCA emerges as an important habitat for both common and conservation-priority species. The detection of *Pteropus vampyrus* and *Hipposideros ridleyi*, alongside multiple Near Threatened species, underscores the role of the TRCA in maintaining populations of bats that are sensitive to environmental change.

The diversity and evenness observed in this assemblage suggest a relatively undisturbed forest structure, supporting a mix of foraging strategies and roosting requirements. These findings not only add to the growing body of data on Sabah's bat fauna but also serve as a crucial reference point for long-term monitoring and biodiversity planning. As pressures on natural forests continue to rise, sites like the TRCA provide a valuable stronghold for species that depend on intact, functioning forest ecosystems.

To strengthen the current baseline and better understand seasonal variation in bat activity, further monitoring is recommended. This includes periodic surveys across different months and using complementary methods such as acoustic detectors, which can capture high-flying and echolocating species that are not easily sampled with mist nets or harp traps. A consistent monitoring program would allow forest managers and conservationists to detect changes in species composition over time and respond proactively to ecological shifts.

Finally, the TRCA's role as part of the larger Yayasan Sabah Forest Management Area should not be overlooked. Its connectivity to surrounding forest blocks provides crucial movement corridors for bats, especially migratory and wide-ranging species. The conservation value of the TRCA would be further strengthened by integrating it into broader habitat linkage or buffer zone planning, ensuring that bat diversity remains protected within a connected forest landscape.

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DECLARATIONS

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Ethical approval/statement. Animal handling procedures were approved by the Animal Ethics Committee of Universiti Malaysia Sabah (Approval Code: AEC-0005/2020).

Generative AI use. The author(s) declare that generative AI has been used in compliance with the JTBC policies, and that I/we have reviewed and edited the content after using this tool and we take(s) full responsibility for the content of the publication.

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