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COMPARATIVE ANALYSIS OF WILD BEES (HYMENOPTERA: APIDAE) ASSEMBLAGES AT ROCKY SALT LICK IN SUNGAI PAPAN, ROYAL BELUM STATE PARK, PERAK, MALAYSIA

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ABSTRACT

Salt licks are unique natural features that play a significant role in supporting wildlife by providing essential ecological resources. Although extensively studied in relation to large mammals, the ecological relevance of salt licks to invertebrate communities, particularly pollinators such as wild bees, remains understudied. This research presents a comparative analysis of wild bees (Hymenoptera: Apidae) assemblages at a rocky salt lick in Sungai Papan, Royal Belum State Park, Perak. A total of 196 individuals were recorded, comprising five identified taxa: *Apis dorsata* (58.16%), *Heterotrigona itama* (19.39%), *Tetragonilla collina* (16.84%), *Tetragonilla atripes* (3.57%) and *Tetragonula melina* (2.04%). The abundance of wild bee species appears to be influenced by specific mineral concentrations associated with rocky salt licks in the vicinity. In this study, five mineral components namely; Calcium (Ca), Potassium (K), Magnesium (Mg), Sodium (Na) and Zinc (Zn) were analyzed by using an Atomic Absorption Spectroscopy (AAS). The highest Ca concentration was recorded during the dry season and wet season with values of 678.40 mg/kg and 1138.00 mg/kg, respectively. Pearson correlation analysis demonstrated differential associations between mineral composition and wild bee abundance at the salt lick, contributing to the first baseline assessment in Malaysia of mineral-related patterns in wild bee assemblages within a natural rocky salt lick ecosystem. Understanding this interaction adds a new dimension to pollinator ecology and highlights the need to conserve unique microhabitats within tropical forest ecosystems.

Keywords: Apidae; pollinator ecology; mineral composition; seasonal variation; tropical forest ecosystem

ABSTRAK

Jenut merupakan ciri semula jadi yang unik yang memainkan peranan penting dalam menyokong hidupan liar dengan menyediakan sumber ekologi yang penting. Walaupun dikaji secara meluas berkaitan dengan mamalia besar, kaitan ekologi jenut dengan komuniti invertebrata, terutamanya pendebunga seperti lebah liar, masih kurang dikaji. Kajian ini membentangkan analisis perbandingan himpunan lebah liar (Hymenoptera: Apidae) di jenut berbatu di Sungai Papan, Taman Negeri Royal Belum, Perak. Sebanyak 196 individu telah direkodkan, terdiri daripada lima taksa yang dikenal pasti: *Apis dorsata* (58.16%), *Heterotrigona itama* (19.39%), *Tetragonilla collina* (16.84%), *Tetragonilla atripes* (3.57%) dan *Tetragonula melina* (2.04%). Kelimpahan spesies lebah liar nampaknya dipengaruhi oleh kepekatan mineral tertentu yang berkaitan dengan jenut berbatu di sekitarnya. Dalam kajian ini, lima komponen mineral iaitu; Kalsium (Ca), Kalium (K), Magnesium (Mg), Natrium (Na) dan Zink (Zn) telah dianalisis menggunakan Spektroskopi Penyerapan Atom (AAS). Ca adalah kepekatan tertinggi semasa musim kemarau dan musim hujan masing-masing dengan 678.40 mg/kg dan 1138.00 mg/kg. Analisis korelasi Pearson menunjukkan perkaitan yang berbeza antara komposisi mineral dan kelimpahan lebah liar di kawasan jenut, yang menyumbang kepada penilaian garis dasar pertama di Malaysia tentang pola berkaitan mineral dalam kumpulan lebah liar dalam ekosistem jenut berbatu semula jadi. Memahami interaksi ini menambah dimensi baharu kepada ekologi pendebunga dan menekankan keperluan untuk memulihara mikrohabitat unik dalam ekosistem hutan tropika.

Kata Kunci: Apidae; ekologi pendebunga; komposisi mineral; variasi bermusim; ekosistem hutan tropika

INTRODUCTION

Wild bees (Hymenoptera: Apidae) are crucial pollinators within terrestrial ecosystems, serving a key function in preserving plant diversity and bolstering global food security. Wild bees aid in the reproduction of flowering plants, promote forest regeneration, and boost agricultural productivity through their pollination efforts. In tropical ecosystems, where interactions between plants and pollinators are very intricate, wild bees play a vital role in maintaining ecosystem stability and resilience. Wild bee populations globally are facing major declines due to habitat destruction, changes in land use, pesticide exposure, climate fluctuations, and limited resources, leading to an urgent need for pollinator conservation (IPBES 2016; Potts et al. 2010). Monitoring the native pollinator provides a crucial foundation for conservation efforts and sustainable management, which may offer strategic data for decision making in ecologically significant regions (Schühli et al. 2025). Specifically, within Southeast Asia, the conversion of forests to monoculture plantations poses a severe threat to native pollinator diversity, necessitating focused research in relatively preserved habitats such as Royal Belum State Park (Phillips et al. 2017; Sodhi et al 2010).

Traditionally, research on bee ecology has focused on floral resources, especially nectar and pollen as the main factors that influencing the wild bees foraging behavior and population dynamics. However, as pollinator declines intensify, understanding the nutritional requirements of wild bees has become increasingly important for the conservation efforts. Although nectar and pollen provide the principal nutritional resources for wild bees, their relatively low concentrations of certain essential minerals, particularly sodium, may necessitate the use of alternative mineral sources, highlighting the potential ecological importance of natural salt licks as supplementary foraging habitats (Bonoan et al. 2017). Nonetheless, increasing evidence shows that the wild bees also rely on non-floral resources as well, particularly inorganic minerals like sodium (Na), calcium (Ca), potassium (K) and magnesium (Mg), which are crucial for physiological functions such as neural transmission, muscle contraction, osmoregulation and brood development (Bonoan et al. 2017; Nicolson 2009). Floral nectar and pollen frequently have small amounts of these minerals, especially sodium, which leads the wild bees to search for additional mineral sources in their surroundings. Observing bees gathering water, mud or substrates that rich in minerals indicates that the mineral foraging is a significant but often overlooked aspect of the wild bee's nutritional ecology (Bonoan & Starks 2014; Seeley 1985).

Salt licks are natural mineral sites created by the geological and hydrological processes that gather vital elements in soils, rocks and water flows. These locations have been thoroughly recorded for their significance to mammals, especially in tropical woodlands, where they are functioning as an essential source of dietary minerals that are not easily accessible from plants (Ayotte et al. 2008; Matsubayashi et al. 2007). Conversely, the ecological significance of salt licks for insects, particularly in wild bees has attracted minimal scientific focus. While incidental observations and experimental research have shown that bees are drawn to water with minerals or salty surfaces, comprehensive studies of wild bee communities at natural salt licks are still very scarce, especially in Southeast Asia (Bonoan et al. 2017; Roubik 2023).

The insufficient understanding of how non-floral resources affect wild bee communities signifies a notable deficiency in pollinator ecology. Salt licks rich in minerals could serve as significant ecological elements that influence the structure, numbers, and behavior of bee populations in forest ecosystems (Nor Bazilah et al. 2025). To our knowledge, the interactions between wild bees and salt licks in Malaysia have not yet been the subject of any documented ecological research, even though the nation boasts significant bee diversity and the ecological significance of protected forest regions like Royal Belum State Park. Understanding how wild bees make use of salt licks is crucial for expanding current perspectives on pollinator resource utilization and habitat needs.

This research explores the wild bees' assemblages at a rocky salt lick in Sungai Papan, Royal Belum State Park and analyzes the link between the wild bee communities and the mineral content found at the study site. This research enhances scientific knowledge of non-floral resources in pollinator ecology by documenting wild bee use of salt licks, recognizes the salt licks as possible ecological hotspots for mammals and wild bees and offers baseline information to aid conservation and management initiatives in tropical forest ecosystems. Additionally, the results aid the biodiversity conservation by emphasizing neglected microhabitats and laying the groundwork for upcoming studies on mineral foraging behavior especially in wild bees. Consequently, understanding how these unique landscape features influence local and regional pollinator assemblages is vital for developing effective conservation strategies that safeguard both native bee diversity and the ecosystem services they provide (Ollerton 2017; Rocha-Filho et al. 2018; Winfree et al. 2018).

MATERIALS AND METHODS

Study Site

The study of the wild bee's population was conducted at a rocky salt lick located along Sungai Papan in Royal Belum State Park, Perak, Malaysia (5°37'58.9"N, 101°24'08.3"E), at an elevation of 296 m (Figure 1).

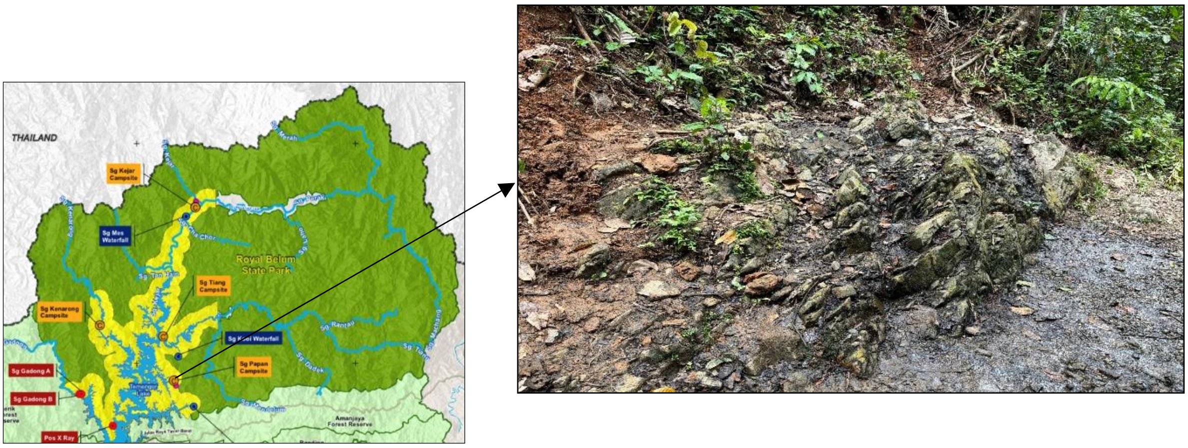

Figure 1. Sampling site locations for wild bees' assemblages in a rocky salt lick at Royal Belum State Park

Data Collection

Wild Bees Sampling

Observations of the wild bees were done consecutively for five days in each month between April and November of 2025. In accordance with standard entomological procedures, wild bees were sampled using sweep nets and bottle traps during peak foraging activity between 0800 and 1200 h (Westphal et al. 2008). Ten bottle traps were deployed at multiple vertical strata to account for vertical variation in bees' activities around the salt lick. Using regional identification keys, every individual seen actively foraging on the rocky salt lick was gathered and identified down to the lowest taxonomic level. The species identification was conducted using morphological characteristics and supported by regional literature on Southeast Asian bees, including references on stingless bees and honey bee diversity (Jalil 2014; Koeniger et al. 2010), alongside with global taxonomic frameworks (Engel et al. 2023).

Mineral Concentration Analysis

Soil samples was collected from the study site during both the dry and rainy seasons between April to November 2025. Based on recognized regional monsoon patterns recorded by the Malaysian Meteorological Department and regional climatological studies, the sampling periods were classified as exhibiting significantly drier and wetter conditions, respectively. The samples were analyzed for concentrations of Ca, K, Mg, Na and Zn (mg/kg), as these elements are known to affect the insect physiology and foraging behavior (Filipiak et al. 2017; Nation 2016).

In the laboratory, soil samples were air-dried, ground and sieved prior to analysis. The exchangeable cations were extracted using the double-acid extraction method (0.05 N HCl + 0.025 N H_2SO_4) following established procedures (Oborn & West 1972; Soil Testing and Plant Analysis Laboratory 1970). Approximately 5.0 g of each prepared sample was transferred into an Erlenmeyer flask and 20 mL of the extracting solution was added. The mixture was shaken mechanically for 15 minutes to facilitate extraction, after which the suspension was filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask and diluted to volume with the same extracting solution.

The concentrations of Ca, K, Mg, Na, and Zn were determined using an Atomic Absorption Spectrophotometer (AAS). Calibration was performed using a series of standard solutions prepared from certified reference materials, covering the expected concentration ranges of each element. A calibration curve was constructed for each element, and instrument accuracy was verified using quality control standards and blank samples. All measurements were conducted in accordance with standard operating procedures for AAS analysis.

Data Analysis

The diversity of wild bees was assessed using the Shannon–Wiener Diversity Index (H′), Simpson's Diversity Index (D) and Pielou's Evenness Index (J′). These indices describe the species richness, dominance and evenness within the community (Magurran 2013). Relative abundance was calculated for each species and community structure was further analyzed using rank–abundance curves in order to evaluate the dominance patterns and resource sharing. A Pearson's correlation coefficient was used to examine linear associations between the bee abundance and the mineral concentrations (Ca, K, Mg, Na, and Zn), with the aim of identifying potential relationships between mineral availability and bee visitation intensity at the salt lick environments.

RESULTS AND DISCUSSION

The Collection of Wild Bees

A total of 196 individuals of wild bees, represented by five taxa that were recorded in the study site (Figure 2). *Apis dorsata* dominated the wild bee assemblage, accounting for 58.16% of total abundance (114 individuals). Meanwhile, *Heterotrigona itama* was the most abundant species of the stingless bees, accounting for 19.39% of total abundance (38 individuals) followed by *Tetragonilla collina*, representing 16.84% of total abundance (33 individuals). *Tetragonilla atripes* and *Tetragonula melina* were found in comparatively low abundances with 3.57% of total abundance (7 individuals) and 2.04% of total abundance (4 individuals), respectively (Figure 3).

Apis dorsata *Heterotrigona itama* *Tetragonilla collina*

Tetragonilla atripes *Tetragonula melina*

Figure 2. The wild bees' assemblages that were collected at the rocky salt lick

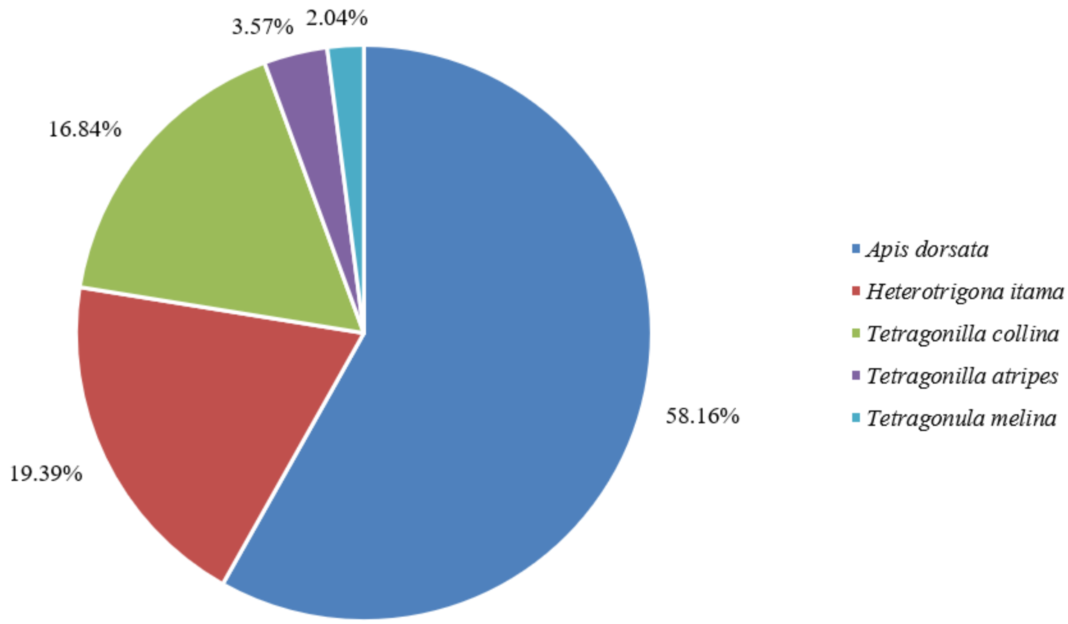

Figure 3. The abundance of the wild bees that were collected at the rocky salt lick

The Diversity of Wild Bees

The wild bee assemblage at the Sungai Papan salt lick demonstrated moderate diversity (Shannon–Wiener index, H′ = 1.13) and intermediate evenness (Pielou's J = 0.70), reflecting an assemblage structured by unequal species abundances. The Simpson's Index (D = 0.59) further indicates a community with evident dominance, largely attributable to the high representation of *Apis dorsata*. Despite this, the presence of multiple less abundant taxa contributes to maintaining overall diversity within the assemblage (Table 1).

The rank-abundance curve demonstrates the distribution pattern of wild bee species at the study site (Figure 4). *Apis dorsata* was the most common species, followed by the less abundant stingless bee species, such as *Tetragonilla collina*, *Tetragonilla atripes* and *Tetragonula melina* were regularly present, contributing to the development of the overall community structure. Overall, these diversity indices and abundance patterns suggest that the wild bee community at the salt lick was relatively balanced, diverse and resilient, where it is capable of maintaining the ecological functions under environmental fluctuations.

Table 1. Community diversity indices of wild bees at the study site

Study Site	Shannon-Wiener Index (H')	Simpson's Index (D)	Pielou's Evenness (J)
Sungai Papan	1.13	0.70	0.59

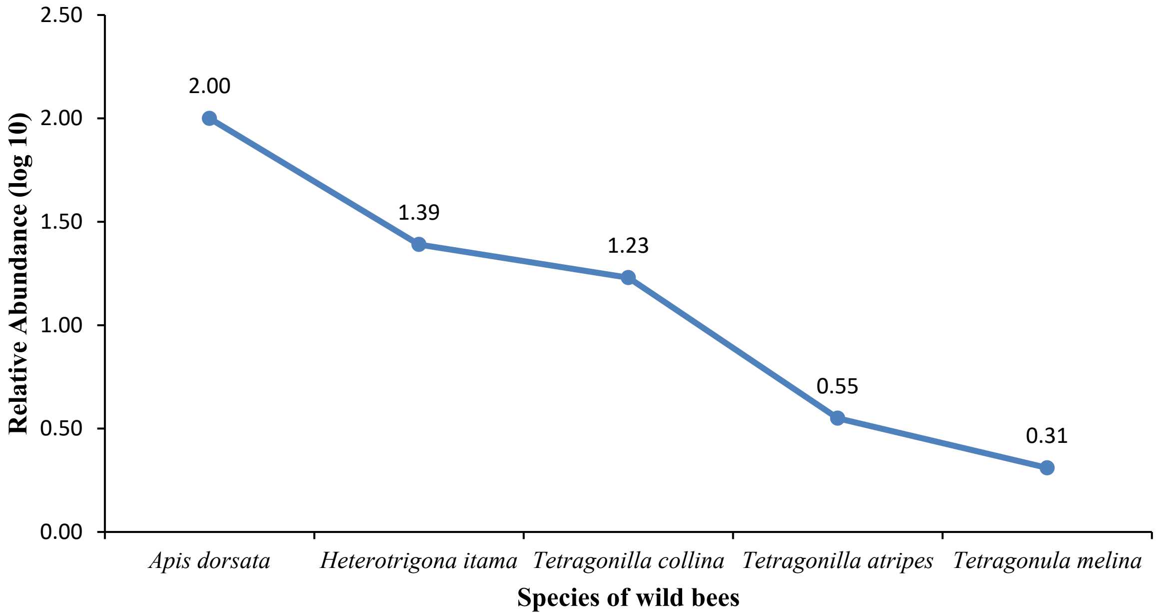

Figure 4. The rank-abundance curve of the wild bees at the rocky salt lick

The Mineral Concentration of the Salt Lick

Mineral concentrations at the rocky salt lick varied between the dry and rainy seasons. In the dry season, the concentration Na was notably high with 230.10 mg/kg compared to rainy season (90.80 mg/kg), whereas Ca (678.40 mg/kg), K (200.40 mg/kg), Mg (98.90 mg/kg) and Zn (5.00 mg/kg). In comparison, the rainy season exhibited significantly elevated levels of Ca (1138.00 mg/kg), K (371.30 mg/kg), Mg (152.90 mg/kg) and Zn (5.53 mg/kg).

Generally, Na exhibited significant seasonal variation, with the peak concentration noted in the dry season (230.1 mg/kg) and lower concentration detected in the rainy season (90.79 mg/kg). Mg and Zn were found in moderate to low levels, yet their regular identification throughout sampling times indicates a steady bioavailability of both macronutrient and trace elements which were crucial for insect physiology (Filipiak et al. 2017; Nation 2016). In this case, soil processes driven by rainfall in the tropical forests could enhance the mineral weathering and the mobilization of cations, where it is potentially accounting for the increased concentration levels of Ca, K, Mg and Zn in the rainy season (Pal & Alkan 2020; Sinsabaugh et al. 2020). Conversely, Na, an ion with high solubility, noted a notable decrease in the rainy season, where it is aligning with the leaching and dilution of soluble salts during periods of heavy precipitation (Chang et al. 2017; Kaspari et al. 2008). The seasonal changes in mineral concentrations at the salt lick indicate that the presence of elements in tropical forest soils is influenced by water movement rather than just static soil chemistry.

Table 2. The mineral concentrations of the rocky salt lick

Samples	Elements	Concentration (mg/kg)
Dry Season	Ca	678.40
	K	200.40
	Mg	98.90
	Na	230.10
	Zn	5.00

Samples	Elements	Concentration (mg/kg)
Rainy Season	Ca	1138.00
	K	371.30
	Mg	152.90
	Na	90.80
	Zn	5.53

Mineral Availability and the Structure of Wild Bee Assemblages

The prevalence of *Apis dorsata* is probably associated with its large colony size, broad foraging range and significant nutritional requirements. Larger honey bee species are recognized for utilizing spatially reliable yet nutritionally essential resources, such as mineral rich substrates, where it is more effectively than smaller bee species (Oldroyd & Nanork 2009). The significant role of *Apis dorsata* further reinforces findings that honey bees intentionally pursue mineral supplementation, especially Ca and Na which are frequently lacking in nectar and pollen diets (Nieh et al. 2003).

Despite their prevalence, stingless bees such as *Heterotrigona itama*, *Tetagonilla atripes*, *Tetragonilla collina* and *Tetragonula melina* collectively accounted for over 40% of the total individuals, contributing to a relatively high level of community evenness. Moreover, stingless bees especially *Heterotrigona itama* are capable of maintaining foraging activities under relatively warm tropical conditions, although increasing environmental temperature may influence their foraging patterns and activity levels (Samsudin et al. 2024). This situation indicates that the mineral presence at the salt lick supports coexistence among multiple species instead of competitive exclusion. Comparable trends have been recorded in various tropical systems, where adequate nutrient access lessens interspecific competition and enables functionally diverse pollinators to utilize common resources (Eltz et al. 2005; Potts et al. 2003).

A correlation analysis provides preliminary insight into the relationship between the mineral composition and bee abundance at the salt lick. Bee abundance exhibited a moderate positive relationship with Na ($r = 0.558$) and negative correlations with Ca ($r = -0.398$), K ($r = -0.507$), Zn ($r = -0.909$) and Mg ($r = -0.037$). This situation implies that Na may have a more influential role in structuring the bee visitation patterns. Moreover, Na is frequently limiting in inland ecosystems and is a known driver of soil and salt lick foraging behavior in insects (Kaspari et al. 2009; Simpson et al. 2011). The higher bee population found during dry season compared to rainy season implies that Na availability may be a significant factor determining the ecological function of salt licks as supplementary resource sites for pollinators. The higher Na concentration recorded in the dry season aligned with the active bees' activities, whereas a significant declined in Na concentration during the rainy season was corresponded with the absence of bees. Na was frequently limiting in inland tropical ecosystems and is vital for neural transmission, muscle activity and ionic balance in insects (Kaspari et al. 2008; Simpson & Raubenheimer 2012). In contrast, despite substantial positive intercorrelations, Ca, K, Zn and Mg revealed moderate connections with bee abundance, showing that their presence may reflect broad geochemical background conditions rather than directly influencing the bee attraction. In that case, the bees have been shown to selectively forage at the salt sources to make up for low Na levels in their floral diets, particularly during periods of high physiological demand (Nieh et al. 2003).

In contrast, the higher concentration of Ca, K, Mg and Zn during the rainy season did not lead to the higher visitation from wild bees. This may be caused as the wild bees preferred their foraging nutrients based on their needs and availability instead of just the presence of minerals. Furthermore, the selective foraging behavior was additionally influenced by seasonal weather conditions, since the rainfall directly limits their flight activities, foraging efficiency and sensory guidance during the rainy season. In addition, the wild bees are very responsive to moisture and rainfall, where the rainfall may disrupt their wing movement, lower body temperature and hinders their visual and smell signals used for navigation and finding resources, which resulting in a significant decrease in foraging behavior in wet conditions (Heinrich 1993; Willmer & Stone 2004). High humidity level and regular rainfall may dilute the chemical and mineral concentrations at the resource locations, such as salt lick. This situation can further diminish the site appeal even when the minerals exist. Additionally, numerous tropical plants exhibit peak flowering in drier times, where it can provide abundant of nectar, pollen and micronutrients. In that case, the necessity for the bees to look for an alternative of non-floral resources like salt licks during heavy rainfall periods was minimized during the rainy season (Nicolson 2009; Roubik 2023).

CONCLUSION

This research shows that the rocky salt lick at Sungai Papan can serve as an important supplementary habitat for wild bees in tropical forest ecosystems, as shown by the distinct seasonal patterns and assemblage structure observed. Wild bee visitation was observed exclusively during the dry season. However, this pattern may be associated with higher Na availability and seasonal differences in environmental conditions that influence foraging activity. During this period, the assemblage was dominated by *Apis dorsata*, accompanied by several stingless bee species, indicating that the salt lick supports multispecies coexistence rather than being utilized by a single taxon. In contrast, the lack of wild bees' visitation during the rainy season, even in the presence of other essential minerals like Ca, K, Mg and Zn, indicates that seasonality and environmental accessibility are of greater significance than just mineral availability in encouraging visitation. In that case, the rocky salt lick is not solely focused as mammal resources but also can act as an ecological hotspot for pollinators, where it provides a critical non-floral mineral supplementation that complements the surrounding floral resources. By influencing which species are present and in what numbers, the rocky salt lick contributes to wild bee nutrition and assemblage structure within the tropical forests. Additionally, protecting these sites therefore has direct implications for biodiversity conservation and the maintenance of pollination services. The establishment of the salt licks as seasonally sensitive microhabitats should be incorporated into forest management and pollinator conservation plans in order to preserve the long-term resilience of the wild bee assemblages in the midst of expected increases in rainfall variability due to climate change.

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AUTHORS DECLARATIONS

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Conflict of Interest
The authors declare that they have no conflicts of interest.

Ethics Declarations
No ethical issue required for this research.

Data Availability Statements
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author's Contributions
Nuramirah Mat Zain conceived the research, designed the study, conducted field and laboratory work, performed data analysis and interpretation and prepared the original manuscript. Norashikin Fauzi supervised the research, contributed to the study design, data interpretation and critical revision of the manuscript. Jayaraj Vijaya Kumaran provided research guidance and critically reviewed the manuscript. Nur Qistina Abd Aziz assisted in field sampling, data collection, laboratory work and manuscript revision. All authors participated in the revision of the manuscript, read and approved the final version.

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