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Ecology and microhabitat model of long-tongued fruit bat *Macroglossus minimus* (Chiroptera: Pteropididae) in karst ecosystem of Klapanunggal, Bogor, West Java, Indonesia

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Abstract. *Wibowo AA, Basukriadi A, Nurdin E, Benhard G. 2022. Ecology and microhabitat model of long-tongued fruit bat* Macroglossus minimus *(Chiroptera: Pteropididae) in karst ecosystem of Klapanunggal, Bogor, West Java, Indonesia. Intl J Trop Drylands 6: 11-15.* Karst ecosystem is an important habitat for Chiroptera, including the long-tongued fruit bat *Macroglossus minimus* (E.Geoffroy, 1810) that feeds on nectar. While Klapanunggal is a karst ecosystem located in Bogor, West Java, Indonesia, Klapanunggal has potential Chiroptera habitat. Here, this study aims to assess and model microhabitat covariates that contribute to the density of *M. minimus* in Klapanunggal. The sampling sites in Klapanunggal karst covered forest, plantation, and settlement sites. Measured microhabitat covariates, including tree covariates (canopy covers, Normalized Difference Vegetation Index/NDVI, diversity, height), air humidity, distance to a river, and distance to a cave. The microhabitat model was developed and measured using Akaike Information Criterion (AIC). The result shows a high density of *M. minimus* was observed in the plantation site (13.96 inds./100 m^2, 95%CI: 4-23 inds./100 m^2), followed by the forest (7.13 inds./100 m^2, 95%CI: 1-14 inds./100 m^2), and settlement sites (4.7 inds./100 m^2, 95%CI: 1-10 inds./100 m^2). Based on AIC values, the best model explaining the microhabitat covariates that have positive effects on the density of *M. minimus* were tree diversity and NDVI. While humidity and distance to river covariates have negative effects. Density of *M. minimus* was positively correlated with increase in tree diversity (AIC= 14.73, r= 0.93) and NDVI (AIC= 22.09, r= 0.18) values. The limiting factors of *M. minimus* populations were high air humidity (AIC= 2.85, r= 0.99) and increase in distance to river (AIC= 20.85, r= 0.46). To conclude, the conservation of *M. minimus,* particularly the karst ecosystem, should emphasize increasing tree diversity.

Keywords: AIC, covariate, density, NDVI, tree

Abbreviations: AIC: Akaike Information Criterion, NDVI: Normalized Difference Vegetation Index

INTRODUCTION

Chiroptera is a mammalian group commonly known as bats. The Chiroptera group comprises more than 1300 species, which covers almost 25% of the Mammalia class. While in Indonesia, there are approximately 215 bat species (Nurfitrianto et al. 2013). Chiroptera has a wide variety of feeding guilds, including frugivores, pollinivores/ nectarivores, carnivores, omnivores, insectivores, piscivores, and hematophagous. This great foraging diversity enables Chiroptera to have many ecological roles, including seed dispersal and natural insect control. Hence, the Chiroptera population is very important for ecosystems. Bat diversity and endemism in Indonesia are high, with 6 islands for fruit bats, and the percentage number of endemism accounts for 0-22.7% (Maryanto and Higashi 2011).

Macroglossus is nocturnal nectarivores and feeds on nectar. It has a wide geographical range since it is found in several countries in South and Southeast Asia (Nangoy et al. 2021). The main characteristic of this species is the longer snout. The microhabitat of *Macroglossus* ranges from wooded or disturbed to rural habitats. In other forest habitats, *Macroglossus* favors the flowers of wild banana trees, and in rural areas, they favor cultivated banana trees (*Musa paradisiaca* L.). *Macroglossus* are also known to visit the flowers of durian (*Durio zibethinus* Murray), coconut (*Cocos nucifera* L.), and guava (*Syzygium samarangense* (Blume) Merr. & L.M.Perry) (Phillipps and Phillipps 2018). By day, *Macroglossus* roost alone or in small groups, typically beneath large palm leaves (Nangoy et al. 2021).

One important habitat for bats is the karst ecosystem. In Southeast Asian regions, including Indonesia, karst possesses high species diversity and levels of endemism (Clements et al. 2006). Karst formations provide roosting sites for large aggregations and substantial numbers of bat species (Vermeulen and Whitten 1999; Mickeburgh et al. 2002). Asian karst ecosystem (Furey et al. 2010) with its caves has been identified as one of four regional priorities for bat conservation research (Kingston 2008). Indonesia has a vast karst area, indicating a great potential for karst biodiversity (Sulistiyowati et al. 2021). In contrast, West Java is a region that has a vast karst ecosystem with biodiversity potential (Putri et al. 2017).

Klapanunggal in Bogor, West Java, Indonesia, is a region that still has a karst ecosystem (Pambudi et al. 2020). The information and data of Chiroptera, particularly *Macroglossus* in this karst, is still limited. So then, this study aims to assess and model the ecology and microhabitat of *Macroglossus* in this karst ecosystem. The findings from this study can be used to support the conservation of Klapanunggal karst and Chiroptera species.

MATERIALS AND METHODS

Study area

The study area was the karst ecosystem in Klapanunggal, Bogor, West Java, Indonesia (Figure 1). This ecosystem is a combination of forests, plantations, and settlements. Klapanunggal is within Bogor District, with high rainfall of 2500-5000 mm/year. The temperature range is 21-26ºC, and the average humidity is 70%.

Procedures

Survey and density of Macroglossus minimus

The study and bat observation was conducted in June 2021 in several sampling sites covering forest, plantation, and settlement. The observation followed previous methods (Bansa et al. 2020; Senawi et al. 2020) and was conducted at noon from 17.00 to 19.00 following bat activity times within a 10 m x 10 m grid (100 m^2) in each sampling site. There were 3 replicated observations in each sampling site. First, Chiroptera abundances were recorded and denoted as individuals/100 m^2. The observed Chiroptera was then identified using a field guidebook by Suyanto (2001) and Prasetyo et al. (2011). For identification purposes, bats were captured following methods by Kunz et al. (2009). For capturing the bats, a mist net sizing 6 m wide x 2.5 m high at 2-3 m above the ground near potential fruit trees (Mubarok et al. 2021a,b) was set up in several sampling sites covering forest, plantation, and settlement. Bats were released after identifications.

Microhabitat covariates

The microhabitat was assessed based on in situ measurement of several environmental covariates, including trees, climate, and physics. The tree covariates were tree diversity (Susilowati et al. 2020), height, cover, and Normalized Difference Vegetation Index/NDVI. The tree diversity was based on the measurement of the number of tree species within a 100 m^2 grid that was used to observe the bats. The recorded tree species was then measured for its length, denoted in m. The tree covers were measured based on the areas of the tree canopy divided by 100 m^2 using the following equation:

$$\text{Tree cover } (\%) = \frac{\text{canopy area}}{100 \text{ m}} \text{ x } 100\%$$

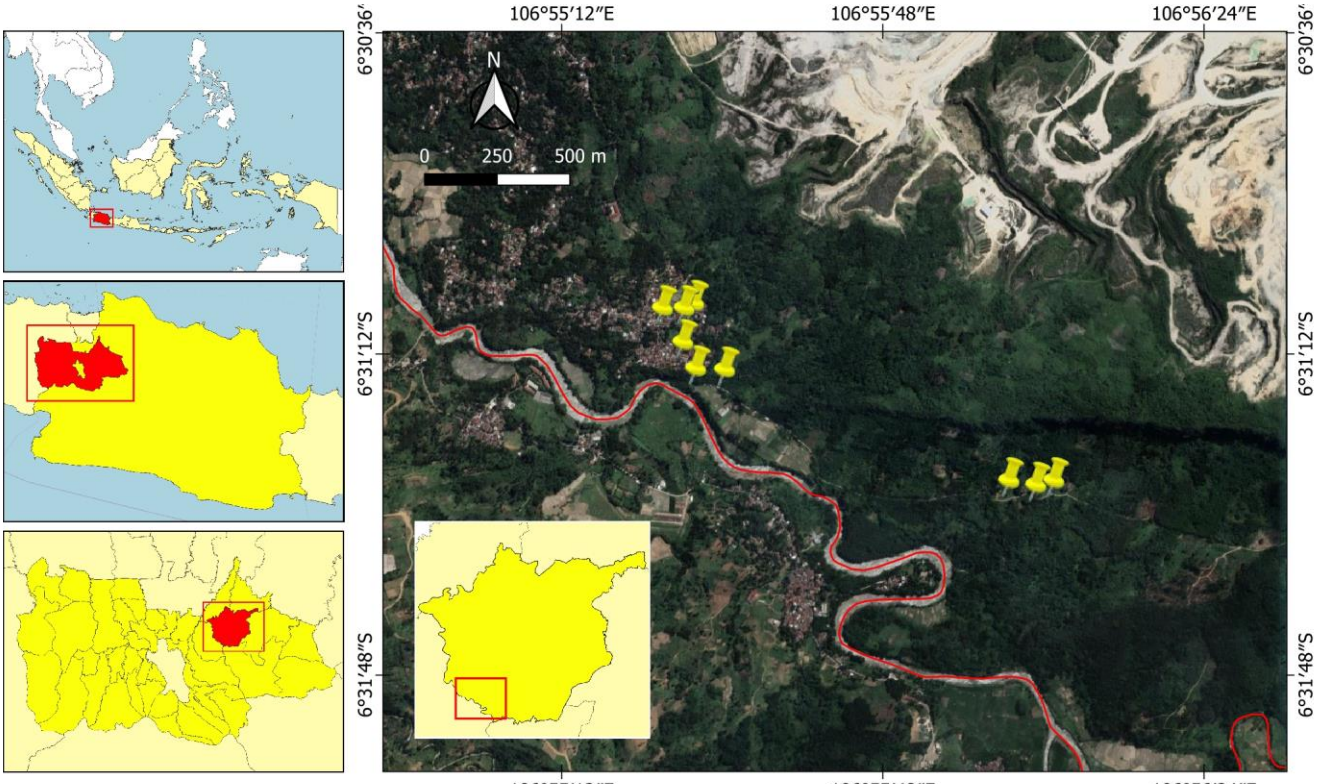

Figure 1. A map of the study area shows nine sampling sites covering forest, plantation, and settlements in the Klapanunggal karst ecosystem, West Java, Indonesia, selected based on the bat preferences and microhabitat variations

The method to measure NDVI of Klapanunggal karst was following Philiani et al. (2016), Kawamuna et al. (2017), and Sukojo and Arindi (2019). The NDVI is described as a simple graphical indicator that can be used to analyze remote sensing measurements, often from a space satellite platform, assessing whether or not the target being observed contains live green vegetation. The NDVI was measured by analyzing the wavelength of satellite image retrieved from Landsat 8 Operational Land Imager (OLI) containing vegetation image, and in this study was forest covers. This measurement is possible since the cell structure of the vegetation leaves strongly reflects near-infrared light wavelengths ranging from 0.7 to 1.1 µm. The calculation of NDVI for each pixel of vegetation pixel was as follows:

NDVI= near-invisible red wavelength – red wavelength / near-invisible red wavelength + red wavelength

The NDVI was denoted as a range from 0 (no vegetation) to 1(high vegetation density). GIS overlaps and maps the NDVI values into Klapanunggal karst land cover layers. The forest covers are then categorized and classified by using NDVI as follows:

- if 0 < NDVI < 0.3 then forest covers < 50%
- if 0.31 < NDVI < 0.4 then forest covers are 50-69%
- if 0.41 < NDVI < 1.0 then forest covers are 70-100%

Climate covariate was measured based on humidity (%). The humidity was recorded using a hygrometer and denoted as %. The physical covariates included distance from sampling sites to nearby rivers and caves and were denoted as a meter (m). The karst ecosystem was characterized by the presence of a cave due to the geological process. Besides that, in the karst ecosystem, bat populations frequently roost caves (Furey et al. 2010).

Data analysis

Principal component analysis and ecology model

The *Macroglossus minimus* (E.Geoffroy, 1810) density correlations with microhabitat covariates (tree canopy covers, NDVI, diversity, height, air humidity, distance to river, and distance to cave) were modeled using Principal Component Analysis (PCA) and validated using Akaike Information Criterion (AIC). The AIC was developed using linear regression with straight-line fit equations of $y_i = b_0 + b_1 x_i + \varepsilon_i$. The ε_i represents the residuals from the straight-line fit. If the ε_i is considered to be i.i.d. (independent and identically distributed) Gaussian with zero means, the model contains three parameters: b_0, b_1, and the Gaussian distributions' variance. As a result, we should use k= 3 when calculating the AIC value of this model. In general, the variance of the residuals' distributions should be counted as one of the parameters in any least-squares model using i.i.d. Gaussian residuals. The measured parameters included in AIC, residual standard error, R-squared, F, and P values. Microhabitat covariates correlating with *M. minimus* density were included in the analysis to build and develop the model. The best model was selected based on the model that has the lowest AIC values.

RESULTS AND DISCUSSION

The density of *Macroglossus minimus*

The result (Figure 2) shows that the average density of *M. minimus* in plantation site (13.96 inds./100 m^2, 95%CI: 4-23 inds./100 m^2) was the highest, followed by forest (7.13 inds./100 m^2, 95%CI: 1-14 inds./100 m^2) and settlement sites (4.7 inds./100 m^2, 95%CI: 1-10 inds./100 m^2). The tree diversity and status varied among sites (Table 1). Settlement and plantation sites have more fruiting tree species than forest sites. Fruiting trees were absent in forest sites. In contrast, trees in forest sites were taller than in other sites.

Principal component analysis and model of *Macroglossus minimus*

PCA (Figure 3) shows several microhabitat covariates with positive, negative, and neutral effects on *M. minimus* density. Covariates that have positive effects, including tree diversity and NDVI. That indicates increasing numbers of trees and NDVI values are causing an increase in *M. minimus* density. In contrast, increasing air humidity and distance to the river will reduce the *M. minimus* density. Tree cover, tree height, and distance to the cave have insignificant effects on density. Significant effects of tree diversity, NDVI, air humidity, and distance to river covariates were validated by AIC values (Table 2). Those covariates have lower AIC values than other covariates, indicating the best covariates to describe the microhabitat model of *M. minimus* density in the Klapanunggal karst ecosystem.

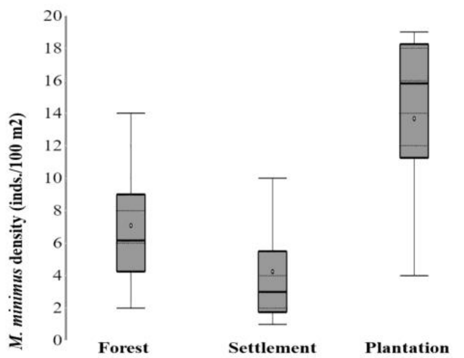

Figure 2. Boxplots of *M. minimus* density (inds./100 m^2) in forest, plantation, and settlement sites in Klapanunggal karst ecosystem, Bogor, West Java, Indonesia

Table 1. Tree diversity in several sites in Klapanunggal karst ecosystem, Bogor, West Java, Indonesia

Sites	Tree species	Status	Height (m)
Forest	*Neolamarckia cadamba*	No fruit	7
	Leucaena leucocephala	No fruit	15.2
Settlement	*Musa paradisiaca*	Fruiting	3.8
	Mangifera indica	Fruiting	5.4
	Cocos nucifera	Fruiting	10.2
Plantation	*Musa paradisiaca*	Fruiting	3.5
	Tectona grandis	No fruit	12.4
	Cocos nucifera	Fruiting	3.3

Table 2. The AIC model of *M. minimus* density with microhabitat covariates (tree canopy covers, NDVI, diversity, height), air humidity, distance to the river, and distance to cave

Microhabitat covariates	AIC	Residual standard error	R-squared	F	P
Tree cover	22.547	6.608	0.054	0.057	0.89
Tree NDVI	22.096*[a]	6.129	0.186**	0.228	0.631
Tree diversity	14.732*[a]	1.796	0.93**	13.31	0.000
Tree height	22.496	6.553	0.069	0.075	0.859
Humidity	2.857*[b]	0.248	0.998**	748	0.000
River distance	20.856*[b]	4.985	0.461**	0.857	0.211
Cave distance	22.0916	6.129	0.182	0.228	0.639

Note: *Best model, **significant correlation, [a]positive correlation, [b]negative correlation

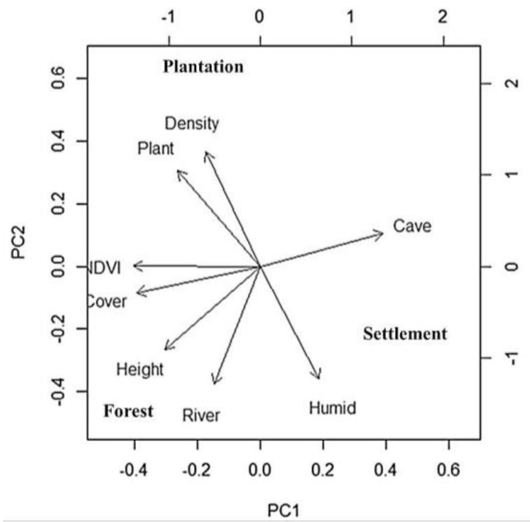

Figure 3. PCA of *M. minimus* (Density) with tree cover, tree NDVI, tree diversity (Plant), tree height, air humidity (Humid), distance to the river (River), and distance to the cave (Cave) in the forest, plantation, and settlement sites in Klapanunggal karst ecosystem, Bogor, West Java, Indonesia

Discussion

The presence of *M. minimus* in Klapanunggal karst is associated with the presence of trees. Karst ecosystem has high tree diversity that can support the bat populations. Karst in Bogor areas was known to have 80 species from 41 families, with the domination of Melastomataceae and Urticaceae (Putri et al. 2017). In Klapanunggal, tree diversity in settlement and plantation sites was dominated by tree species that have commercial values, including *M. paradisiaca* (banana tree), *Mangifera indica* (mango tree), and *C. nucifera* (coconut tree).

Based on the result and model, *M. minimus* was significantly correlated with the tree diversity covariates. This species prefers a habitat with high tree diversity. The *M. minimus* roosts in rolled leaves, large palm leaves, in-ground plants, or under tree branches. *M. minimus* roosts alone or in small groups. These roost sites are sometimes in the trees used for foraging. The *M. minimus* feeds primarily on nectar and pollen and drinks soft fruit juices (Nowak 1991). The flowers *M. minimus* mainly feeds on are from plants of the banana tree (Musaceae), the coconut tree (*C. nucifera*), and even mangroves (Sonneratiaceae) (Gunnell et al. 1996). The high density of *M. minimus* in the plantation of Klapanunggal was associated with the presence of banana trees. That is considering that banana trees dominated plantations in rural West Java. During the survey, the trees were at the fruiting stages. Lower density in forest sites compared to plantation sites despite the preference for tall trees, high tree covers, and NDVI was related to the limited numbers of fruiting trees. In the forest sites, the tree species were *Neolamarckia cadamba* (Roxb.) Bosser and *Leucaena leucocephala* (Lam.) de Wit were not producing fruit.

The density of *M. minimus* in the forest was close to the density in settlements rather than a plantation. The forest site was close to the settlement site, creating a mixed habitat. Borneo's combination of pristine forest habitat with the heavily disturbed forest has provided diverse microhabitat assemblage structures and forest tree species exploration for bats (Bansa et al. 2020). In this study, the disturbed habitat in the form of settlement had the lowest density. This condition is comparable to the previous findings. Settlement sites were characterized by low tree covers and indicating an open habitat. These low abundances may reflect that many bats combine wing morphologies and echolocation call designs, ill-suited for prey detection and capture in the more open habitats typical of degraded landscapes comparable to settlement sites.

In the Klapanunggal karst, the limiting covariates of *M. minimus* were humidity and distance to the river. The *M. minimus* density was lower when the distance to the river was high. In Klapanunggal, water resources were available in the form of river streams in the south of sampling sites, whether in forest, settlement, or plantation sites. This finding agrees with the findings from other studies (Downs and Racey 2006; Kelm et al. 2014). Bat is also a mammal that experiences dehydration; drinking water and proximity to water resources are fundamental covariates for all terrestrial mammals. Furthermore, considering the bat's peculiar morphology and physiology, much water is lost through the bat's body surface, especially via the respiratory system and the extensive surfaces of wing membranes. Then, for this reason, bats prefer to forage in sites close to water resources (Russo et al. 2012), which explains negative correlations between distance to the river and *M. minimus* density.

Besides distance to the river, another covariate affecting the density of *M. minimus* was the humidity. In Klapanunggal karst, an increase in humidity will reduce *M. minimus* density. The presence of bats decreased with an increase in humidity, consistent with previous studies since humidity influenced total bat activity levels and foraging activity. General bat presence and activity and foraging activity decreased with humidity covariates. Humidity affects thermoregulation processes involved in bat flight (Katunzi et al. 2020).

To conclude, the presence and distributions of *M. minimus* across karst ecosystems were varied. Those variations were influenced by numerous environmental covariates, including canopy cover, NDVI, diversity, height, air humidity, distance to a river, and distance to a cave. Among those covariates, river distance and humidity were the limiting covariates for bats. In contrast, tree NDVI and density were covariates supporting the *M. minimus* population.

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