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Diversity, abundance, and distribution patterns of stingless bees (Hymenoptera: Meliponini) in Yogyakarta, Indonesia

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Abstract. *Trianto M, Purwanto H. 2022. Diversity, abundance, and distribution patterns of stingless bees (Hymenoptera: Meliponini) in Yogyakarta, Indonesia. Biodiversitas 23: 695-702.* Stingless bees (Hymenoptera: Meliponini) are eusocial insects with high economic value in terms of their honey and propolis yield. The bees are widely distributed in tropical regions, including Indonesia. This study aimed to estimate the diversity, abundance, and distribution pattern of stingless bees in the Special Region of Yogyakarta Province, Indonesia. The following seven species of stingless bees have been identified in previous research: *Tetragonula laeviceps, T. iridipennis, T. biroi, T. sapiens, T. sarawakensis, Heterotrigona itama,* and *Lepidotrigona terminata*. The current work determined the scores of diversity (H': 0.98), abundance (N: 14.0 ind/m^2), and distribution pattern (id: 0.51) of stingless bees in Yogyakarta, Indonesia. The results were analyzed and then subjected to principal component analysis to determine the dominant characteristics on the basis of the environmental parameters that influence the presence of stingless bees in three habitat types in the Special Region of Yogyakarta Province, Indonesia. Results revealed that temperature is one such environmental parameter affecting the presence of stingless bees in the Special Region of Yogyakarta, Indonesia.

Keywords: Abundance, distribution pattern, diversity, stingless bees, Yogyakarta

INTRODUCTION

Stingless bees belong to the Apidae family and Apinae subfamily. Stingless bees are eusocial insects that live together in nests (Erniwati 2013). They have complex communication, build permanent colonies, and maintain adivision of caste (Efin et al. 2019). Stingless bee hives consist of one queen, a few thousand male drone bees, and thousands of worker bees that develop complex communication and maintain a caste system (Michener 2013; Roopa et al. 2015). Queen and male bees are fertile bees, while worker bees are sterile female bees. Queen bees play an important role regulating the work system in hives (Kelly et al. 2014; Roopa et al. 2015) and producing new tillers, male drones and workers. Worker bees collect food in the form of pollen and nectar, as well as saps for hive building (Couvillon 2012; Kelly et al. 2014; Jaffé et al. 2015; Hrncir et al. 2016; Jacob et al. 2019).

In Indonesia, stingless bees have various names, including *teuwel* (Sundanese), *galo-galo* (Minang) (Syafrizal et al. 2020), *tannese* (Central Sulawesi) (Suriawanto 2017), and *klanceng* (Java) (Trianto and Purwanto 2020a). Around 200 species of stingless bees are estimated to exist in the tropics and subtropics (Barbosa et al. 2016), and approximately 50 species of stingless bees have been identified in Southeast Asia. Meanwhile, 49 species of stingless bees are distributed in several islands: 5 species in Sulawesi, 29 species in Kalimantan, 24 species in Sumatra, and 8 species in Java (Kahono et al. 2018).

Java is an island with a high level of biodiversity (Setyawan et al. 2020). Information and publications about the species of stingless bees in Yogyakarta are lacking. Trianto and Purwanto (2020a; 2020b; 2020c) reported that seven species of stingless bees, namely, *Tetragonula laeviceps*, *T. biroi*, *T. sapiens*, *T. sarawakensis*, *T. iridipennis*, *Lepidotrigona terminata*, and *Heterotrigona itama*, are scattered in several areas in the Special Region of Yogyakarta Province. The discovery of these stingless bees species set a new record for the area. Hence, through the exploration and identification of other species of stingless bees, new records can be set for Yogyakarta, Indonesia. For such purpose, we need data that have yet to become available, such as data on diversity, abundance, and distribution patterns.

Such data need to be developed because they can contribute to the preservation and utilization of one of Indonesia's important biodiversity resources. In these processes, complementary data in the form of diversity, abundance, and distribution patterns of stingless bees are necessary. In the current study, we estimated the diversity, abundance, and distribution patterns of stingless bees in the Special Region of Yogyakarta Province, Indonesia.

MATERIALS AND METHODS

Study area

This research was conducted in May-July 2019 on three types of habitat in the Special Region of Yogyakarta Province, Indonesia, namely a secondary forest, an urban area, and a rural area (Figure 1 and Table 1).

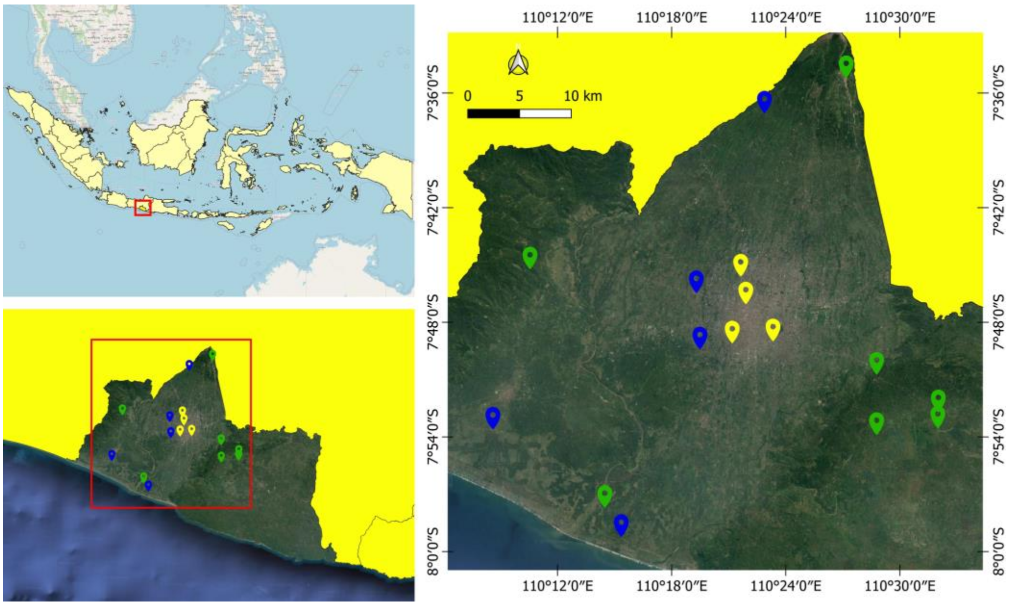

Figure 1. Study sites or the sampling of stingless bees in the Special Region of Yogyakarta Province, Indonesia. The green symbols mark secondary forests, the yellow symbols denote urban habitats, and the blue symbols indicate rural habitats

Table 1. Coordinates of habitat locations

Sampling sites	Coordinates	
Secondary forest		
Patuk Subdistrict	7º53’34.00”S	110 º32’00.47”E
Mount Merapi National Park	7º48’31.51”S	110 º28’26.31”E
Wanagama Forest	7º52’43.30”S	110 º32’01.83”E
Bukit Bintang	7º50’41.82”S	110 º28’49.82”E
Jatimulyo Village	7º53’54.40”S	110 º28’47.41”E
Srandakan Sub-district	7º57’43.43”S	110 º14’29.48”E
Girimulyo Sub-district	7º45’14.34”S	110 º10’33.59”E
Urban habitat		
Sinduadi Village	7º45’37.07”S	110 º21’38.41”E
Gedongkiwo Village	7º49’06.80”S	110 º21’11.60”E
Gowongan Village	7º47’04.23”S	110 º21’54.50”E
Pandeyan Village	7º49’00.36”S	110 º23’20.29”E
Rural habitat		
Wono Kerto Village	7º37’04.79”S	110 º22’53.48”E
Tamantirto Village	7º49’25.79”S	110 º19’29.73”E
Wates Village	7º53’37.43”S	110 º08’36.48”E
Gadingsari Village	7º59’14.51”S	110 º15’21.55”E
Sidoarum Village	7º46’28.96”S	110 º19’18.55”E

Procedures

Determination of sampling sites

Sampling sites were established using a purposive sampling method and reflected habitat diversity. A total of 16 sampling sites were identified (Table 1). For each sampling site, 10 observation points that were 100 m apart from one another were determined.

Collection, preservation, and identification of stingless bee specimens

The collection of the stingless bees was conducted on two consecutive days. At 07:00 on the first day, a sugar solution was sprayed on 1 × 1 m^2 plots at the determined observation points. On the second day, the stingless bees visiting the plot were captured using a sweep net. The catching activities were conducted three times daily at 07:00, 13:00, and 16:00. The specimen collection was performed on the second day to increase the chance of capturing stingless bees in the study area. The collected samples were placed in glass bottles with 90% ethanol (Trianto and Purwanto 2020a).

The stingless bee specimens were identified in the Laboratory of Entomology and the Laboratory of Structure and Animal Development, Faculty of Biology, Universitas Gadjah Mada, Indonesia. They were then identified on the basis of their morphological characteristics and morphometric measurements Smith (2012), Trianto and Purwanto (2020a, b, c). Morphometric measurements were performed using the binocular microscope XSZ-107 BN and analyzed using OptiLab Viewer and Image Raster software.

Environmental parameters

The environmental conditions measured in this study were temperature using a thermometer, humidity using a hygrometer, and light intensity using a lux meter. Furthermore, the data on the environmental conditions of the three habitat types of the stingless bees were evaluated using the principal component analysis (PCA) method in PAST3 software.

Data analysis

The data on the diversity, abundance and distribution patterns of the stingless bees for each habitat type were merged in one table. Several indices were adopted in this research, and they included the diversity indices of Shannon-Wiener and Shannon-Evenness and the dominance index of Simpson, the abundance index of Meyer, and the distribution pattern index of Morisita. The equations of these indices are shown herein.

Diversity index

Shannon-Wiener index

$$H = -\sum(ni/N) \ln (ni/N)$$

Where:
H: Diversity index
ni: Number of individual types
N: Total number of individuals

Shannon-Evenness index

$$E = H' / \ln S$$

Where:
E: Evenness index
H': Diversity index
S: Number of species

Simpson's dominance index

$$D = \sum (pi)^2 \rightarrow pi = ni.ni/N$$

Where:
D: Dominance index of Simpson
pI: Total sample proportion based on i-th species
ni: Number of i-th individual species
N: Total number of all obtained individuals

Abundance index

$$N = IS / A$$

Where:
N: Number of stingless bee genera, cm^2
IS: Median of number of individual stingless bees
A: Area of sampling point

Distribution pattern index

$$Id = n ((\Sigma xi2 - \Sigma xi) / (\Sigma xi)2 - \Sigma xi))$$

Where:
Id: Morisita index
n: Number of plots
xi: Number of individual stingless bees on i-th plot

The standardized Morisita index is calculated by the following equations:

Ip: $0.5 + 0.5 ((Id - Mc) / (n - Mc))$; if $Id \geq Mc > 1$
Ip: $0.5 ((Id - 1) - (Mc - 1))$; if $Mc > Id \geq 1$
Ip: $0.5 ((Id - 1) / (Mu - 1))$; if $1 > Id > Mu$
Ip: $0.5 + 0.5 ((Id - Mu) / (Mu))$; if $1 > Mu > Id$

A continuous distribution pattern is indicated by Mu and Mc, which are given as

$Mu = (x^2_{0.975} - n + \Sigma xi) / (\Sigma xi) - 1$
$Mc = (x^2_{0.025} - n + \Sigma xi) / (\Sigma xi) - 1$

Where:
Mu: Morisita index on uniform pattern of distribution
Mc: Morisita index on clustered pattern of distribution
$x^2_{0.975}$: Value of x^2 with n1 degree of freedom and confidence interval of 97.5%
$x^2_{0.025}$: Value of x^2 with n1 degree of freedom and confidence interval of $x^2_{0.025}$
xi: Number of individual stingless bees on i-th plotCriteria of stingless bee distribution pattern:
if $Ip < 0$: Uniform
if $Ip = 0$: Random
if $Ip > 0$: Clustered

RESULTS AND DISCUSSION

According to Trianto and Purwanto (2020a, b), the following seven species of stingless bees exist in the Special Region of Yogyakarta Province, Indonesia: *T. laeviceps, T. biroi, T. iridipennis, T. sarawakensis, T. sapiens, H. itama,* and *L. terminata* (Figure 2). In the current work, advanced data on the diversity, abundance, and distribution patterns of stingless bees in the Special Region of Yogyakarta Province, Indonesia, were obtained.

Diversity of stingless bees

The results showed that the diversity index of stingless bees found in the three habitat types in the Special Region of Yogyakarta Province, Indonesia is moderate.

As indicated in Table 2, the Shannon-Wiener (H') species diversity index for the rural habitat had the highest diversity value of H': 1.21, while that for the urban habitat had the lowest value of H': 0.84 (Table 2).

Abundance of stingless bees

A total of 420 individual stingless bees from 7 species types were recorded in the Special Region of Yogyakarta Province, Indonesia. The most dominant species recorded in this study were *T. laeviceps* (283 individuals) and *H. itama* (79 individuals). Meanwhile, the minority species were *T. iridipennis* (28 individuals), *T. sapiens* (16 individuals), *T. biroi* (6 individuals), *T. sarawakensis* (3 individuals), and *L. terminata* (5 individuals) (Figure 3).

Table 2. Diversity of stingless bee species

Parameter	Habitat			Total
	Secondary forest	Urban	Rural	
Σ individual	194	80	146	420
Relative (%)	46.19	19.05	34.76	100
Total species	7	4	7	7
Shannon-Wiener (H')	0.89	0.84	1.21	
Dominance-Simpson (D)	0.58	0.57	0.38	
Shannon-Evenness (E)	0.44	0.39	0.58	

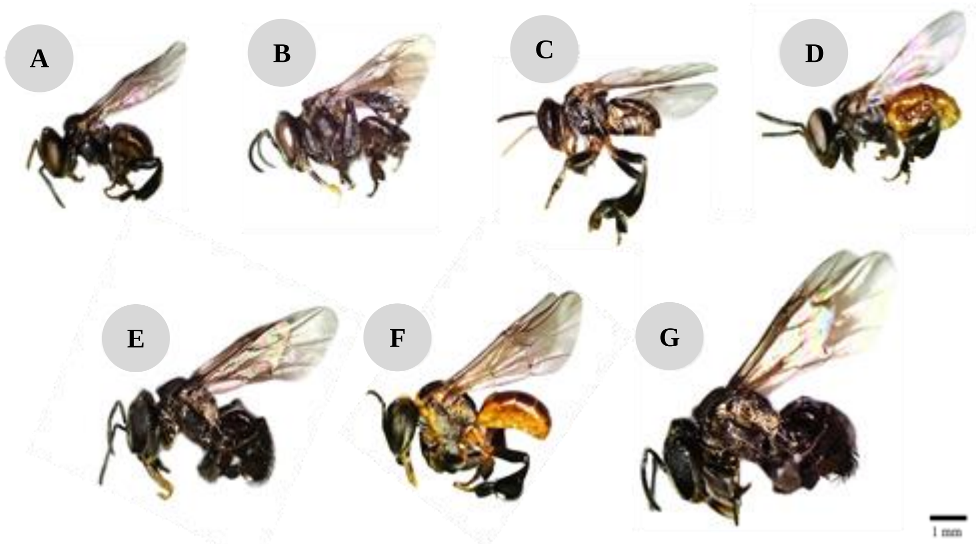

Figure 2. Stingless bees found in the Special Region of Yogyakarta Province, Indonesia: A. *Tetragonula laeviceps*; B. *T. biroi*; C. *T. sapiens*; D. *T. sarawakensis*; E. *T. iridipennis*; F. *Lepidotrigona terminata*; G. *Heterotrigona itama.* Scale bar: 1 mm (Trianto and Purwanto 2020a)

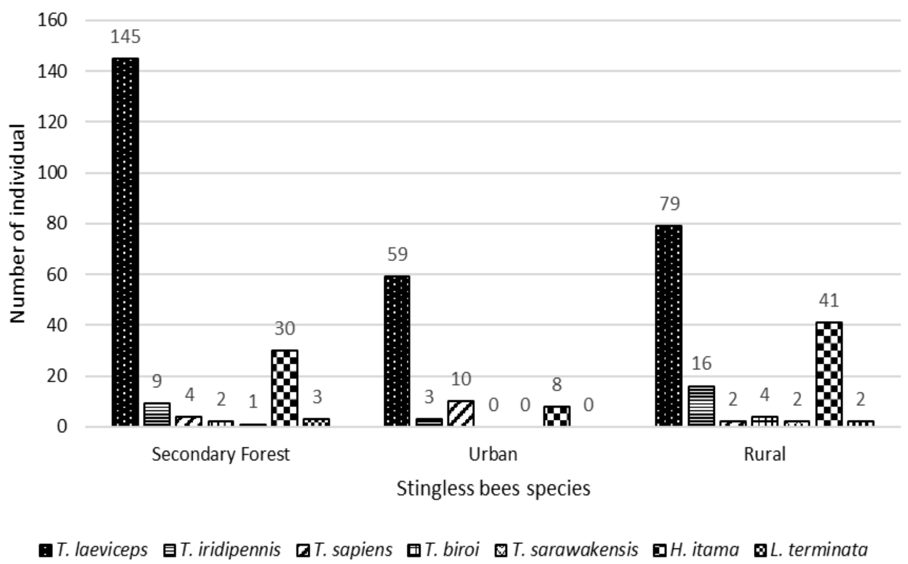

Figure 3. Abundance of stingless bee species

The highest abundance of stingless bees was found in secondary forests, with 194 individuals identified (19.4 ind/m^2). The lowest abundance was recorded in urban habitat with 80 individuals (8.0 ind/m^2). Seven species of stingless bees were found in secondary forests and rural habitats, while *T. biroi*, *T. sarawakensis*, and *L. terminata* were not found in urban habitats (Figure 3).

Distribution patterns of stingless bees

An ecosystem has three primary species distribution patterns, namely, random, clustered, and uniform. Species distribution patterns can be identified on the basis of several distribution indices with various ratio and mean values, including the crumpling index, green coefficient, and standardized index of Morisita. The Morisita index is widely used because it has been proved to be the best method for calculating the spatial distribution patterns of species independent of population and sample size. The standardized Morisita index is an improvement of the Morisita index and is differentiated by using an absolute scale between -1 and 1. The distribution patterns of stingless bees are presented in Table 3.

The highest Morisita index of 1.78 was observed for secondary forests, while the lowest index of 1.03 was noted for urban habitats. The pattern of distribution based on the Morisita index is determined with the Mu and Mc equations. The results of the calculations were in accordance with the hypothesis from one of the standardized Morisita indices, that is, Id ≥ Mc > 1. Hence, each habitat was deemed to be clustered because Ip > 0 (Table 3).

Table 3. Distribution patterns of stingless bee species

Habitat	Σxi	Σxi²	Id	Mu	Mc	Ip	Distribution pattern
Secondary forest	194	22.036	1.78	0.97	1.03	0.54	Clustered
Urban	80	3.654	1.03	0.98	1.01	0.49	Clustered
Rural	146	8.206	1.22	0.97	1.02	0.51	Clustered

Note: Σxi: Number of individual stingless bees on i-th plot; Σxi²: Total square of Σxi; Id: Morisita index; Mu: Morisita index (unifo; m pattern of distribution); Mc: Morisita index (clustered pattern of distribution); Ip: Standardized Morisita index

Environmental parameters

The number of individuals that can live in a certain area (i.e., grow and reproduce) is influenced by environmental factors. In this research, these factors included the median temperature of 28.4°C, humidity of 83.9%, and light intensity of 1.014.6 (Table 4).

The obtained environmental parameters were analyzed using the PCA method in PAST3. The analysis aimed to determine the dominant characteristics affecting the diversity, abundance, and distribution patterns of stingless bees in the three habitat types in the Special Region of Yogyakarta Province, Indonesia.

The correlation analysis between clusters yielded eigenvalue and percent variance, as shown in Table 5. A scatter plot is shown in Figure 4, and a loading plot of the components is presented in Figure 5.

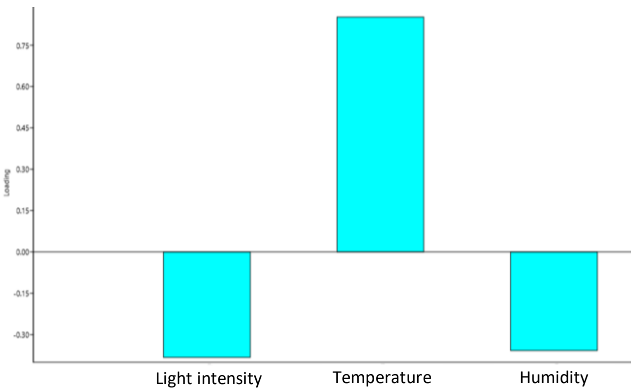

Figure 5. Loading plot of components

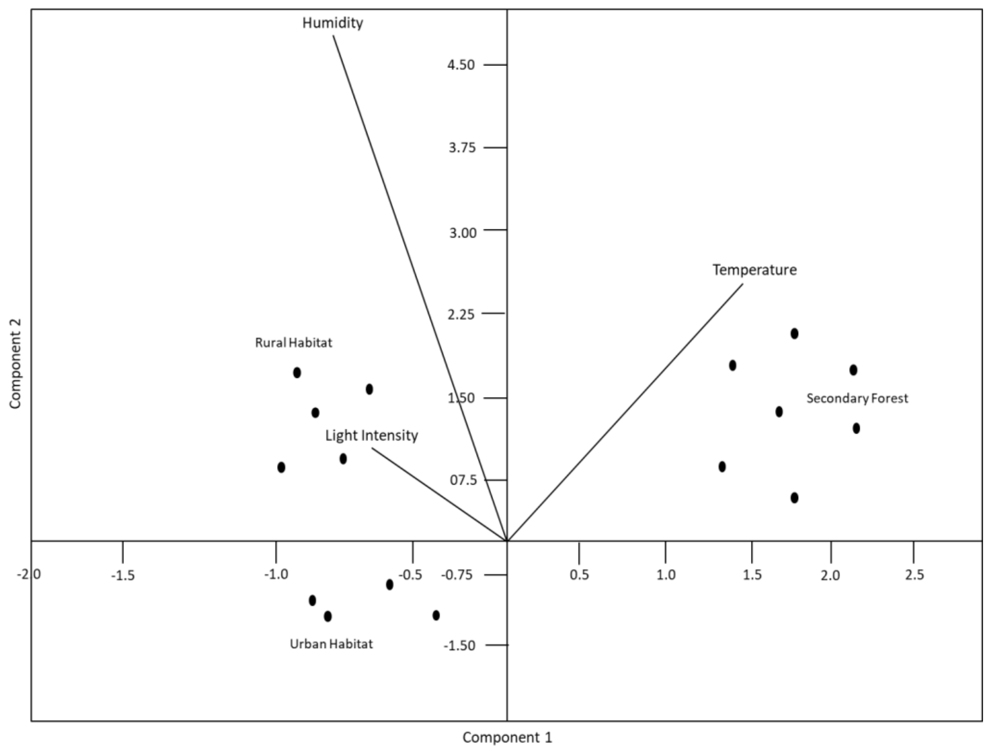

Figure 4. Scatter plot of PCA results

Table 4. Environmental parameters for each habitat

Habitat	Environmental parameter		
	Temp. (°C)	Humidity (%)	Light intensity (lux)
Secondary forest			
Patuk Sub-District	27.9	84.6	1013.4
Mount Merapi National Park	27.0	85.8	1013.0
Wanagama Forest	27.8	84.7	1013.3
Bukit Bintang	28.5	83.8	1014.3
Jatimulyo Village	28.0	84.3	1013.8
Srandakan Sub-district	28.3	84.0	1014.5
Girimulyo Sub-district	27.6	87.9	1013.0
Mean	27.9	85.0	1013.6
Urban habitat			
Sinduadi Village	29.3	82.5	1014.7
Gedongkiwo Village	29.0	83.1	1014.1
Gowongan Village	29.2	82.6	1014.6
Pandeyan Village	29.4	82.2	1015.2
Mean	29.2	82.6	1014.6
Rural habitat			
Wono Kerto Village	28.5	83.8	1014.3
Tamantirto Village	28.5	83.8	1014.3
Wates Village	28.9	83.3	1014.9
Gadingsari Village	28.8	83.6	1014.5
Sidoarum Village	28.4	83.9	1014.3
Mean	28.6	83.7	1014.5

Table 5. Eigenvalue and % variance

PC	Eigenvalue	% variance
1	2.45301	89.029
2	0.210156	7.6273
3	0.0921307	3.3438

Discussion

Sugar syrup was used in this work to attract stingless bees in the field. The use of sugar syrup was considered successful and yielded maximal results relative to other existing materials. This result was proved by the number of stingless bees obtained herein (420 individuals) (Table 5). By contrast, Jaapar et al. (2016) utilized salted fish and oil (63 individuals), honey and lemon (20 individuals), and honey and salt (50 individuals). Salim et al. (2012) used honey (46 individuals).

According to Trianto and Purwanto (2020a, b, c), the following seven species exist in the Special Region of Yogyakarta Province, Indonesia *T. laeviceps, T. biroi, T. iridipennis, T. sarawakensis, T. sapiens, H. itama,* and *L. terminata* (Figure 2). The dominant species in the current work, as indicated by the number of individuals, were *T. laeviceps* (283 individuals) and *H. itama* (79 individuals) (Figure 3). Such dominance indicated the good adaptability of these two species. Salim et al. (2012), and Jaapar et al. (2016), stated that these species had been domesticated for meliponiculture. This finding was supported by Jaapar et al. (2016, who reported that *T. laeviceps* and *H. itama* are cultivated by the Malaysia Agriculture Research and Development Institute for meliponiculture. Meanwhile, few individuals of *T. iridipennis* (28 individuals), *T. sapiens* (16 individuals), *T. biroi* (6 individuals), *T. sarawakensis* (3 individuals), and *L. terminata* (5 individuals) were found to be distributed in several habitats in certain districts of the Special Region of Yogyakarta Province, Indonesia (Figure 3). The number of species found in the Special Region of Yogyakarta Province, Indonesia is less than that found by Erniwati (2013), who reported the following eight species of stingless bees in Java Island *T. iridipennis, T. laeviceps, T. apicalis, T. nitidiventris, T. ventralis, T. terminata, T. fuscobalteata,* and *H. itama.*

The measurement of the diversity, abundance and distribution patterns of stingless bees in the Special Region of Yogyakarta Province in this work is an extension of existing research. The current study is the first report on the diversity of stingless bees (Hymenoptera: Meliponini) in the Special Region of Yogyakarta Province, and the results should contribute to the preservation and utilization of one of Indonesia's important biodiversity resources. The Shannon-Wiener (H') species diversity index showed the highest value of H': 1.21 for rural habitats and the lowest value of H': 0.84 for urban habitats (Table 2). A similar trend was observed in the Shannon-Evenness index (E), which highlighted differences in the rural and urban habitats. The same was not observed for Simpson's dominance index (D), with the results indicating that E was more preponderant than D for the determined value of H'. The value of D was inversely associated with H'; for example, the rural habitat was the lowest because the diversity of plant life, which provides the needs of stingless bees, is greater in rural habitats than in urban habitats. Wratten et al. (2012) stated that the diversity of stingless bees is affected by the abundance of flower and plant types that serve as food sources in the environment. Kelly et al. (2014) reported that rural habitats is the biotopes located in areas where agriculture is practiced, this will result in a high diversity of insects. Rural residential areas generally have large yards, and the average size of rural houses is greater than 100 m^2. Moreover, many open waterways support insect life. Insect species diversity in rural areas is also higher than that in urban areas. Wu et al. (2011) reported that rural areas with high vegetation equate to a high diversity of insects.

The Meyer abundance index (N) indicated that secondary forests had the highest abundance with N: 194 individuals and that urban habitats had the lowest with N: 80 individuals (Figure 3). This result could be attributed to the fact that urban areas have small spaces available for growing various types of plants, which support the lives of stingless bees, whereas secondary forests are generally overgrown by various types of plants. Kelly et al. (2014) described urban habitats as a boundary between cities and villages, which almost have similar characteristics to cities. Urban areas have few empty lands and little vegetation, and they are almost completely filled with buildings, which also become habitats for insects. The housing types in urban areas generally do not have yards, and the average residential area is 96 m^2. Many waterways are closed and are thus unable to support insect life. These conditions relate to the lack of public knowledge in urban areas about the role of stingless bees as insects that produce honey and propolis and support pollination. Stingless bees have also been regarded as intruder insects that destroy house components. These conditions have led to the low abundance of stingless bees in urban habitats. Suriawanto (2017) described that the misconception about stingless bees may partly explain the decreased abundance of these insects and that efforts must be exerted to manage information from various aspects.

According to the results of the Morisita pattern index (Id), the distribution of stingless bees in the three habitats in the Special Region of Yogyakarta Province, Indonesia, shows a clustered pattern (Table 3). This result was assumed to be due to the usage of land for building development purposes, in which case stingless bees do not spread uniformly and are instead clustered in one area. Jaapar et al. (2016) reported that changes in land use in Malaysia affect the distribution patterns of stingless bees and thus call for an extensive study. Orr et al. (2021) described that a clustered pattern of insect distribution might be attributed to several factors, such as the merging of environmental factors, social behavior, reproduction ability, and interactions. Inayat et al. (2011) reported that the distribution patterns of insects are naturally affected by the prey and predator species existing in a particular habitat.

The environmental parameters herein included temperature, humidity, and light intensity and were analyzed using the PCA method in PAST3 software. The data analysis aimed to determine the dominant characteristics affecting the diversity, abundance, and distribution patterns of stingless bees in the three habitats in the Special Region of Yogyakarta Province, Indonesia. The correlation analysis yielded the eigenvalue and percentage variance (Table 5). A scatter plot is shown in Figure 4, and a loading plot of components is presented in Figure 5. The main component that can represent the data in the PCA process is PC1. According to Yudha et al. (2019), the number of main components can be considered as useful and sufficiently representative if the % variance generated is over 70%. According to the PCA results, the temperature is the environmental parameter with the greatest impact on the diversity, abundance, and distribution patterns of stingless bees in the Special Region of Yogyakarta Province, Indonesia. This result is reflected by the length of the arrows in Figure 4 and the loading plot of the components in Figure 5. Given the long arrows and high graphs in the figures, the effect of this environmental parameter on the ecology of stingless bees is also high. Similarly, Indraswari et al. (2016) reported that according to PCA, the temperature tends to be positively correlated with the number of species and individuals of bees. In addition, the temperature obtained in the current study was classified as the normal temperature range required by bees for proper development. Bordier et al. (2017) explained that bees would be normally active at ambient temperatures of 18°C-35°C and an ideal temperature of 27°C; temperatures above or below these ranges disrupt the activities of these insects. Li et al. (2019) reported that bees are most active while collecting nectar at temperatures of 24.5°C-34.5°C.

In conclusion, the data presented in this research set a new record for the Special Region of Yogyakarta Province, Indonesia. The availability of different types of habitats affects the diversity value, abundance, and distribution patterns of stingless bees in the Special Region of Yogyakarta Province, and temperature is one of the environmental parameters with the greatest impact. This research is expected to expand the database of the conditions of stingless bees, particularly in the Special Region of Yogyakarta Province, Indonesia. It is also projected to provide initial information for stingless bee cultivation.

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