

Article

The Impact of Rice Phenology on Local Bat Activity and Community Composition in Gunung Keriang, Malaysia

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Abstract

Bats' ecosystem services, especially as insect pest controllers, are often neglected. Studies on bats in the rice fields provide valuable insights into the bat species that forage during different phases of paddy growth. A bat detector was used to record bat activity at three identified sites in the rice fields of Gunung Keriang. A total of 947 recordings with 15 bat species were recorded for the dry season, and 1710 recordings with 12 bat species were recorded for the wet season. Overall, 16 bat species were identified from the recordings, including 11 forest foragers (*Rhinolophus pusillus*, *Rhinolophus affinis*, *Rhinolophus coelophyllus*, *Rhinolophus stheno*, *Rhinolophus malayanus*, *Rhinolophus refulgens*, *Hipposideros armiger*, *Hipposideros bicolor*, *Hipposideros diadema*, *Hipposideros larvatus*, and *Myotis muricola*), four edge foragers (*Taphozous melanopogon*, *Scotophilus kuhlii*, *Miniopterus pusillus*, and *Miniopterus magnater*), and one bat species of open-space forager (*Chaerephon plicatus*). Our study revealed a significant presence of *Rhinolophus* species passing through and foraging in rice fields. The results indicated that bat species associated with edges and open spaces dominated the overall bat activity in the rice fields, emphasizing the importance of rice fields as crucial foraging areas for these insectivorous bat species.

Keywords: acoustics; rice fields; Peninsular Malaysia



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1. Introduction

Bats are known for their remarkable echolocation abilities, which play a crucial role in their foraging [1,2] and navigation [3]. By emitting ultrasonic calls and analyzing the echoes that bounce back from surrounding objects, bats can effectively detect prey, avoid obstacles, and navigate through their environment [4,5]. Understanding the relationship between bat echolocation calls and their foraging behavior is essential for unraveling the ecological dynamics of bat species. In agricultural landscapes such as paddy fields, bats can serve as valuable allies in pest control and can significantly contribute to pest regulation and crop productivity. While species composition is known to vary with habitat and foraging strategies, it is less clear how these strategies shift with paddy growth phases.

Gunung Keriang, a limestone hill situated 217 m above sea level, stands prominently amidst the surrounding rice field area. This site provides an ideal habitat for bats, as it features a variety of caves of different sizes that offer a stable environment for thermoregulation and roosting. These caves serve as a habitat for a large bat colony, enabling them to roost together.

The presence of this large bat colony in the caves of the hill has a substantial impact on the local ecosystem, notably resulting in a significant reduction in insect populations in the rice fields.

Paddy cultivation undergoes distinct growing phases, including germination (period of germination until the emergence of the first leaf), vegetative (active tillering and maximum tillering stage), reproductive (booting and heading stage), ripening (milky, dough, yellow, ripening, and mature stage), and harvesting stages [6]. Each phase introduces unique environmental conditions that potentially influence bat foraging patterns. Vegetation structure, prey availability, and resource distribution vary throughout the growing season, likely affecting the echolocation calls emitted by bats. Paddy plants are semi-aquatic plants that grow in a flooded condition. Depending on the variety, paddy plants may withstand flooding for a certain period of time [7]. This condition creates a favorable environment for a diverse insect fauna. The insect fauna in the rice fields is composed of a variety of migratory and aquatic species [8], each corresponding to the different growing phases of paddy plants. The stagnant water in the rice fields is often used as a breeding ground for mosquitoes (eggs and larvae) [9]. A few studies have demonstrated that bats are efficient insect pest suppressors in agricultural areas, as they actively prey on mosquitoes [10–13]. Using the acoustics approach, we can determine which bat species display increased activity during certain periods, likely in response to the abundance of food resources present in the rice fields.

Open-space bat species often use low-frequency calls to detect objects or prey in areas with fewer obstacles, which increases their detection range [14]. Bats in different foraging guilds respond differently according to their environment based on their foraging behavior and diet composition [11,15]. In the past, bat guilds were classified mainly based on their habitat utilization [16,17]. Bat calls within the guilds are not specific, and the calls often change to adapt to the changes in their environment [14,18]. Unfortunately, it is not always possible to identify all open-space bat calls up to their species level. Due to this condition, the identification of bat species based on their calls becomes more challenging. Consequently, the classification of bat calls into sonotypes is utilized as a solution [19–21].

This study aims to investigate the echolocation calls emitted by bat species during foraging in response to the various stages of paddy growth at Gunung Keriang, Malaysia. Understanding the foraging behavior of bats in relation to the different growing phases of paddy fields can provide valuable insights for ecological conservation and agricultural management strategies. Conservation efforts can benefit from the knowledge gained by identifying the specific bat species involved in pest control within paddy fields and also collecting sonograms that can later support lure-based trapping (similarly to Preble et al., 2021 [22]). By identifying ecological needs and preserving suitable foraging habitats, we can promote the coexistence of bats and farmers and enhance the sustainable management of agricultural ecosystems. Moreover, understanding how bats adapt their echolocation calls during different growing phases of paddy fields can provide valuable insights for optimizing pest management strategies and increasing crop yields.

2. Materials and Methods

2.1. Study Area

Sampling was conducted in two different paddy field growing seasons (based on the irrigation's schedule by Muda Agricultural Development Authority (MADA) Kedah):

Season 1—Dry season (April 2021–September 2021).

Season 2—Wet season (October 2021–February 2022).

Three sampling sites were selected in the rice fields around Gunung Keriang:

- (1) MADA A (6°10' 59.2'' N, 100°19' 22.4'' E)—This site is located in a rice field area near residential areas alongside the main road, which is equipped with streetlights;

- (2) MADA B (6°11' 57.4'' N, 100°19' 50.0'' E)—This site is located in a rice field area near residential areas, adjacent to a small stream along the main road;
- (3) MADA C (6°11' 22.4'' N, 100°20' 30.2'' E)—This site is located in a rice field area near a stream that provides water to the paddy plants, with residential areas scattered along the rice fields.

The recording of bat calls was conducted every month for three consecutive days in MADA A, MADA B, and MADA C, starting from April 2021 until February 2022. There are five main phases of paddy growth: germinating, vegetative, reproductive, ripening, and harvesting. For the dry season, a sample for the reproductive phase of paddy growth was excluded due to movement restriction. For the wet season, we recorded all the phases of paddy growth.

2.2. Echolocation Call Recording

The bat activity was recorded using the bat detector Song Meter 2 (SM2) (Wildlife Acoustics, MA, USA). The bat detector was set up in the rice field area at three identified sites, with the microphone attached to a pole approximately 2 m from the ground. The device recorded bats' echolocation calls for the entire night, from 19:00 until 07:00.

2.3. Data Analysis

Bat calls recorded from the SM2 were analyzed using Kaleidoscope Pro version 5.4.6 (Wildlife Acoustics, MA, USA) using platform Mac OS. The number of bat passes per minute was used to evaluate the bat activity. A bat pass was defined as a sequence of calls with at least two sweeps within 1 s. The number of passes was recorded per hour as a relative measure of bat flight and feeding activity. We left the maximum inter-syllable gap and minimum number of pulses at the default value of 500 ms and two pulses, respectively.

For species identification, we conducted manual classification by comparing calls with the reference calls collected from a previous study (Nur-Izzati and Nurul-Ain, in preparation) as well as reference calls collected throughout this study. Only search-phase calls recorded in the flight tent and when the bat was released were used. The distress calls produced during handling were excluded to avoid bias. Parameters such as start frequency (SF), end frequency (EF), peak frequency (PF), call duration (CD), and inter-pulse interval (IPI) were measured and recorded to identify the calls to their respective species level. For the bat calls that we could not match to any reference calls collected, all the information collected on the call parameters will aid in further classifying the calls into their representative sonotypes group, such as CF, CF-FM, FM, FMqCF, and QCF. We also used the reference calls available in the bat calls library, ChiroVox [23], to identify the bat calls. The reference call library from this study is also planned for deposition in ChiroVox.

The regression model was run for each of the edge and open-space bat species, namely *Taphozous melanopogon*, *Scotophilus kuhlii*, *Miniopterus magnater*, *Miniopterus pusillus*, and *Chaerephon plicatus*, to determine which bat species are dependent on the different phases of paddy growth. The mean comparison was performed using three-way ANOVA to examine the effect of month, phase of paddy growth, and temperature on the number of bat passes in the rice fields. All the statistical analyses were performed using R version 4.3.1.

3. Results

A total of 947 acoustic files representing 15 bat species were recorded during the dry season, while 1710 files representing 12 bat species were recorded during the wet season using the SM2 bat detector. Based on the trapping, we captured a total of 1608 individual bats from six families and 21 species during the dry season, while for the wet season, 891 individuals from five families and 23 species were recorded [24]. Among the captured

individuals, three of the edge-forager guild were identified: *Scotophilus kuhlii*, *Taphozous melanopogon*, and *Miniopterus magnater*.

The sonotypes recorded represent 16 bat species, including *Taphozous melanopogon*, *Scotophilus kuhlii*, *Miniopterus pusillus*, and *Miniopterus magnater*, which belong to the edge-forager guild. Additionally, we observed *Rhinolophus pusillus*, *Rhinolophus affinis*, *Rhinolophus coelophyllus*, *Rhinolophus stheno*, *Rhinolophus malayanus*, *Rhinolophus refulgens*, *Hipposideros armiger*, *Hipposideros bicolor*, *Hipposideros diadema*, *Hipposideros larvatus*, and *Myotis muricola* from the forest-forager guild. Moreover, we also identified a potential bat species *Chaerephon plicatus* from the family Molossidae (FMqCF20) from the open-space-forager guild (Table 1). The majority of the bat calls belonged to the families Miniopteridae, Vespertilionidae, Rhinolophidae, Hipposideridae, Emballonuridae, and Molossidae. Our study focused on all the edge and open-space bat species present in different growing phases of paddy fields for both of the seasons.

Table 1. List of bats identified according to their respective sonotypes at Gunung Keriang.

Sonotype Name	Species/Potential Species	Guild	Number of Bat Passes According to Season		Percentage of Dominant Bat Activity in Phase of Paddy Growth Phase by Season (%)	
			Dry	Wet	Dry	Wet
<i>H. bicolor</i>	<i>Hipposideros bicolor</i>	Forest	2	0	Vegetative (0.4%)	0
<i>H. larvatus</i>	<i>Hipposideros larvatus</i>	Forest	7	0	Harvesting (0.3%)	0
<i>H. diadema</i>	<i>Hipposideros diadema</i>	Forest	2	23	Germination (0.9%)	Harvesting (0.3%)
<i>H. armiger</i>	<i>Hipposideros armiger</i>	Forest	14	6	Vegetative (1.3%)	Germination (0.4%)
<i>R. affinis</i>	<i>Rhinolophus affinis</i>	Forest	1	0	Harvesting (0.2%)	0
<i>R. coelophyllus</i>	<i>Rhinolophus coelophyllus</i>	Forest	14	1	Vegetative (2.2%)	0
<i>R. malayanus</i>	<i>Rhinolophus malayanus</i>	Forest	82	1	Vegetative (11.5%)	0
<i>R. stheno</i>	<i>Rhinolophus stheno</i>	Forest	41	36	Harvesting (5.2%)	Harvesting (2.0%)
<i>R. refulgens</i>	<i>Rhinolophus refulgens</i>	Forest	38	41	Germination (13.9%)	Harvesting (0.6%)
<i>R. pusillus</i>	<i>Rhinolophus pusillus</i>	Forest	72	161	Harvesting (9.5%)	Harvesting (2.4%)
<i>M. muricola</i>	<i>Myotis muricola</i>	Forest	0	3	0	Germination (0.3%)
<i>S. kuhlii</i>	<i>Scotophilus kuhlii</i>	Edge	471	2237	Ripening (44.7%)	Harvesting (29.1%)
FMqCF72	<i>Miniopterus pusillus</i> *	Edge	665	1724	Germination (55.3%)	Germination (28.1%)
<i>M. magnater</i>	<i>Miniopterus magnater</i>	Edge	1	2	Vegetative (0.2%)	0
FMqCF20	<i>Chaerephon plicatus</i> *	Open space	5	252	Harvesting (0.8%)	Harvesting (3.7%)
<i>T. melanopogon</i>	<i>Taphozous melanopogon</i>	Edge	67	3124	Germination (17.6%)	Germination (42.1%)

* This species was not captured using the trapping method in this study.

In the dry season, five edge and open-space bat species were recorded using SM2, including *T. melanopogon*, *S. kuhlii*, *M. pusillus*, *M. magnater*, and *C. plicatus*. The recorded families were Miniopteridae (44.94%), Vespertilionidae (31.78%), Rhinolophidae (16.73%), Emballonuridae (4.52%), Hipposideridae (1.69%), and Molossidae (0.34%). During this season, the majority of the calls were from the FMqCF component, with *M. pusillus* dominating the recorded calls. The overall bat activity displayed two peaks throughout the night, occurring from 20:00 to 21:00 and 04:00 to 05:00. Among the edge and open-space bat species, *M. pusillus*, *C. plicatus*, and *M. magnater* exhibited a single peak time throughout the night, aligned with the first peak time of overall bat activity. *Taphozous melanopogon* and *S. kuhlii* also followed the first peak time of overall bat activity but with different second peak times of activity. The second peak time for *T. melanopogon* was observed between 01:00 and 02:00, while for *S. kuhlii*, it occurred between 06:00 and 07:00.

Four edge and open-space bat species were also recorded in the wet season: *T. melanopogon*, *S. kuhlii*, *M. pusillus*, and *C. plicatus*. The bat calls recorded were from the families Miniopteridae (57.34%), Vespertilionidae (26.09%), Emballonuridae (5.54%), Rhinolophidae (4.41%), Molossidae (3.27%), and Hipposideridae (0.38%). There were fewer bat calls recorded in this season, with *T. melanopogon* dominating the recorded calls. The overall bat activity exhibited two peaks during the night, occurring from 20:00 to 21:00 and 06:00 to 07:00. *Scotophilus kuhlii* and *M. pusillus* shared the same peak time as the overall bat activity. *Taphozous melanopogon*, on the other hand, was active from 22:00 to 23:00 and 06:00 to 07:00, aligned with the second peak time of overall bat activity. *Chaerephon plicatus* showed a peak time from 21:00 to 22:00 and 05:00 to 06:00.

In the wet season, the detector recorded either a few bat individuals or no bats during the period before or after rain and occasionally no bats at all after rain. For the edge and open-space bat species, their emergence followed the peak time of overall bat activity. *Taphozous melanopogon* demonstrated irregular emergence, being late compared to the rest of the bat species and remaining actively foraging throughout the night.

The number of bat passes varied across different phases of paddy growth and between seasons as well (Figure 1). The highest number of bat passes indicated the highest bat activity exhibited by the bat species. In the dry season, the overall bat passes were highest during the vegetative and harvesting phases. We observed active foraging by *R. malayanus* and *R. refulgens* during the vegetative phase, with *R. refulgens* showing the highest activity during the germination phase. In the wet season, the bat passes were highest during the germination and harvesting phase. Notably, *R. pusillus* showed active foraging during the harvesting phase, along with *R. stheno*.

Our findings reveal that the edge and open-space bat species were actively engaged in foraging during the harvesting phase in both seasons (Figures 2 and 3). Intriguingly, during the dry season, *T. melanopogon*, *S. kuhlii*, and *M. magnater* had the highest number of bat passes during the vegetative phase. In contrast, *M. pusillus* and *C. plicatus* demonstrated increased activity during the harvesting phase. Meanwhile, in the wet season, *T. melanopogon* and *S. kuhlii* recorded the highest number of bat passes in the germination and harvesting phases. *Miniopterus magnater* recorded the highest number of bat passes during the germination phase, while *M. pusillus* and *C. plicatus* exhibited the highest number of bat passes during the harvesting phase.

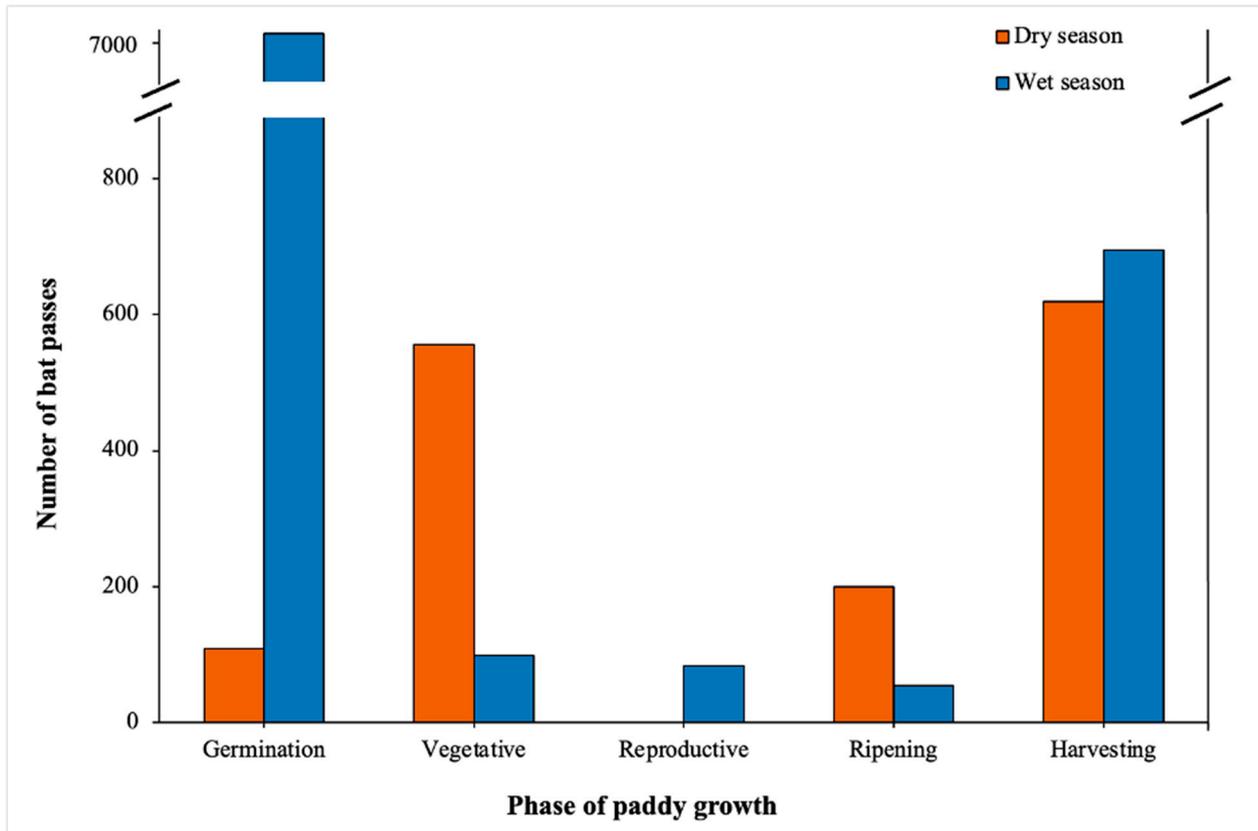


Figure 1. The number of bats passes across different growing phases of paddy in both the dry and wet seasons.

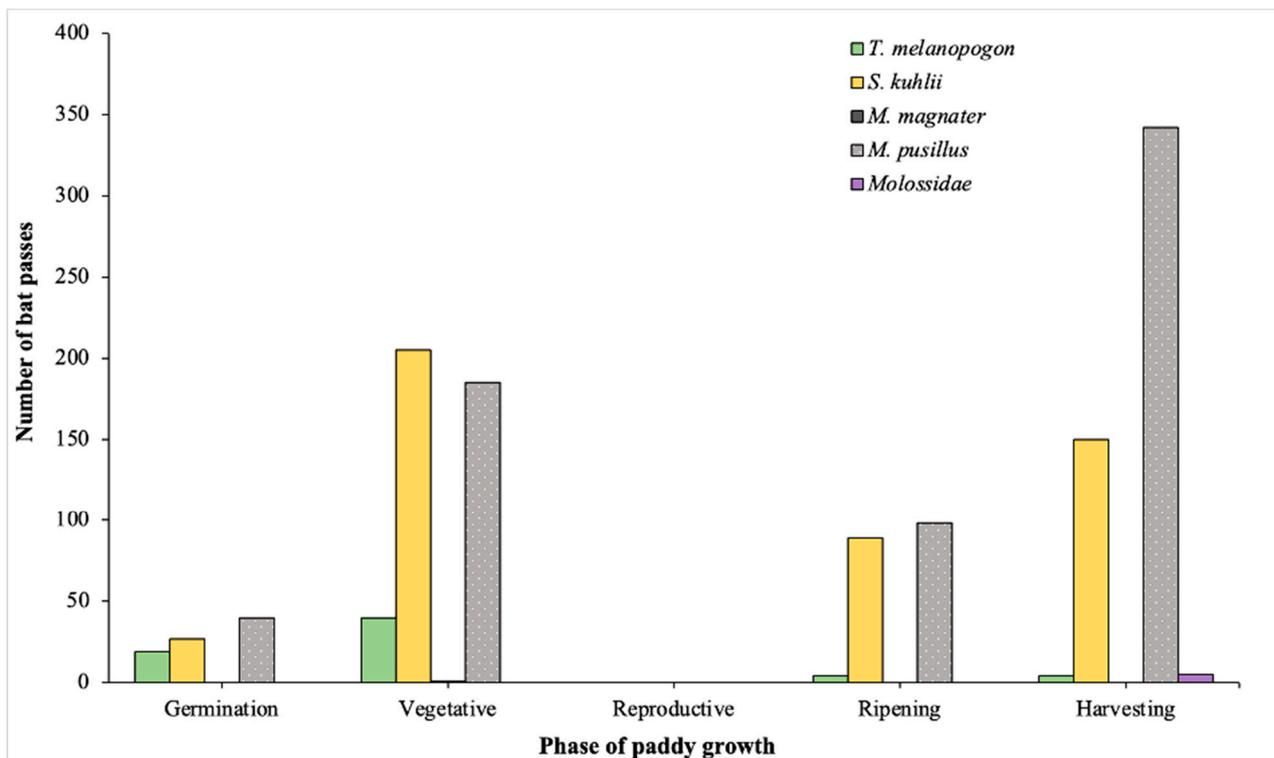


Figure 2. The number of bat passes for open-space and edge bat species in different growing phases of paddy for dry season.

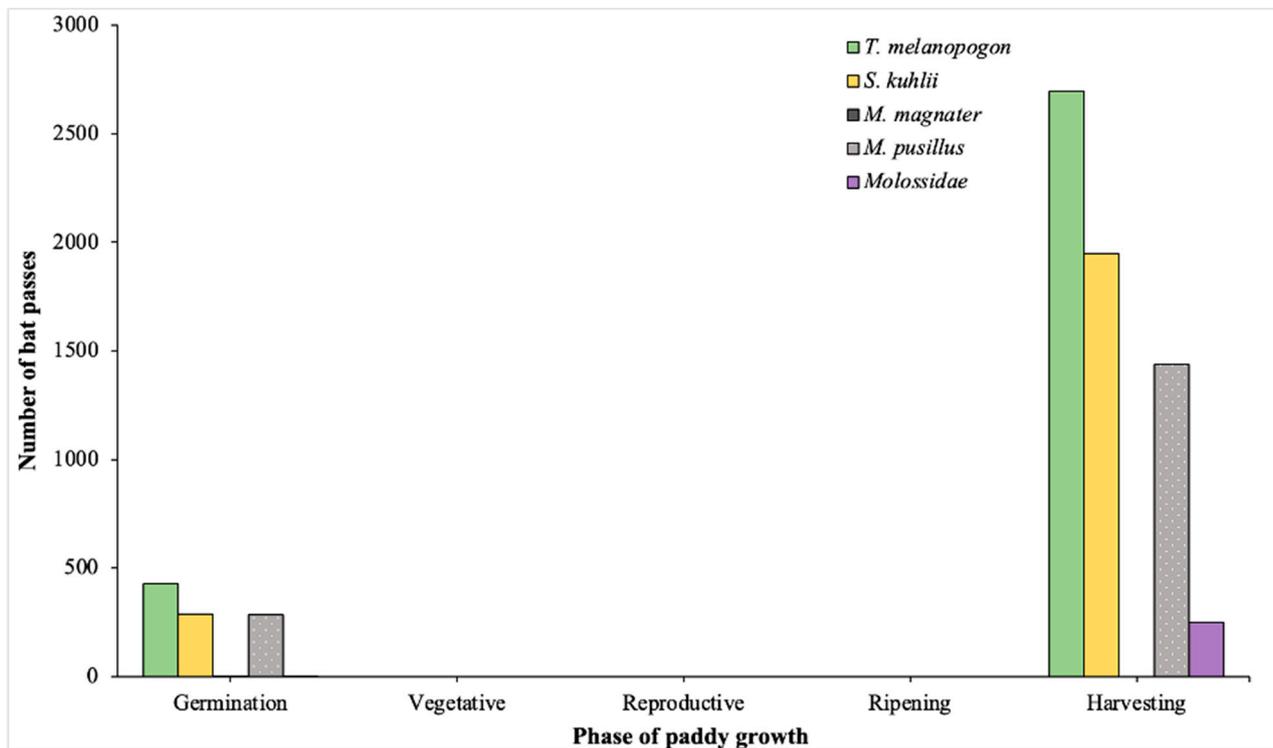


Figure 3. The number of bat passes for open-space and edge bat species in different growing phases of paddy for wet season.

When comparing overall bat passes among different bat species, in the dry season, *M. pusillus* was the dominant bat species, followed by *S. kuhlii* and *R. malayanus*. We only observed a single bat pass by *M. magnater* and *R. affinis* during this season. In the wet season, *T. melanopogon* exhibited the highest number of bat passes compared to the other bat species, followed by *S. kuhlii* and *M. pusillus*. We observed only single bat passes for *R. malayanus* and *R. coelophyllus* during this season. We also recorded a considerable number of *R. pusillus* and *R. steno* as well in this season.

A significant seasonal effect on bat activity was observed, particularly in the wet season ($F_{(1,59)} = 8.95$; $p = 0.0041$). However, we observed no significant effect of any of the phases of paddy growth. Furthermore, none of the edge and open-space bat species exhibited dependence on any of the phases of paddy growth in any season as well. Regarding the interactions among the three variables (month, paddy growth phases, and temperature), none exhibited statistical significance concerning bat activity in the rice fields. The results indicated non-significant effects for the month ($F_{(8,32)} = 0.89$; $p = 0.53$), paddy growth phases ($F_{(4,32)} = 1.03$; $p = 0.41$), and temperature ($F_{(1,32)} = 0.17$; $p = 0.68$). These findings imply that none of these factors significantly influenced the number of bat passes. However, we did observe statistically significant impacts of the interactions between the month and insect abundance on bat activity in the rice fields.

4. Discussion

Six bat species from the family Rhinolophidae were recorded in this study. A study conducted by Dendup et al. (2021) [25] reported that *Rhinolophus* species are rarely observed in open spaces such as rice fields. However, our study revealed a significant presence of *Rhinolophus* species passing through and foraging in the rice fields, contrary to previous findings. *Rhinolophus* species are commonly found in cluttered habitats and have been reported as the most abundant bat species in a previous study by Kingston et al. (2003) [26] and one by Dendup et al. (2021) [25]. The echolocation calls emitted by bats are highly

influenced by habitat complexity and food availability within their foraging area [25,27]. *Hipposideros bicolor* was recorded by the SM2, indicating its presence in the study area. This bat species is known as a forest and edge forager, often found in forest gaps and the understory of primary and secondary forests. They can also be found foraging in orchards, agricultural settings, or plantations near roosting caves [28]. The recorded bat calls from *H. bicolor* suggest that it also opportunistically forages within rice fields. Taken together, the occurrence of *Rhinolophidae* and *Hipposideridae* in this study area is likely linked to the limited availability of forested habitats, with the nearest large forest patch located more than 20 km away, thereby driving these species to exploit rice fields as alternative foraging sites.

This study revealed that the different paddy growth phases do not affect bat activity in the rice fields. Instead, the abundance of insects directly affects the number of bat passes. A higher presence of edge and open-space bat species during the early and end stages of paddy planting indicates their response to the availability of insects in the landscape. This highlights the predator–prey interdependence within rice field ecosystems, where fluctuations in food supply directly affect predator behavior and abundance. Such results support the role of rice fields as important foraging grounds for insectivorous bat species [29]. It is well established that insect availability underpins seasonal variation in bat activity. In our study area, the primary prey groups consumed by insectivorous bats include Coleoptera, Lepidoptera, Diptera, and Hemiptera, as reported in our earlier dietary study [30]. While we do not repeat detailed dietary analyses here, fluctuations in these insect taxa likely explain the seasonal patterns of bat activity observed in the present study.

The growing phases of paddy fields, including germination, vegetative, reproductive, ripening, and harvesting, are closely linked to the pest life cycles [31,32]. For instance, brown planthoppers (*Nilaparvata lugens*: Hemiptera) attack paddy plants from the vegetative to ripening stages, feeding on the sap of the plant, whereas stem borers (*Chilo polychrysus*: Lepidoptera) infest mainly during the vegetative phase, targeting the leaves and stems [33–36]. These distinct patterns suggest that insect populations are stage-specific, but our results indicate that bat activity responds more strongly to overall insect abundance than to the paddy growth phase itself. Environmental factors such as rainfall and temperature are likely stronger determinants of insect fluctuations [37]. The damage caused by insect pests can disrupt the physiology of paddy plants and lead to a decrease in crop yield [38]. Synchronized planting by the farmer will minimize the continuous infestation by these insect pests. Furthermore, planting different varieties will also help to minimize the proliferation of pests, ultimately resulting in decreased pesticide usage [39].

Seasonal differences further highlight the connection between food supply and bat activity. Distinct bat species dominated in the dry versus wet seasons, reflecting dietary preferences and variation in insect community composition [30,40]. Food availability strongly influences bat activity within the region. Agricultural settings like rice fields support a substantial population of aquatic insects, which plays a crucial role in attracting bat activity due to the presence of water bodies [28,41]. For instance, coleopterans, hemipterans, and dipterans are known to rely on the presence of water bodies in the rice fields for breeding. The swarming of these insects in turn attracts bats to feed in the rice fields. The timing of bat emergence also varied: Some species mirrored overall peaks of activity, while others emerged later. In the wet season, peak bat activity did not always coincide with peak insect emergence, likely due to intermittent rainfall altering insect availability. Bats also appeared to stagger emergence times to reduce intra- and interspecific competition [42]. Feeding buzzes recorded across the study sites confirm that rice fields serve as active foraging grounds for multiple bat species.

To date, no prior surveys have used ultrasonic detectors specifically in Malaysian rice fields. The only available inventory of the Muda Rice agroecosystem, by Shah et al. (2008) [43], relied on mist netting techniques and documented two edge bat species, *Scotophilus kuhlii* and *Taphozous saccolaimus*. In contrast, our study detected multiple species not previously reported, underscoring the advantages of acoustic survey. Similar findings have been reported in Thailand, where acoustic monitoring revealed seasonal variation in bat diversity and activity within rice agroecosystems [44–47]. Acoustic techniques have proven particularly effective at detecting high-flying, echolocating insectivores that would otherwise be missed using mist nets alone, suggesting that their application in Malaysian rice fields could greatly improve species inventories and facilitate cross-regional comparisons.

From a methodological perspective, our results reinforce that no single sampling technique is sufficient to capture the full diversity of bats in agroecosystems. Mist nets and harp traps remain valuable for collecting morphological, genetic, and dietary data, but they underrepresent aerial insectivores that fly above netting height or detect and avoid nets via echolocation [48–50]. Acoustic monitoring, though requiring time-intensive call verification and manual processing [51], is efficient for detecting a wide range of species and behaviors. Social calls, in particular, are more reliably captured by acoustic monitoring systems, and advanced detectors can even classify calls into ethograms [52], providing novel opportunities for behavioral studies. The development of acoustic lures based on synthetic calls [22] also suggests new synergies between passive monitoring and capture-based methods.

While some studies reported no significant differences between acoustic and capture methods [53], our findings align with O’Farrell & Gannon (1999) [54] and MacSwiney et al. (2008) [49], demonstrating that acoustic surveys capture greater species richness in open landscapes. In our case, acoustic monitoring revealed a higher diversity of edge and open-space species than mist netting [25]. The simultaneous use of both methods in this study allowed for direct comparison, highlighting how their integration yields the most complete picture of bat community composition [55].

Taken together, these results demonstrate that rice fields in Malaysia serve as significant foraging habitats for a variety of insectivorous bat species. Seasonal and temporal differences in activity patterns reflect both prey availability and adaptive strategies to minimize competition. Although methodological limitations exist, the combined use of acoustic and trapping approaches provides a stronger foundation for documenting species richness and ecological interactions. Understanding bat foraging in rice landscapes is critical not only for advancing ecological knowledge but also for guiding conservation strategies and biodiversity-friendly agricultural practices across Southeast Asia.

5. Conclusions

Our study demonstrates that bat activity within rice fields is significantly influenced by seasonal variation, primarily driven by insect abundance rather than the specific growth phases of paddy fields. Although various bat species, particularly edge and open-space foragers, were active throughout the paddy growth cycle, no species showed a statistically significant dependency on any particular phase. These findings underscore the ecological role of rice fields as important foraging grounds for insectivorous bats and highlight the value of integrating acoustic monitoring with traditional trapping methods for comprehensive biodiversity assessments. Strengthening bat conservation within agricultural landscapes not only contributes to sustainable pest management but also promotes biodiversity-friendly rice farming practices.

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Data Availability Statement: Data are contained within the article.

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