Bat community response to insect abundance in relation to rice phenology in Peninsular Malaysia

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Abstract

Bats provide us with important ecosystem services including insect population controllers in agricultural areas. Studies on bats and insect abundance in Malaysian rice fields are still lacking. Two harp traps and two mist nets were used to trap bats at the Gunung Keriang while a light trap was used to sample insects in the rice field area at three identified sites. A total of 2499 bats from 27 species were captured and for insect abundance a total of 161,539 individuals from 11 orders were captured. Rhinolophus pusillus was recorded as the dominant bat species in all seasons. In the dry season, the dominant insect pest was *Chilo polychrysus* (Stem borer) and in the wet season, *Nilaparvata lugens* (Brown planthopper) the dominant insect pest species. Insects from the Order Coleoptera (the dominant insect Order in dry season) may be eaten by bats that have a larger body size and that have a strong bite force. Due to high food availability and insect abundance, the peak time of bat foraging activity is the same as the peak time of insect emergence. We found that there is a significant relationship between bat activity with temperature and rainfall, but not with insect abundance. This study further highlights the importance of bats in regulating the insect pests population naturally in the rice field area.

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Keywords

Rice fields, Limestone karst, Insect pest controller, Biological control, Biodiversity conservation

Introduction

Bats provide us with important ecosystem services. Bats serve as pollinators, seed dispersers and insect population controllers (Kunz*et al* ., 2011; Vincenot *et al* ., 2017). Locusts, planthoppers, leafhoppers, and rice stem borers are common insect pests in rice fields (Khoo *et al* ., 1991; Whitaker, 1993). Chemical, physical, and biological controls are the main option for pest controls in agricultural areas especially in rice fields. The usage of chemicals such as herbicide, rodenticide and insecticide has been proven to have a long-term effect towards the ecosystem (Chiaia-Hernandez *et al* ., 2017).

Biological controls can also be a good option since it is more efficient as all pests have their own natural enemies (Ooi, 2015). However, this approach has long been neglected, probably due to either ignorance or to farmers preferring immediate results. Barn owls (*Tyto alba*) have been infrequently used to control rat populations in rice fields (Hafidzi, 2003; Hafidzi & Naim, 2003). Using insects that are natural predators of insect pests is another example of biological control. Ladybugs, ants, spiders, dragonflies and mirids (Way & Heong, 1994; Ooi, 2015) as well as some vertebrates like frogs, birds, and bats (Leelapaibul *et al.,* 2005) can control the insect pest population naturally. Since rice fields have become the foraging areas for bats, they can potentially be a biological control for insect pests (Lee & McCracken, 2005).

Insect-eating bats play a role as a natural predator in safeguarding the surrounding protected areas as a biological control (Lee & McCracken, 2005). About 70% of bats are insectivorous (Simmons, 2005). Caves serve as an essential roosting site for many bat species all around the world. In caves, bats often roost in a large colony, which can result in the large-scale depletion of insects, especially insect pests in the surrounding agricultural area.

The contribution of bats towards controlling agricultural pests has been mostly documented in the United States (McCracken *et al.* , 2010; Boyles *et al.* , 2011), some parts of Canada (Clare *et al.* , 2009), Europe (Puig-Montserrat *et al.* , 2015) and Madagascar (Kemp*et al.* , 2019). In Southeast Asia, Thailand (Leelapaibul *et al.* , 2003; Leelapaibul *et al.* , 2005; Wanger *et al.* , 2014) has the highest reported studies of bats in rice field areas. However, the situation remains unclear in Malaysia and other Southeast Asian countries. Studies on bats in Malaysian rice field areas are still lacking and more information is needed to determine their contribution to the ecosystem.

The objective of this study is to document the insect abundance and insect pest availability at different growing phases of paddies during various growing seasons in rice fields nearby Gunung Keriang. Up to date, there is still a lack of data regarding insect abundance especially insect pests at different growing phase of paddy in rice field area. This study aimed to test the importance of bats to potentially help to control insect pest population naturally in the rice field areas.

Methods and materials

Study area

Gunung Keriang is a small limestone hill rising out from a vast rice field areas north of Alor Setar (northern Peninsular Malaysia). Sampling was conducted in two different paddy growing seasons (based on MADA's irrigation schedule):

Season 1 – dry season (started in April 2021 end in September 2021)

Season 2 – wet season (started in October 2021 end in February 2022)

Three identified sites were chosen around Gunung Keriang: MADA A (6°10' 59.2" N, 100°19' 22.4" E), MADA B (6°11' 57.4" N, 100°19' 50.0" E), and MADA C (6°11' 22.4" N, 100°20' 30.2" E) (Figure 1).

The trapping 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 growing which are germination, vegetative, reproductive, ripening and harvesting. For the dry season, the reproductive phase was excluded due to restriction movement that was implemented during that growing phase of paddy. For the wet season, we recorded all the phases of paddy growth.

Insect Trapping

Insects were sampled using light traps that were placed at the three identified sites before sunset. Each light trap used 60W 12V tungsten bulbs and were set more than 1km distance from one another within a 2km radius from Gunung Keriang where the harp traps are located. Insect collections were conducted every hour starting at 19:00 until 07:00. The trapped insects were killed by using ethyl acetate, following this they were sorted and identified to Order or Family level based on Salleh (1990) and Borror *et al.* (1996). Selected insect pests were identified to species and then stored in 97% alcohol for future molecular analysis.

Bat Trapping

Insectivorous bats were captured using two harp traps at different elevations of Gunung Keriang (top, middle and low) and two high nets were also used in the rice field area, for three consecutive nights per sampling. High nets were set up at dusk (19:00), were checked every 10 to 15 minutes and were closed at 22:00. Harp traps were set up at midnight (00:00), were checked every hour and were closed just after dawn (07:00). Captured bats will be weighed, sexed and identified based on their morphology (Kingston *et al.* , 2006).

Local weather monitoring

The total monthly rainfall, plus the maximum and minimum monthly temperature were provided by the Malaysian Meteorology Department for Alor Setar, Kedah.

Data analysis

Peak time of insect emergence was analyzed based on the number of insects collected per hour. It can be associated with bat foraging activity in the following objective of the study. Insect presence was used to estimate food availability for bats based on different stages of paddy growth (germination, vegetative, reproductive, ripening and harvesting). Insect data is recorded in two parameters: relative abundance (number of insects of specific taxa/total number of insects) and absolute abundance (number of insects of specific taxa). All the statistical analyses were calculated in R version 4.2.2. The Pearson parametric correlation test was used for the correlation analysis. The variables were first centered and scaled before running for the statistical test. For the multiple linear regression, the model used is lm(bat activity ~ minimum temperature + rainfall, data=mydata). We also run the regression model for these dominant bat species: *Rhinolophus pusillus* , *Myotis ridleyi* ,*Hipposideros larvatus* , *Rhinolophus malayanus* and*Rhinolophus refulgens* . Multiple linear regression requires some conditions of application for the model to be usable and the results can be interpretable. The function check_model() from the {performance} package was used to test all of the conditions of the model.

Results

A total 2499 individual bats from 6 Orders and 27 species were captured. 1608 individuals from 6 Orders and 21 species were recorded for the dry season and 891 individuals from 5 Orders and 23 species were recorded for the wet season (Table 1). *Rhinolophus pusillus* was recorded as the dominant bat species with the highest capture rate in the dry season as well wet season. Throughout this study, a few single individuals of rare bats were encountered and species that had never been recorded previously at Gunung Keriang. These were*Hipposideros halophyllus* and *Rhinolophus marshalli* .*Miniopterus magnater* and *Scotophilus kuhlii* are a few open space bat species that were captured in the dry season. In the wet season, single individuals of *Macroglossus minimus* and*Cynopterus sphinx* , the frugivorous bats, were caught.

Based on the correlogram, the results show that the bat activity was positively correlated with the average temperature and negatively correlated with maximum temperature and rainfall (see diagnostic plot in Suppl. Mat. Table 1). The insect activity was positively correlated with minimum temperature and rainfall (Figure 2). The multiple linear regression model met the conditions of validity (see diagnostic plot in Suppl. Mat. Figure 1).

The coefficient of determination, R^2 is 0.35, therefore this indicates that 35% of the variance in bat activity can be explained by the predictors based on the model (Figure 3). The coefficient value for minimum temperature is significant with a p-value of 0.007 while rainfall is significant with a p-value of 0.002. Regression analysis for the five bat species separately did not return statistically significant results and were therefore discarded.

For the dry season, 12 Orders of insects were recorded at the rice fields (Figure 4) and the dominant insect Order was Coleoptera. The germination phase of the paddy had the highest insect abundance compared to the rest of the paddy phases. *Chilo polychrysus* (Stem borer) from the Order Lepidoptera is the insect pest species that was captured for all phases of paddy growth in the dry season.

Meanwhile for the wet season, 13 Orders of insects were also recorded at the rice fields (Figure 5). The dominant insect Order for this season is Homoptera. The vegetative phase recorded the highest insect abundance compared to the rest of the paddy phases. *Nilaparvata lugens*(Brown planthopper) from the Order Hemiptera is the insect pest species that was captured for all phases of paddy growth in the wet season.

Insects from the Orders Araneae and Odonata have also been captured in the dry and wet season. These two insect Orders are known to be natural enemies of insect pests in rice fields. From the Order Araneae,*Lycosa pseudoannulata* was the most common species captured and for the Order Odonata, *Agriocnemis* sp. was the most common species captured. The most common natural enemies of insect pests in rice field area are *Ophionea* sp., *Paederus fuscipes* ,*Harmonia octomaculata* , *Euborellia stali* , *Limnogonous fossarum* and *Riptortus linearis* .

Peak time of insect emergence with the highest individuals captured for dry season was from 20:00 until 21:00 while for wet season, 19:00 until 20:00 (Figure 6). This time frame is expected to be the same as peak time of the bat foraging activity. The time of bat emergence in the dry season was from 19:00 until 21:00 while for wet season was from 20:00 until 21:00.

Discussion

Bats are known as opportunistic feeders which consume insects that fit the best for their diet in terms of nutritional value and also depends on their energy demand. Coleoptera is the most abundant insect Order captured. Order Coleoptera possess a high number of insect species with a wide range of size (Chown & Gaston, 2010). Insects from the Order Coleoptera also may be eaten by bats that have a larger body size, and that have a strong bite force to feed on the hard-bodied prey. Bats with bigger body sizes have more robust skulls and larger teeth, so these bats are able to consume a wider size range and more hard-bodied prey (Aguirre *et al* ., 2003). However, it is still unsure that only bigger bats only will consume insects from the Order Coleoptera. Bats are known to regulate quite a number of insect pest Orders such as Coleoptera, Lepidoptera, Diptera, Hemiptera and Isoptera (Kunz *et al.* , 2011).

The preliminary diet analysis study of *Taphozous melanopogon*(black-bearded Tomb bat) in rice field area in Gunung Keriang found that they mainly consume insects from the Orders Lepidoptera, Coleoptera and Diptera (Nur-Izzati & Nurul-Ain, 2019). *Rhinolophus pusillus* was the most captured bat in the dry and wet season with insects from the Order Coleoptera being the most captured insect Order throughout the study. It is possible that *R. pusillus* may feed on insects from the Order Coleoptera since both of them had the highest capture rate. In this study, *R. pusillus* was captured the most during dawn from 03:00 until 07:00.

Insects from the Order Coleoptera were sampled throughout the night, but their abundance is the highest during dusk. Further study should be carried out to prove that *R. pusillus*feed on insects from the Order Coleoptera in the near future.

The results from the regression in this study indicate that the predictors are actually partially explaining the bat activity. Since none of the contributions of the variables could not be statistically established, there are definitely more important factors that play valuable roles in influencing the results, such as the amount of light, humidity or the result from the pooling of bats and insects. Since we only take into account the temperature and rainfall in this study, other variables may have been neglected. Moonlight and streetlight may affect the insects that bats consume and also some bats may benefit from it (Rowse *et al* ., 2016). Slow-flying bats are highly affected by the illuminance as this bat species forage insects in cluttered vegetation and expose to predation rather than fast-flying bats such as open space bat species which benefit by the large swarming of the flying insects near streetlights (Azam *et al* ., 2015; Azam *et al* ., 2015).

Bat activity is often associated with local microclimates such as temperature and rainfall while insect activity is proven to rely on rainfall instead of temperature (Nurul-Ain *et al* ., 2017). In this study, we found that bat activity was influenced by temperature and rainfall. Bats would avoid emerging from their roost site during rain to avoid sensory constraint by rain drops on echolocation and emerge right after the rain stops. Based on this observation, in the wet season, there were only few or no bats before and after rain. But still a few bat species would forage in rain when the resources offer a sufficient energy gain (Voigt *et al.* , 2010). Bats also tend to have a few peak times on rainy nights. Bats emerge from their roosts starting at dusk and actively forage for the first hour and just before dawn. A few studies also reported that bat emergence and activity is associated with the fluctuation in temperature (Wolbert *et al* ., 2014; Gorman*et al* ., 2021). Due to high food availability and insect abundance, the peak time of bat foraging activity is the same as the peak time of insect emergence.

The insect abundance in each growing phase of paddy is diverse according to different seasons. Different parts of the paddy plant such as leaf, stem, seeds, and root were usually attacked by insect pests during the development period of the plant (Maisarah *et al* ., 2015).*Chilo polychrysus* (Stem borer) was the dominant insect pest captured in the dry season while *Nilaparvata lugens* (Brown planthopper) was the dominant insect pest captured in the wet season. In this study, a conspicuous pattern was shown by the brown planthoppers as they are the dominant insect pest captured in the wet season. The high population of brown planthoppers is related to the heavy rainfall, high temperature and high humidity (Win *et al* ., 2011). Throughout this study, insect activity was higher on warmer nights. The rainfall may not affect the overall insect activity but impact certain insect species. Further investigation should be made to find out more regarding the relation of which insect Order or species is affected by the temperature.

Brown planthoppers are highly attracted to light and were caught the most when using light traps. Light traps are commonly used to sample insect populations. By using light traps, it aids in monitoring the actual pest population in the field. The light trap usage also is more reliable and gains more accurate results in predicting the risk and damage to the crops (Mohammad Aufa *et al.* 2022). The early detection of insect pest density, the population growth and the risk of outbreak events can be successfully predicted for the late crop stage (Badrulhadza *et al* ., 2013). The Malaysia Agriculture Research and Development Institute (MARDI) has created an early warning system that would also help with a better insecticide application schedule plan where there is a huge possibility of preventing excessive pesticide usage and avoiding wasting operation costs (Mohammad Aufa *et al.*2022).

Insects from the Order Araneae and Odonata have also been captured along with a few other insects that are known to be natural predators of insect pests in rice fields (Ooi, 2015). *Cyrthorhinus lividipennis* and spiders are two important predator species that aid in reducing the population of the planthopper (brown planthopper, *N. lugens* and whitebacked planthopper, *Sogatella furcifera*) (Ooi*et al.* 1978; Ooi, 1980; Ooi, 1982). *Agriocnemis* sp. and*Harmonia octomaculata* were commonly sighted throughout our study in the rice field areas. The increase in the predator population in the rice fields was correlated with the abrupt increase in the pest population (Ooi *et al.* 1978). An effort should be made to ensure the predator population in the rice field area will remain continual to prevent any recurrent outbreaks.

Based on the IUCN Red List of Threatened Species, *Rhinolophus convexus* was listed as data deficient (DD), *Hipposideros pomona*as endangered (EN), *Hipposideros halophyllus* as vulnerable (VU),*Myotis ridleyi* and *Hipposideros lekaguli* as near threatened (NT) and the rest of the bat species captured in this study were listed as least concern (LC) (IUCN, 2023). By capturing more*R. convexus* in the future, perhaps we can investigate and learn more regarding this species' dietary habits and their potential foraging ground. A high number of *Myotis ridleyi* individuals were captured suggesting that the decrease in this bat species population may have a huge impact on the rice fields.

Our study further emphasizes on the role of bats in regulating insect pests populations in agricultural areas such as rice fields. By investigating their diet and microclimate factors, not only allows us to gain a better insight on their environmental services, but also helps us in understanding their behavior which is vital for mitigating conservation plans. Even though the usage of insecticide is still widely used by farmers, the combination of ecological-friendly methods for controlling pests in agricultural areas help to ensure the sustainable agriculture system. It helps to increase crop production and lower the damages sustained by pests. Minimizing the chemical usage in rice fields can slow down the process of pesticide resistance among insect pests. The importance of understanding the need to conserve bats and their roost site at Gunung Keriang is crucial as the bats aid in controlling insect pest populations naturally in the rice fields.

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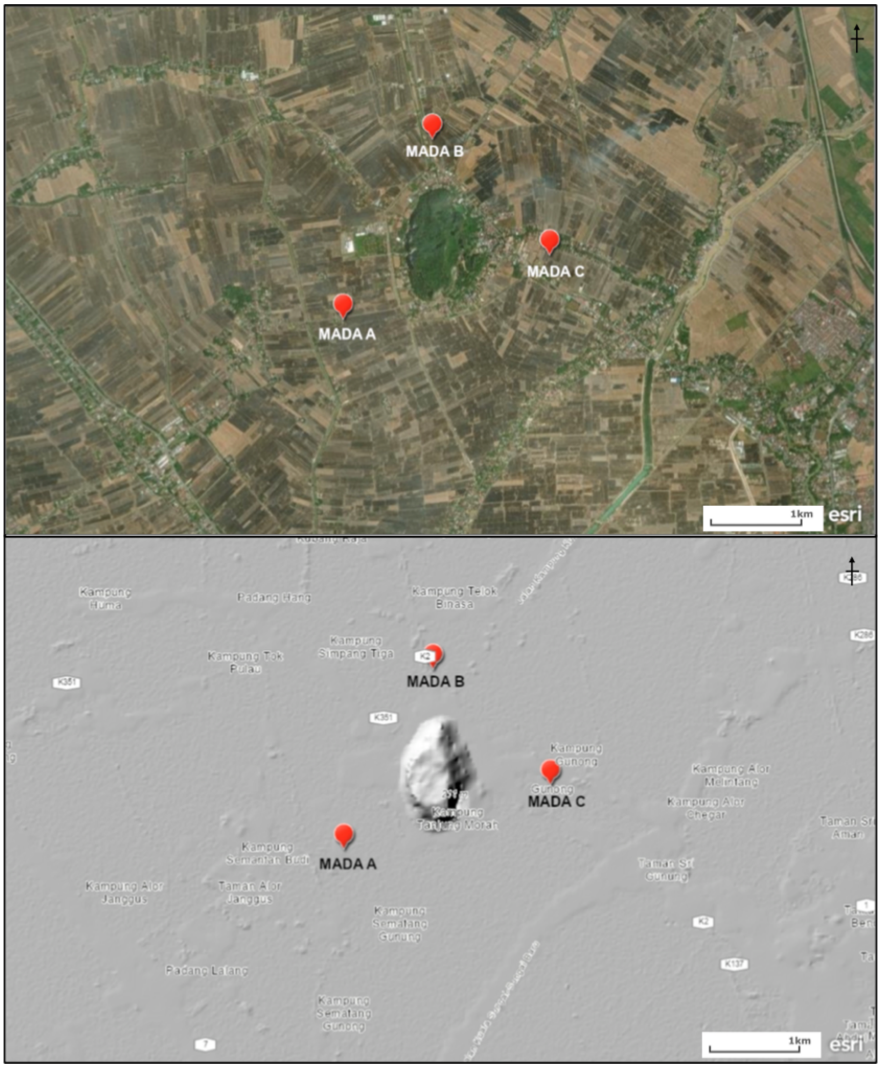
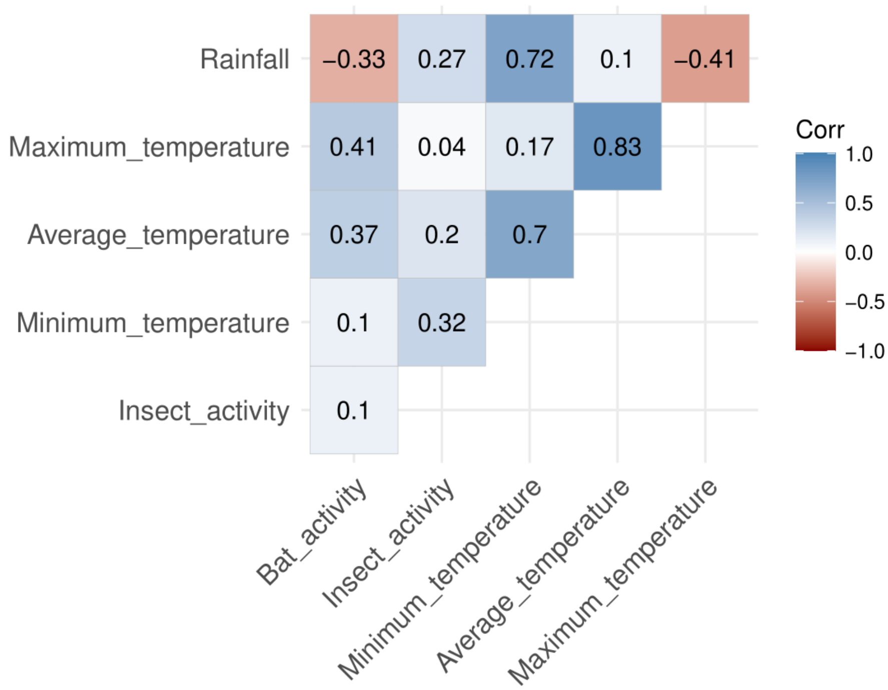
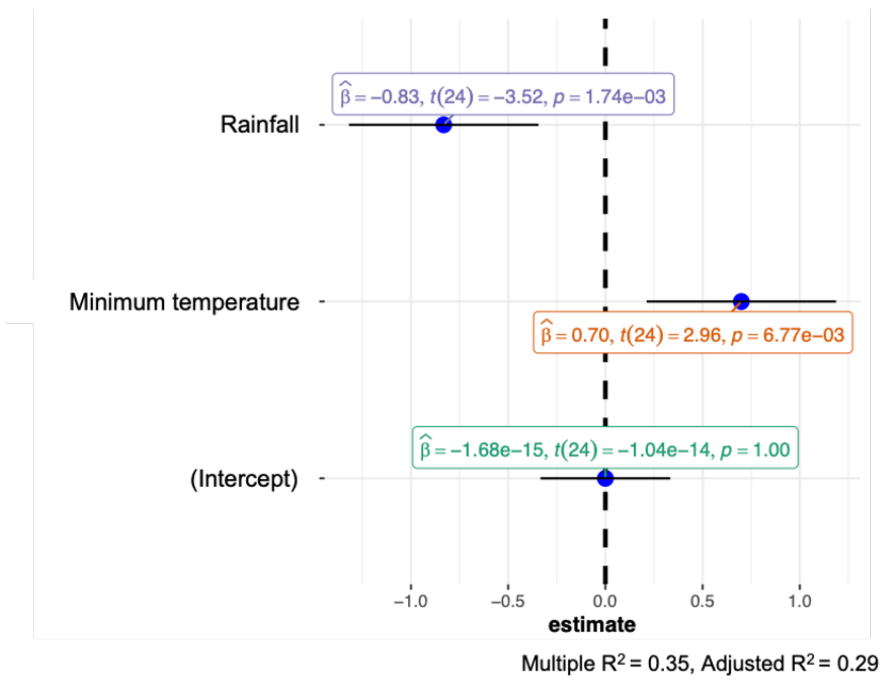
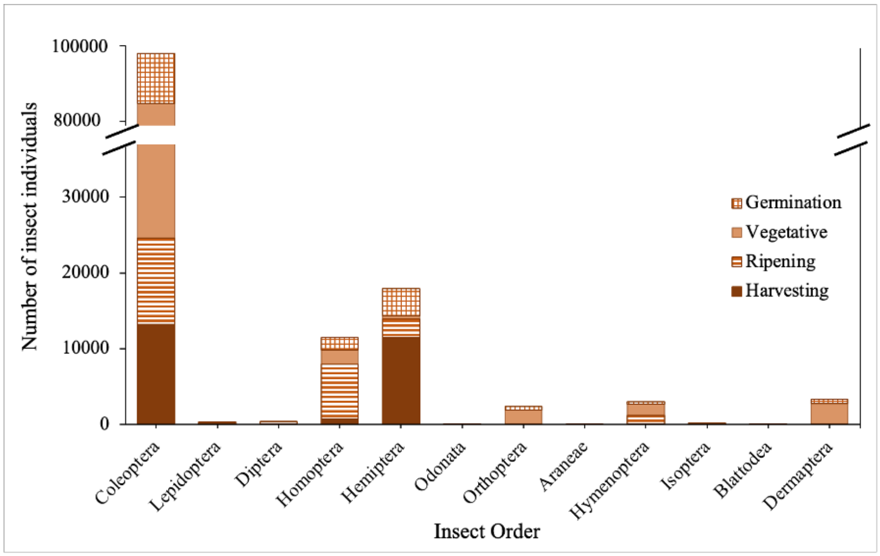
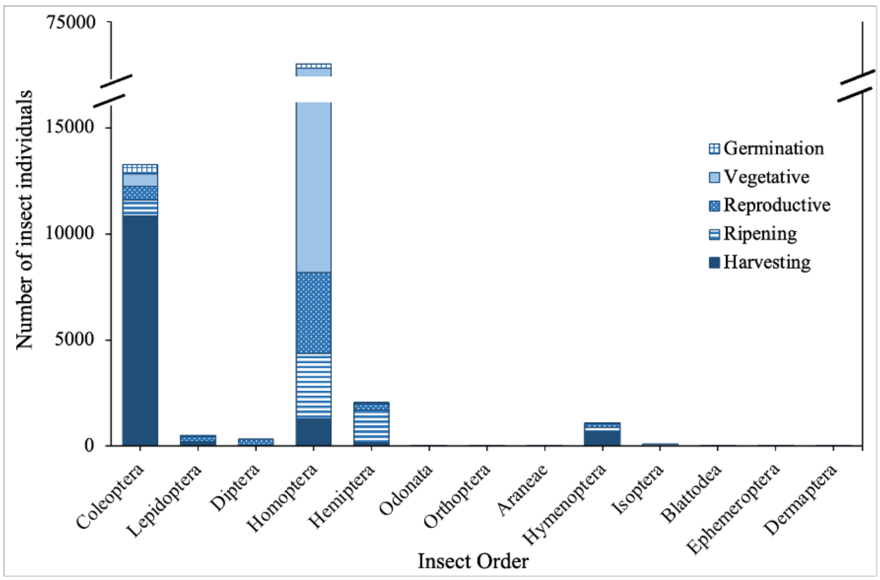
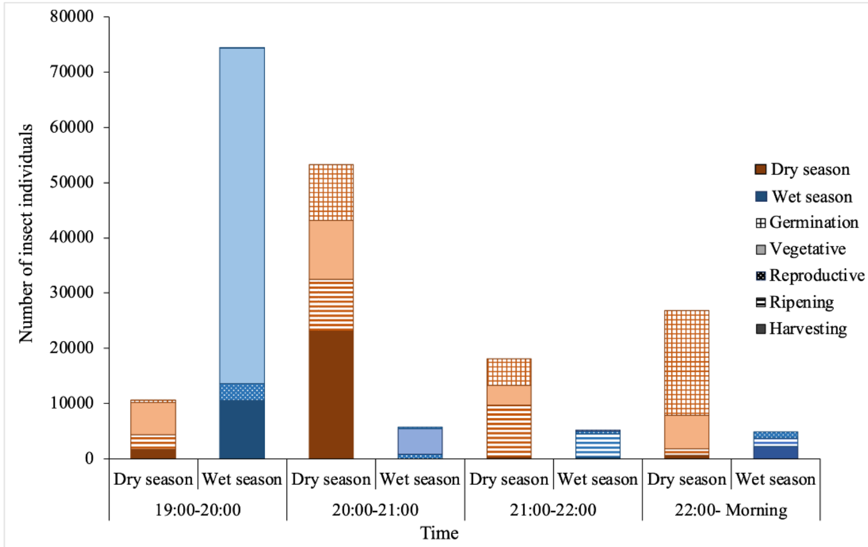

MADA B
MADA C
MADA A
1km
esri
MADA B
MADA C
MADA A
1km
esri


Rainfall
Maximum_temperature
Average_temperature
Minimum_temperature
Insect_activity
−0.33
0.27
0.72
0.1
−0.41
0.41
0.04
0.17
0.83
0.37
0.2
0.7
0.1
0.32
0.1
Bat_activity
Insect_activity
Minimum_temperature
Average_temperature
Maximum_temperature
Corr
1.0
0.5
0.0
−0.5
−1.0


β̂ = −0.83, t(24) = −3.52, p = 1.74e−03
Rainfall
Minimum temperature
β̂ = 0.70, t(24) = 2.96, p = 6.77e−03
β̂ = −1.68e−15, t(24) = −1.04e−14, p = 1.00
(Intercept)
−1.0
−0.5
0.0
0.5
1.0
estimate
Multiple R² = 0.35, Adjusted R² = 0.29


100000
80000
30000
20000
10000
0
Number of insect individuals
Germination
Vegetative
Ripening
Harvesting
Coleoptera
Lepidoptera
Diptera
Homoptera
Hemiptera
Odonata
Orthoptera
Araneae
Hymenoptera
Isoptera
Blattodea
Dermaptera
Insect Order


75000
15000
10000
5000
0
Number of insect individuals
Germination
Vegetative
Reproductive
Ripening
Harvesting
Coleoptera
Lepidoptera
Diptera
Homoptera
Hemiptera
Odonata
Orthoptera
Araneae
Hymenoptera
Isoptera
Blattodea
Ephemeroptera
Dermaptera
Insect Order


80000
70000
60000
50000
40000
30000
20000
10000
0
Number of insect individuals
Dry season
Wet season
Germination
Vegetative
Reproductive
Ripening
Harvesting
Dry season
Wet season
Dry season
Wet season
Dry season
Wet season
Dry season
Wet season
19:00-20:00
20:00-21:00
21:00-22:00
22:00- Morning
Time