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The study of diversity and distribution of bats in several fragmented forests and small adjacent islands in Batam City, Riau Island, Indonesia

FAUZIAH SYAMSI[1,2], WILSON NOVARINO[1,♥], DAHELMI[1], CHAIRUL[1]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Andalas. Limau Manis, Padang 25163, West Sumatra, Indonesia. Tel./fax.: +62-751-71671, ♥email: wilsonnovarino@sci.unand.ac.id

[2]Department of Biology Education, Teacher Training and Education Faculty, Universitas Riau Kepulauan. Jl. Pahlawan No. 99, Bukit Tempayan, Batu Aji, Batam 29425, Riau Island, Indonesia

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Abstract. *Syamsi F, Novarino W, Dahelmi, Chairul. 2025. The study of diversity and distribution of bats in several fragmented forests and small adjacent islands in Batam City, Riau Island, Indonesia. Biodiversitas 26: 223-232.* Bats are ecologically and taxonomically diverse and crucial in tropical ecosystems, including on islands. This study compares bat diversity in fragmented forests on urban islands and adjacent islands connected by bridges to assess the impact of urbanization on bat populations, providing insights for conservation and habitat management. We sampled bats across four sites in Batam City, Indonesia, including two secondary forests (SF1 and SF2) and two small islands (SI1 and SI2). Using 120 harp trap nights and 120 net nights, we captured 429 bats representing 15 species and 4 families. Our findings revealed moderate bat diversity (H' 1.02 to 1.66), with SF1 being the most stable habitat, showing balanced species richness, evenness (0.72), and low dominance (0.24), indicating an evenly distributed community. The Bray-Curtis Similarity index indicated that SF1 had a distinct bat community with only 58% similarity to other habitats. Notably, two near-threatened species were found in SF1, emphasizing its ecological significance. The study suggests that fragmented forests with healthy vegetation and habitat complexity surrounding urban areas are more supportive of bat populations than small islands with limited resources. These results highlight the need for targeted conservation efforts in forest fragments surrounding urban areas to preserve bat diversity in Batam City, Riau Island, Indonesia.

Keywords: Bat assemblage, Bray-Curtis Similarity index, forest fragment, small islands, urban biodiversity

INTRODUCTION

Bats represent an ecologically and taxonomically diverse group of animals, contributing approximately one-fifth of global mammalian diversity (Frick et al. 2019). Their presence is vital in tropical ecosystems, particularly on islands where they are often the only native mammals (Jones et al. 2009; Frick et al. 2019; Ferreira et al. 2022). Bats play a crucial role in maintaining island ecosystems by dispersing seeds over long distances (Shilton and Whittaker 2009), functioning as pollinators and insect predators (Fleming and Racey 2009; Tanalgo et al. 2016; Valdespino and Sosa 2017; Harahap and Yonariza 2022; Damião da Silva et al. 2024), hosting specialized ectoparasites (Estrada-Villegas et al. 2018; Lim et al. 2020), serving as prey for predators, and contributing nutrients to vegetation (Leong and Chan 2011).

Over the past few decades, bat populations have been increasingly threatened by anthropogenic pressures such as deforestation, forest fragmentation, and urbanization (Lintott et al. 2014; Russo and Anciloto 2015; Frick et al. 2019). Urbanization, a widespread and intense form of land use, often leads to biodiversity decline (Nunes et al. 2016). Forest fragments within urban areas, known as urban remnant forests, typically contribute to decreased biodiversity by reducing available habitats and increasing edge effects, which disrupt the ecological integrity of the forest (Wang and Yang 2022). Furthermore, animal assemblages within forest fragments are influenced by factors such as patch area, shape, and the structure of the local plant community (Banul et al. 2018). Bats respond differently to habitat fragmentation, with forest-dependent species being more vulnerable than non-forest-dependent species (Webala et al. 2019). This fragmentation isolates bat populations, limiting gene flow and increasing their risk of extinction (López-Wilchis et al. 2021), while also affecting their provision of ecological services (Kingston 2013).

Recent studies have emphasized the critical importance of understanding how land-use change on islands affects the diversity and distribution of bats. The research by Norder et al. (2020) and Castro-Fernandes et al. (2025) highlights that anthropogenic land-use changes on islands significantly drive the ongoing biodiversity crisis. These changes have notably altered bat species distributions and assemblages (Wiantoro et al. 2016; Lesinski et al. 2018; Costa et al. 2020). The reduction in landscape complexity threatens many mammal species, including bats, due to the loss of roosting sites and foraging habitats (Gili et al. 2020).

The rapid urbanization of Batam City, Riau Island, Indonesia, has significantly altered the landscape, leading to forest conversion and the fragmentation of natural habitats within urban areas. These changes have disrupted local ecosystems, intensifying pressures on bat populations, which are particularly sensitive to habitat loss and fragmentation (Threlfall et al. 2012; Lintott et al. 2014; Russo and Ancillotto 2015). The conversion of continuous habitats into smaller, isolated patches limits access to essential resources like foraging sites and roosting locations, which are critical for many bat species (Fonderflick et al. 2015; Hazard et al. 2023). Furthermore, the effects of urbanization extend beyond the city itself, impacting small islands connected to Batam by bridges, with varying intensities depending on their proximity to urban areas. These islands, inherently vulnerable to ecological changes, face compounded threats from natural and anthropogenic factors, such as land-use change and increasing urbanization (Aguillon et al. 2024).

Although understanding bat populations in urbanized islands like Batam is crucial for conservation, research on bats in Indonesia remains limited. This knowledge gap hampers effective conservation strategies in the region (Voigt and Kingston 2016). Studies suggest that urbanization often leads to shifts in bat species composition, favoring opportunistic species while putting specialist species at greater risk (Avila-Flores and Fenton 2005; Webala et al. 2019).

Loss of natural habitats has led to a decline in bat species in urban areas. Previous research has shown that urbanization negatively impacts bat populations. However, there have been limited studies on its effects in island habitats. Most previous studies have focused on mainland areas and have not adequately considered small islands with significant land use changes. Therefore, understanding bats' diversity, distribution, and specific conservation needs in fragmented forests and nearby islands is essential for effective biodiversity management. This study aims to fill this gap by investigating bat diversity and distribution in the fragmented forests of Batam and its surrounding islands, providing critical data to support conservation policies and management strategies in urbanized landscapes.

MATERIALS AND METHODS

Study area

Batam is located in Indonesia between 00°25'29″-1°15'00″ North Latitude and 103°34'35″-104°26'04″ East Longitude. Administratively, it borders the Singapore Strait to the north, Bintan Island to the east, Lingga Island to the south, and Karimun District to the west. The total area of Batam City is 3,868.97 km^2, consisting of land and water/sea areas. Batam City has an elevation ranging from 0 to 160 meters above sea level and is relatively flat with hilly variations. Batam City has a tropical climate with an average temperature of 2022 ranging from 26.8°C to 28.8°C and average humidity from 78% to 86% (BPS-Statistics Indonesia 2023). The study areas are illustrated in Figure 1.

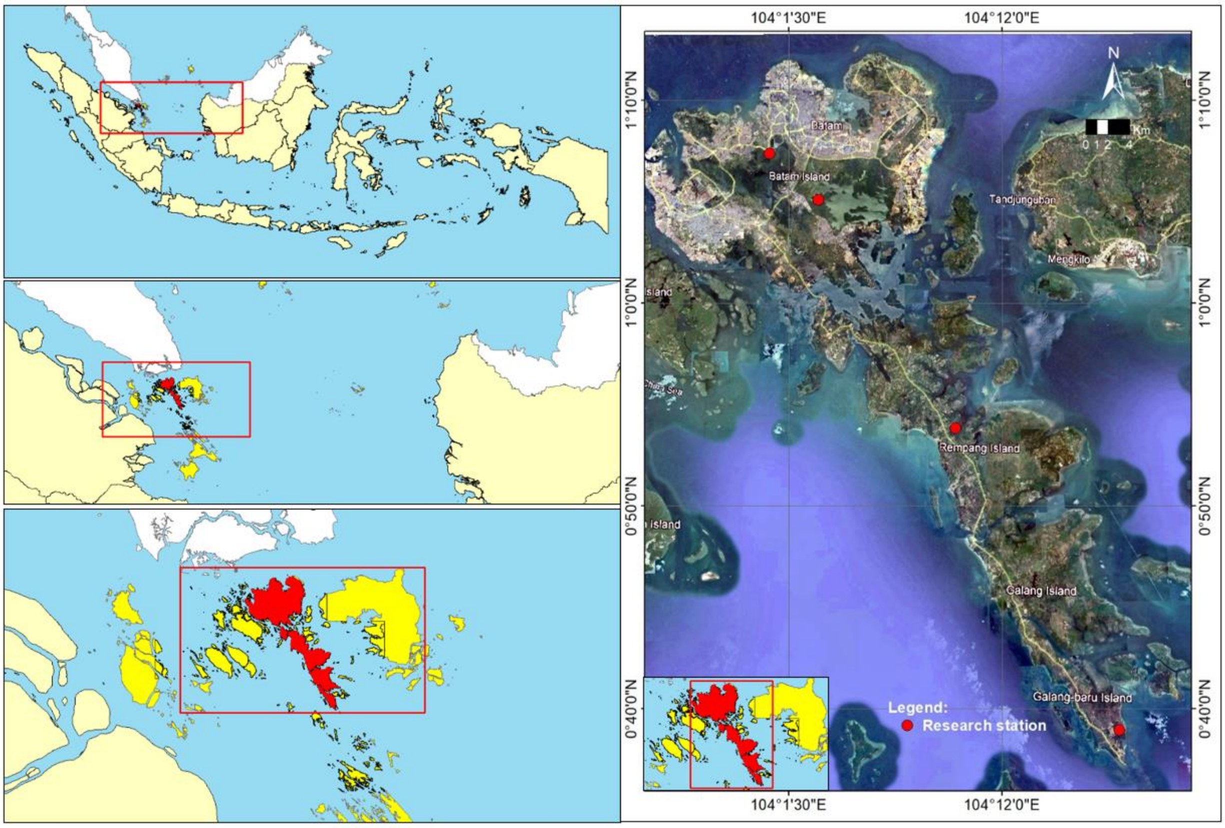

Figure 1. Location of bat sampling site in Batam and Rempang-Galang Baru Islands, Indonesia

Sampling sites

This study was conducted at four locations in Batam City, Riau Island, Indonesia: Two sites in the lowland secondary forests of Batam Island (urban), namely Sungai Ladi and Duriangkang Protected Forest; one site in the peri-urban habitat on Rempang Island, which borders Batam; and one site in the rural area at the end of the sixth bridge, Galang Baru Island (Table 1). Sampling sites were determined based on distance from the city, on the assumption that the farther from the city, the less disturbance and the greater the number of bat species. Research stations were identified using purposive sampling at locations where bats were expected to be found. A total of 12 research stations were established, with three at each sampling location. The Sungai Ladi and Duriangkang Protected Forests are dominated by trees with dense vegetation, such as fig tree (*Ficus* sp.), Myrtaceae family (*Eugenia* sp.), and Pepper family (*Piper* sp.). In contrast, Rempang and Galang Baru feature mangrove and coastal forests with sparse vegetation, dominated by mangroves and shrubs such as fern (*Gleichenia linearis* (Burm.fil.) C.B.Clarke)) and Malabar melastome (*Melastoma malabathricum* L.). Another site on Rempang, known as Rempang Cate, consists of an *Acacia* plantation with tree diameters more than 15 cm. The conditions of each sampling location are illustrated in Figure 2.

Table 1. Habitat types at each research location

Island	Location	Landscape type	Number of stations	Habitat type
Batam	Sungai Ladi (SF1)	Urban	3	Secondary forest
Batam	Duriangkang (SF2)	Urban	3	Secondary forest
Rempang	Rempang Cate, Sungai Rempang, Tiga Putri beach (SI1)	Peri-urban	3	Acacia forest, Mangrove, Island vegetation, Coastal vegetation
Galang Baru	Elyora beach 1, Elyora beach 2, Cakang beach (SI2)	Rural	3	Mangrove, Island vegetation, Coastal vegetation

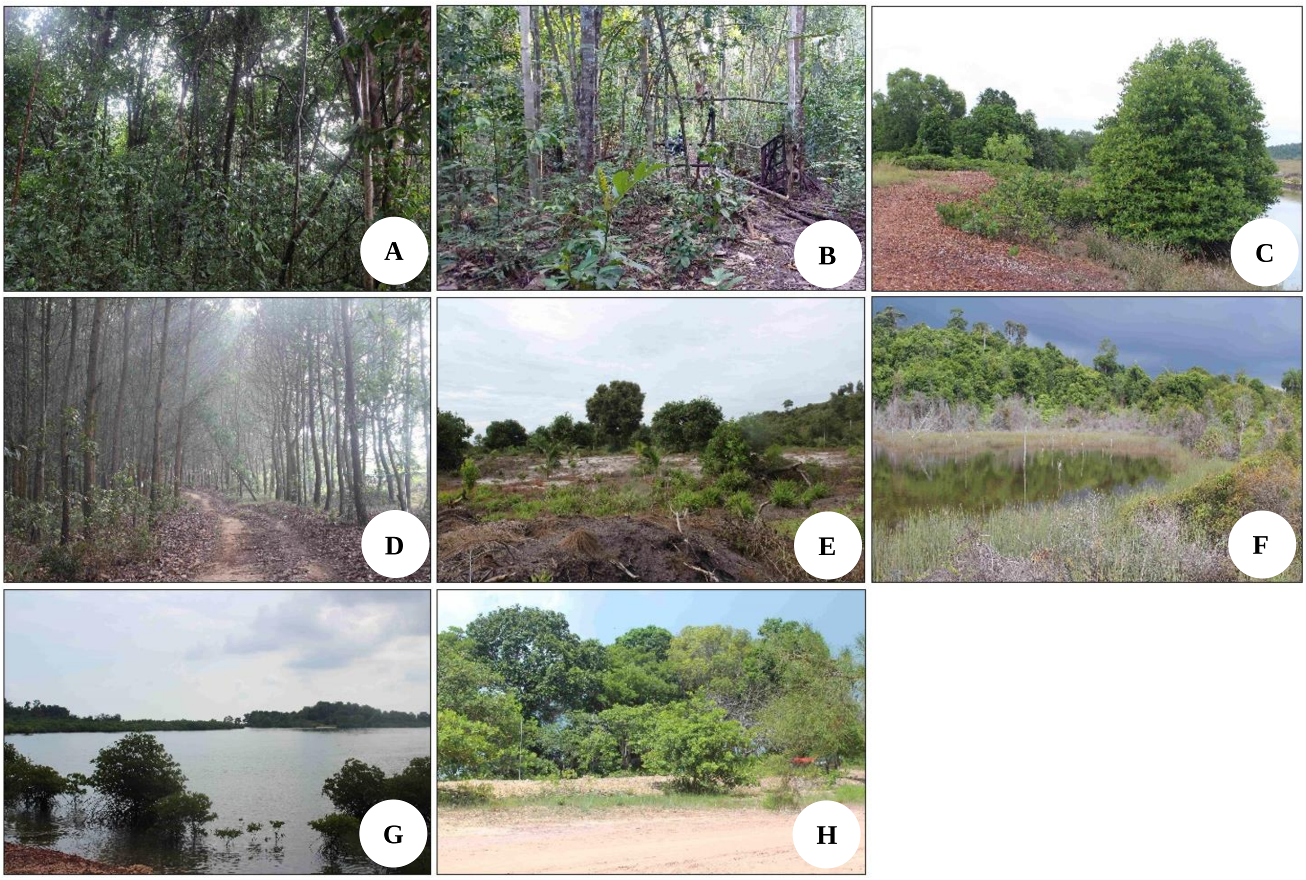

Figure 2. Habitat conditions at each sampling location in Batam, Indonesia. Batam Island: A. Sungai Ladi Protected Forest; B. Duriangkang Protected Forest. Rempang: C. Sungai Rempang; D. Rempang Cate; E. Tiga Putri Beach. Galang Baru: F. Elyora Beach 1; G. Elyora Beach 2; H. Cakang Beach. Photos by: F. Syamsi

Data collection

We used five mist nets and five four-bank harp traps to capture bats. Each mist net measured 12 meters in length and 2.6 meters in height. The mist nets were set up parallel at each research station for four nights. They were installed at least 50 cm above the ground to permit space for other terrestrial animals to pass underneath. The distance between the net lines was approximately 30-50 cm, shaping pockets to hold trapped bats. Mist nets were set up from 18:00 to 24:00. Nets were checked hourly to minimize the time bats were trapped, reducing stress and potential damage. The nets were rolled up out of bat capturing hours to avoid capturing other winging animals: birds, insects, and other animals. The total sampling effort using mist nets amounted to 120 net nights.

Harp traps have been installed on forest trails or where bats might fly over. The traps were installed 1-1.5 meters above the ground to allow passage for other terrestrial animals and humans. The distance between traps was approximately 50 meters. Traps were set up at different points each night. They were deployed from 06:00 pm until 06:00 am the following morning. Traps were checked at once in the night and once in the morning before moving to a new location. This schedule was chosen because the design of harp traps can hold bats for extended periods with minimal risk of escape or death. The total sampling effort using harp traps amounted to 120 harp trap nights.

Bats caught in mist nets and harp traps are carefully removed and placed into cloth bags. Extricating bats from mist nets is conducted with caution to prevent injury. Subsequently, each cloth bag is labeled with the capture number, trap number, day/date, inspection time, and bat species. Bats are transported to the research station for further examination, including identification and documentation.

Bats taxonomic identification and species composition bats

Identification involves observing body characteristics such as head shape, nasal structure, dental morphology, ear configuration, tail shape, coloration, sex, and other distinctive traits. While some bat species can be identified solely by their visible morphological features, others may require additional measurements of specific body parts for accurate classification. The body parts measured for species identification refer to Payne et al. (2000) and Kingston et al. (2009). The measurement parameters employed using calipers include forearm length (FA), measured from the elbow's outer edge to the wrist's outer edge along the curved wing (mm). The body weight (W) of each individual (g) is measured using a micro-scale. Identification is also conducted using keys from Kingston et al. (2009) and Huang et al. (2014). After identification, the bats' morphological characteristics, including fur color, nose shape, and ear shape, are described in as much detail as possible. A photograph was taken of each bat following the completion of processing. The bats were then released back into their natural habitat. We confirm that no bats were harmed during this study.

Data analysis

The relative abundance of each species was determined by dividing the number of individuals of a species by the total number of individuals across all species. A rank abundance curve for bats in the sampled habitats was created to analyze species abundance distributions across different sites using Microsoft Excel. Diversity indices, including Shannon-Wiener (H'), Evenness (eH'/S), and Dominance, were calculated to assess biodiversity. Bray-Curtis Similarity was applied to evaluate the compositional similarity between sites. The calculations for diversity indices, the Bray-Curtis Similarity index, and the creation of graphical representations were performed using PAleontological Statistics (PAST) version 4.13 and Microsoft Office Excel 2021.

RESULTS AND DISCUSSION

Species composition and relative abundance

A total of 429 individuals representing four families, 10 genera, and 15 species were identified from the study site (Table 2, Figure 3). Among all individuals, 96.97% (416) belonged to the Pteropodidae family, commonly known as fruit bats. Within this dominant family, Lesser dog-faced fruit bat (*Cynopterus brachyotis* (Müller, 1838)) emerged as the most abundant species, with a capture count of 217 individuals (50.58%). Following *C. brachyotis* in terms of abundance was the Greater short-nosed fruit bat (*Cynopterus sphinx* (Vahl, 1797)), which captured 102 individuals (23.78%). Horsfield's fruit bat (*Cynopterus horsfieldii* (Gray, 1843)) was the third most captured species within Pteropodidae with 72 individuals (16.78%), followed by the Spotted-winged fruit bat (*Balionycteris maculata* (Thomas, 1893)) with 18 individuals (4.20%), Dagger-toothed long-nosed fruit bat (*Macroglossus minimus* (E.Geoffroy, 1810)) at 5 individuals (1.17%). Lastly, two species captured only one individual (0.23%), namely Common nectar bats (*Eonycteris spelaea* (Dobson, 1871)) and Lucas's short-nosed fruit bat (*Penthetor lucasii* (Dobson, 1880)). In contrast to the presence of fruit bats, only 13 individuals (3.03%) of insect bats were spread across the Vespertilionidae, Megadermatidae, and Rhinolophidae families. The family Vespertilionidae also had a relatively high species count, with six species: Common woolly bat (*Kerivoula hardwickii* (Horsfield, 1824)) 3 individuals (0.7%), Clear-winged woolly bat (*Kerivoula pellucida* (Waterhouse, 1845)) 2 individuals (0.47%). Another four species only captured one individual (0.23%), namely Small woolly bat (*Kerivoula intermedia* (Hill & Francis, 1984)), Peters's myotis (*Myotis ater* (Peters, 1866)), Nepalese whiskered bat (*Myotis muricola* (Gray, 1846)), and Least pipistrelle (*Pipistrellus tenuis* (Temminck, 1840)). Only one species represented the families Megadermatidae and Rhinolophidae, Lesser false vampire (*Megaderma spasma* (Linnaeus, 1758)) and Trefoil horseshoe bat (*Rhinolophus trifoliatus* (Temminck, 1834)) with two individuals (0.47%) in each species.

Differences in the abundance of individuals across species and families are thought to be due to varying resource needs. The almost complete dominance of frugivorous bats could be attributed to these fruit bats adapting well to a wide range of habitats (Jose et al. 2021). The availability of foods, such as abundant fruits and flowers, in research stations may make a sampling site a favorable foraging location for bats. According to Lama et al. (2023), foraging locations and food sources can vary the number of individuals and species at the sampling stations. According to Pastor et al. (2024), A diverse assemblage of fruit-bearing trees and flowers within the surveyed area is a suitable habitat for the dietary needs of fruit bats. Their large numbers indicate that the environment offers a dependable food supply year-round. Besides that, the presence of large numbers of fruit trees and the structural complexity of the forest would also contribute to their success in invading all the sites sampled.

On the other hand, the very low number of insectivorous bats (Megadermatidae, Rhinolophidae, and Vespertilionidae) captured, represented by 13 individuals from eight species, due to a lack of prey abundance, particularly aerial insects (Pastor et al. 2024). The low abundance of insect bats during the sampling period may be attributed to seasonal fluctuations in prey availability. The absence of caves in the area could be the reason for the low catch of insect bats (Lama et al. 2023). The leading cause of the abundance of insect bats is deforestation, such as for agriculture, settlement, and other human modification. Agriculture is considered one of the primary factors limiting the availability of roosting sites and foraging habitats for bats (Park 2015).

Results show that SF1 recorded the most significant number of species (n: 10). *Cynopterus brachyotis* was the most abundant species in SF2, SI1, and SI2 (RA: 47.06%, 58.72%, 63.38%). The area's more significant amount and wide variety of food resources probably make it a favorable foraging site for bats (Lama et al. 2023). Moreover, *C. horsfieldii* was the most abundant species in SF1, with relative abundance of 32.89%. The said two species (*C. brachyotis* and *C. horsfieldii*) can tolerate a wide range of habitats, making them exist in both non-forest and forest areas (Mickleburgh et al. 1992; Johnson et al. 2008; Lama et al. 2023), hence explaining their presence in all sampling sites. Various studies, including those by Roslan et al. (2016), Pounsin et al. (2018), and Ramona (2019) have also demonstrated that *C. brachyotis* is the most common species in the study area. *Cynopterus sphinx* was also recorded at all sites in Batam. They are the second most abundant bat captured in this study (Table 2). *Cynopterus sphinx* is highly ecologically flexible (Son et al. 2022). This species had a high degree of resource overlap with *C. brachyotis*. *Cynopterus sphinx* is a larger species (forearm length 64-79 mm) that seems to eat larger fruits, such as *Gmelina arborea* (diameter of ~25 mm), while *C. brachyotis* (forearm length 54.7-66.7 mm) feeds smaller fruits more frequently, such as *Ficus septica* Burm.fil. (diameter of ~15-20 cm) (Sheherazade et al. 2017).

Several species are only found in the lowland secondary forest (SF1 and SF2), namely *B. maculata*, *E. spelaea*, *P. lucasii*, *R. trifoliatus*, *K. hardwickii*, *K. intermedia*, *K. pellucida*, and *P. tenuis*. These species depend highly on forest habitats and cnot survive in other habitats, such as mangroves and coastal forests. For example, *B. maculata* requires forest-dwelling trees for roosting (Meijaard et al. 2006), insectivorous bats like *R. trifoliatus, K. hardwickii, K. intermedia, K. pellucida,* and *P. tenuis* prefer habitats with high insect diversity and abundance, commonly found in primary/secondary forests.

Table 2. Species composition, conservation status, and abundance of bats in Batam, Indonesia

Family/Species	**Conser-vation status[a]**	**Catego-ry[b]**	**Sampling sites**								**Total**	**(RA%)**
			SF1	**(RA%)**	**SF2**	**(RA%)**	**SI1**	**(RA%)**	**SI2**	**(RA%)**		
Family: Pteropodidae												
Balionycteris maculata	LC	D	8	10.5	10	9.8	-	-			18	4.2
Cynopterus brachyotis	LC	E	15	19.7	48	47.1	64	58.72	90	63.38	217	50.6
Cynopterus horsfieldii	LC	E	25	32.9	14	13.7	18	16.51	15	10.56	72	16.8
Cynopterus sphinx	LC	E	21	27.6	25	24.5	25	22.94	31	21.83	102	23.8
Eonycteris spelaea	LC	A	1	1.32	-	-	-	-	-		1	0.23
Macroglossus minimus	LC	B	-	-	-	-	2	1.83	3	2.11	5	1.17
Penthetor lucasii	LC	A	1	1.32	-	-	-	-	-	-	1	0.23
Family: Megadermatidae												
Megaderma spasma	LC	B	1	1.32	-	-	-	-	1	0.7	2	0.47
Family: Rhinolophydae												
Rhinolophus trifoliatus	NT	B	1	1.32	1	0.98	-	-	-	-	2	0.47
Family: Vespertilionidae												
Sub Family: Kerivoulinae												
Kerivoula hardwickii	LC	B	2	2.63	1	0.98	-	-	-	-	3	0.7
Kerivoula intermedia	LC	A	-	-	1	0.98	-	-	-	-	1	0.23
Kerivoula pellucida	NT	B	1	1.32	1	0.98	-	-	-	-	2	0.47
Sub Family: Vespertilioninae												
Myotis ater	LC	A	-	-	-	-	-	-	1	0.7	1	0.23
Myotis muricola	LC	A	-	-	-	-	-	-	1	0.7	1	0.23
Pipistrellus tenuis	LC	A	-	-	1	0.98	-	-	-	-	1	0.23
Total			76	17.7	102	23.8	109	25.41	142	33.1	429	100

Figure 3. Bats recorded in Protected Forests Fragments of Batam and Connected Islands, Indonesia in which: A. *B. maculata*; B. *C. brachyotis*; C. *C. horsfieldii*; D. *C. sphinx*; E. *E. spelaea*; F. *M. minimus*; G. *P. lucasii*; H. *M. spasma*; I. *R. trifoliatus*; J. *K. hardwickii*; K. *K. intermedia*; L. *K. pellucida*; M. *M. ater*; N. *M. muricola*; O. *P. tenuis*. Photos by F. Syamsi

In contrast, three species are exclusively found in small islands (SI1 and SI2): *M. minimus*, *M. ater*, and *M. muricola*, found in mangrove and coastal edge forests. Widayati and Nurjana (2018) were also reported to have found *M. minimus* on beaches far from settlements rather than in forests and beaches close to settlements. The presence of species in the area might be attributed to the condition of the forest and potential habitats for species (Lama et al. 2023).

The lowland secondary forests on Batam Island (SF1 and SF2) have diverse tree species, providing a suitable environment for multiple bat species. According to Rigo et al. (2024), the presence of trees and dead wood above land influenced the richness of bat species in forests. On the other hand, small islands (SI1 and SI2) are mainly of mangroves and coastal forests with a less diverse range of tree species, resulting in fewer bat species. SI1 has the fewest species richness (N: 4, n: 109, RA: 25.41%). A few species are estimated to inhibit this site because the habitat types, consisting of islands and coastal vegetation, are limited in quality and can only support several species, especially species that can adapt to environmental changes. In addition, the location of the sampling site, which is not so far from the anthropogenic island (Batam), gives this area more urbanization impacts than SI2. Most of the lowland forests in this site have been converted to settlements, plantations, livestock areas, tourist attractions, and other human activities, resulting in decreased natural forest areas serving as animal habitats.

The number of bats of each species also indicates the rarity status of that species at the study site. Environmental carrying capacity influences the variety of species abundance in particular locations. The bat species are classified into a range of categories depending on the number of individuals present at the study site (Table 2). Six bat species of type A (rare, n: 1), as indicated by the small number of individuals captured (only one of each species during the entire study period). These species are *E.*

spelaea, P. lucasii, K. intermedia, M. ater, M. horsefieldii, and *P. tenuis*. Type B (uncommon, n: 2 to 5) are *M. minimus, M. spasma, R. trifoliatus, K. hardwickii,* and *K. pellucida*. Type C (relative common, n: 6 to 10 bats were not discovered in this study despite their relative prevalence. One bat species of type D (common, n: 11 to 50), *B. maculata* (n: 18), is only found on Batam Island. There are three bat species of type E (widespread, n>50), which are *C. brachyotis, C. horsfieldii,* and *C. sphinx*. These species can adapt to environmental changes and are often found in open areas. *Cynopterus brachyotis* can occupy various habitats ranging from urban areas, forests, and mangroves (Mubarok et al. 2021) and survive in landscapes dominated by humans (Meijaard et al. 2006).

The rank abundance curve (Figure 4) shows that *C. brachyotis* was the most abundant species in sites SF2, SI1, and SI2. Moreover, *C. horsfieldii* was the most abundant species in SF1. The abundance of bats in a location is related to suitable foraging areas, which potentially have many of their favorite fruits. The high abundance of *C. horsfieldii* in SF1 implies a possible preference for different fruit types or a more general diet compared to *C. brachyotis* (Pastor et al. 2024). The following most common species is *C. sphinx*. This finding aligns with a report by Ramona (2019) that bats are most abundant in the Jambi Harapan Forest, with *C. brachyotis* being the most abundant, followed by *C. sphinx*. It is also essential to consider the abundance of each species at each study site, which is influenced by habitat conditions and available resources.

Diversity and similarity

Diversity analysis (Table 3) showed that SF1 was the best habitat among all sites, characterized by the most significant number of species (N: 10) and the highest diversity index (H': 1.66). The evenness value (e: 0.72) indicated a relatively even species distribution, supported by a low dominance value (D: 0.24), suggesting that no single species dominated the community. SF1 may be a stable habitat with sufficient resources to support species evenly. SF2 had a moderate diversity index (slightly lower than SF1) with a value of H': 1.43. The evenness index was lower than SF1 (Evenness: 0.65), indicating a slight imbalance in species distribution, but was still relatively even. The dominance value (D: 0.51) was higher than SF1, suggesting that some species, such as *C. brachyotis*, may be more dominant at this site. SF2 is a reasonably favorable habitat, but the presence of dominant species may influence the overall structure of the community diversity index value (Lama et al. 2023).

The small islands (SI1 and SI2) are habitats with low biodiversity. SI1 has only 4 species, and the diversity index (H': 1.02). However, its evenness (e: 0.74) shows that the species in this location are relatively evenly distributed. This is because the 3 species in this area are widespread and relatively balanced in number, namely *C. brachyotis, C. sphinx, and C. horsefieldii*. Only one species, *M. minimus*, has a small population and does not significantly impact the evenness index value. SI2 supports seven species but has low biodiversity (H': 1.04) and low evenness (evenness: 0.54), reflecting an uneven distribution of species, with a few species dominating. The highest dominance among all sites (D: 0.46) indicates the presence of one species dominating this community. SI1 and SI2 are considered less favorable habitats due to limited resources or ecological disturbance in these areas.

Thus, SF1 is the most stable habitat, exhibiting the best balance between species richness, diversity, and dominance. As indicated by increasing dominance, SF2 shows signs of a stressed ecosystem but still supports a relatively diverse community. On the other hand, SI1 and SI2 are stressed ecosystems with low diversity, possibly due to limited resource availability, small habitat size, and lack of heterogeneity. Based on these results, the environmental conditions in SF1 and SF2 should be maintained to conserve biodiversity. Additionally, efforts should be made to restore habitats in SI1 and SI2 to reduce environmental pressures leading to low diversity. For future research, long-term monitoring should be conducted to track diversity and dominance trends, ensure ecosystem sustainability, and assess habitat quality through vegetation analysis at all sites.

The results of Bray-Curtis Similarity showed that the close similarity between SI1 and SI2 at 85% (Figure 5) indicates a highly overlapping community structure, possibly due to similar environmental conditions or shared species dispersal pathways on the small islands. Another factor, such as similar habitat characteristics (e.g. vegetation type, fruit availability) that cater to the same bat species or geographical proximity, allows for easy movement between sites (Pastor et al. 2024). In contrast, SF1 demonstrates a much lower similarity, clustering at 58%, suggesting a distinct community composition compared to the other habitats. Various factors, such as differences in habitat type, resource availability, or geographic isolation, could influence this difference. Additionally, the clustering pattern shows SF2 as more similar to the small islands, clustering with them at a moderate similarity of 70%. This finding might reflect some shared species or intermediate ecological characteristics of SF2. The overall pattern of Bray-Curtis Similarity emphasizes the heterogeneity in species composition across the habitats, underlining the importance of site-specific conservation strategies.

Table 3. Biodiversity indices of bats in several fragmented forests and island Habitat in Batam, Riau Island, Indonesia

Sampling sites	Number of species	Diversity (H')	Evenness (eH'/s)	Dominance (D)
SF1	10	1.66	0.72	0.24
SF2	9	1.43	0.65	0.31
SI1	4	1.02	0.74	0.42
SI2	7	1.04	0.54	0.46

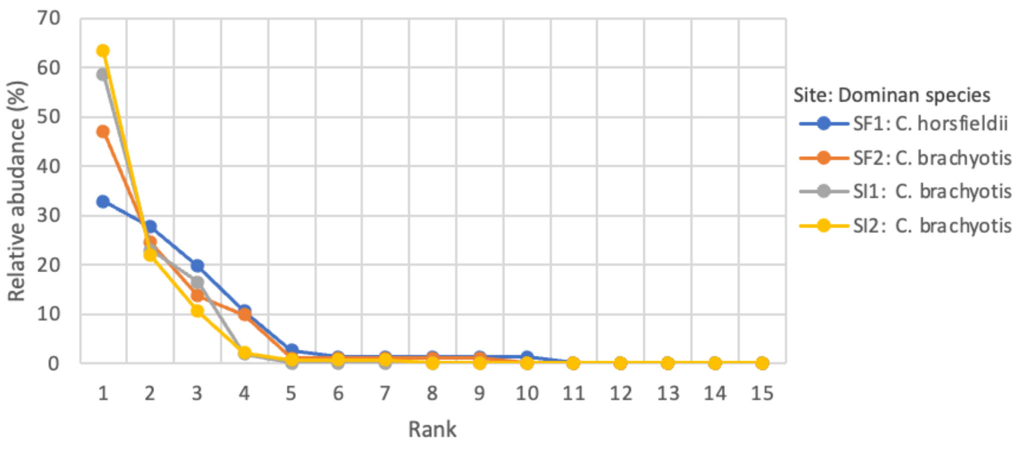

Figure 4. Rank-abundance curve of bat species in each sampling site

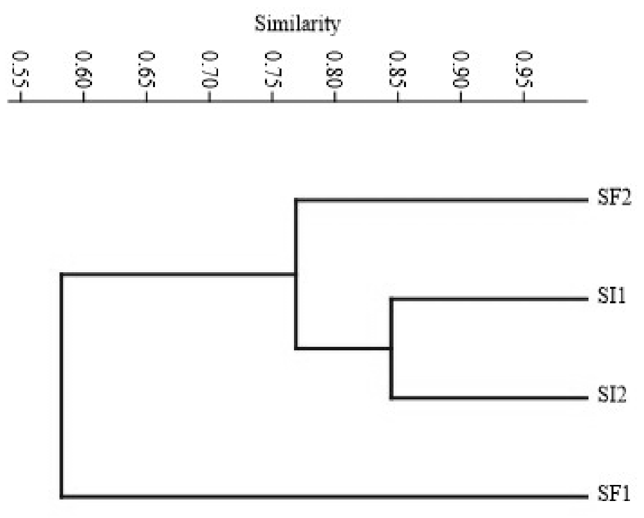

Figure 5. Bray-Curtis Similarity of bat species across sampling sites. SF1 (Secondary Forest 1/ Sungai Ladi Protected Forest); SF2 (Secondary Forest 2/ Duriangkang Protected Forest); SI1 (Small Island 1/ Rempang); SI2 (Small Island 2/ Galang Baru)

Conservation priorities

Two of the 15 bat species found have Near Threatened (NT) status according to the 3.1 version of the International Union for Conservation of Nature (IUCN) Red List, namely *R. trifoliatus* (found in SF1 and SF2) and *K. pellucida* (found in SF1). Near Threatened status is a conservation status given to a species when it has been assessed against the criteria but is not currently classified as critically endangered, endangered or vulnerable, but is likely to become or is likely to become eligible for classification as threatened in the near future. *Rhinolophus trifoliatus* is listed as Near Threatened as its global population is suspected of declining by 25-30% over the past 15 years (two generations). It will continue to decline over the next 7.5 years (three generations total; generation length: 7.5 years. The species is declining due to continuing threats from forest loss. Extinction of some local populations is expected across its distribution range (Huang 2020). *Kerivoula pellucida* population has decreased by around 25-30% due to deforestation, conversion of habitat to agriculture, and forest fires (Nor Zalipah 2020). The presence of near-threatened species at SF 1 and SF2 suggests that these habitats may be of higher quality than other sites. SF1 and SF2 still have resources (such as food and roosting sites) for these species. Near-threatened species may indicate that the ecosystem is healthy enough to support more biodiversity.

This study revealed moderate bat diversity (H': 1.02 to 1.66) across four sampling sites in Batam City, Indonesia. SF1 emerged as the most stable habitat, demonstrating a balanced relationship between species richness, diversity, evenness, and dominance. The evenness (0.72) and dominance (0.24) values indicate a relatively uniform distribution of species without any single species dominating. The Bray-Curtis Similarity index showed SF1 as distinct from other habitats, with only 58% similarity, further highlighting its unique community composition. Notably, two near-threatened species in SF1 suggest the habitat's ecological significance. Based on these findings, we recommend focused conservation efforts, particularly in SF1, to enhance bat populations in Batam City. Urban-adjacent fragmented forests with healthy vegetation and complex habitats are more likely to support bat species than small islands with limited resources.

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