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Preliminary Exploration of the Species, Distribution, and Nest Ecology of Stingless Bees Along the Krueng Woyla River, Sumatra, Indonesia

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ABSTRACT

Stingless bees (Meliponini) are important pollinators in tropical ecosystems; however, information on their species diversity, distribution, and nesting ecology along the river of Sumatra remains limited. This study was conducted from October to November 2025 along the Krueng Woyla River in West Aceh Regency, Aceh Province, Indonesia. An exploratory survey, combined with local ecological knowledge, was conducted to document stingless bee colonies and describe their nesting characteristics. The study identified a single species, *Tetragonula fuscobalteata*, characterized by a bicolored body (black with a yellowish abdomen) and small morphometric size, with a total body length of 3.35-3.61 mm, head width of 1.40-1.47 mm, and forewing length of 3.68-3.91 mm. A total of 47 nests were recorded across three sub-districts, all located in settlement areas and constructed on four types of nesting substrates. Nest entrances, which were generally small, varied in dimensions, color, shape, texture, pore presence, and resin occurrence. Nests were found at heights of 40-302 cm above ground level and within 5 km of the river. Overall, *T. fuscobalteata* demonstrated high adaptability to riverine environments, indicating that these areas provide suitable nesting substrates and food resources. This finding indicates that semi-natural environments along river corridors are important ecosystems that should be conserved, while also underscoring their role as potential habitats for stingless bees.

1. Introduction

Stingless bees (Hymenoptera: Apidae: Meliponini) are social pollinators that play a crucial role in tropical and subtropical ecosystems. This group exhibits high taxonomic, ecological, and behavioral diversity and contributes substantially to the pollination of both wild and cultivated plants, thereby influencing plant community structure and overall ecosystem productivity. Recent synthesis studies have emphasized that stingless bees display a wide range of nesting behaviors and maintain complex mutualistic relationships with flora and microorganisms in tropical environments. This group of insects plays an important role in maintaining ecosystem stability (Roubik 2023).

Species diversity and community structure of Meliponini vary across geographic regions, habitat types, and levels of human disturbance. Studies conducted in Southeast Asia and the Indonesian archipelago have

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demonstrated distinct species compositions among primary forests, secondary forests, agroecosystems, and residential areas, with certain species showing a high degree of adaptability to human-modified landscapes (Trianto *et al*. 2023). However, inventories, morphometric analyses, and genetic mapping over the past decade indicate that local data on species richness and community composition remain fragmented. Consequently, several habitat types, particularly along river environments, remain poorly documented, highlighting the importance of exploratory studies in these areas to complete the regional biodiversity framework (Withaningsih *et al*. 2023).

Beyond species diversity, investigations into the nesting ecology of Meliponini are essential for understanding the ecological roles and adaptive strategies of these beneficial insects. Variations in body size, morphological traits, nesting substrates, and nest architecture among species reflect their responses to local environmental conditions (Emil *et al*. 2024). Colony distribution patterns are further influenced by the availability of nesting substrates, landscape structure, food resources, and microclimatic conditions, which in several studies have been examined using spatial approaches that integrate field surveys with landscape-level data. Research findings indicate that land-cover change and climatic dynamics can alter colony distribution, emphasizing the importance of local-scale documentation of nesting ecology and spatial patterns for conservation and sustainable management (Gonzalez *et al*. 2018; Wayo *et al*. 2020; Makori *et al*. 2022).

Despite the growing body of research on Meliponini diversity and ecology, integrative studies that simultaneously examine species diversity, nesting ecology, and distribution within riparian environments remain scarce, particularly in Sumatra. Riparian ecosystems, characterized by mosaics of natural vegetation, settlements, and small-scale agricultural areas, offer high potential as habitats for stingless bees; however, they have yet to be systematically investigated. In the area surrounding the Krueng Woyla River, studies on the species composition of Meliponini across diverse research regions, as well as their nesting characteristics, remain limited and poorly integrated (Withaningsih *et al*. 2023). Therefore, this study introduces a novel, locally grounded integrative approach that combines species diversity inventories, detailed analyses of nesting ecology, and assessments of colony distribution within a riparian landscape. This approach is expected to fill existing knowledge gaps, provide robust baseline scientific data, and serve as a foundation for the management and conservation of stingless bees in riparian corridors of Sumatra.

2. Materials and Methods

2.1. Time and Research Location

The study was conducted over two months, from October to November 2025, along the Krueng Woyla River in Sumatra, Indonesia. The Krueng Woyla River is one of the major rivers in West Aceh Regency, Aceh Province, flowing through the districts of Woyla Barat (4°19'58.5"N-96°01'28.2" E), Woyla Induk (4°22'35.9"N-96°04'26.0" E), and Woyla Timur (4°25'36.8"N-96°03'42.0" E). The research focused on river segments located within these three districts. The upstream, middle, and downstream sections of the Krueng Woyla River are represented by Woyla Timur, Woyla Induk, and Woyla Barat, respectively.

2.2. Research Design

This study employed an exploratory survey approach covering areas along the Krueng Woyla River, particularly around buildings, gardens, and residential yards. Local knowledge was used to facilitate data collection, with the active involvement of local communities helping researchers locate nests (Silvy 2020; Emil *et al*. 2024).

2.3. Field Data Collection

When a stingless bee nest was located, data were collected by hand-short sampling of individuals entering and exiting the nest, with 10 individuals collected per nest. To preserve the integrity of the samples, each individual was stored in a 1.5 mL microtube containing 70% ethanol. In addition, the geographic coordinates of each nest were recorded, and the nests were observed both quantitatively and qualitatively. Quantitative data included the length of the nest entrance (cm), horizontal and vertical diameters of the nest entrance (cm), nest height from the ground (cm), and distance from the main water source of the Krueng Woyla River (m). Qualitative observations included nesting location, dominant entrance color, shape and texture of the entrance cavity, presence of pores, and the presence of sticky resin at the nest entrance (Kelly *et al*. 2014; Rivaldy *et al*. 2023; Hora *et al*. 2023; Emil *et al*. 2024). Additional data on colony behavior were obtained through direct observation at the nest entrance for 5-10 minutes per colony under normal activity conditions.

2.4. Abiotic Factors

During the study, abiotic factors were recorded across three districts in the observation area. The measured parameters included air temperature (°C), relative humidity (%), visibility (Km), and air pressure (hPa), which were subsequently presented as minimum and maximum values throughout the study period. Measurements were conducted using a Lutron four-in-one LM8000A, a transmissometer, and a barometer provided by the Basic Animal Biosciences Laboratory, Faculty of Agriculture, Teuku Umar University.

2.5. Laboratory Analysis

The samples collected in the field were analyzed at the Seed Technology Laboratory of the Faculty of Agriculture, Teuku Umar University, in December 2025. Sample identification was conducted based on morphological references (using a Nikon SMZ745 stereo microscope) from Sakagami *et al*. (1990), Jalil (2017), Engel *et al*. (2018), Engel *et al*. (2023), and Emil *et al*. (2024). Once identified, the samples were verified with reference to the zoogeographical distribution of stingless bees in the Indo-Malayan region and voucher specimens from the Museum Zoologicum Bogoriense (MZB) with registration numbers MZB Hymn 44666-MZB Hymn 44695. The identified samples were subsequently deposited at the Basic Animal Biosciences Laboratory, Faculty of Agriculture, Teuku Umar University, as reference materials and educational specimens under registration number BSH-UTU 2025 Hymn 01.

Body measurements were recorded from 10 individuals of the same bee species collected at each location, for a total of 30 individuals across the three sites. Measurements were obtained using a digital caliper (Deli Tools, measurement accuracy ≤±0.2 mm, measuring range 0-150 mm) with the aid of a stereo microscope and a magnifying glass to enlarge the object from the head to the tip of the abdomen to obtain body length (mm), between the bases of the eyes for head width (mm), and from the tegula to the base of the forewing for forewing length (mm). The values of the 10 individuals were then averaged, their standard deviations calculated, and the results presented as ranges from minimum to maximum (Emil *et al*. 2024).

2.6. Data Analysis

The data were analyzed using quantitative descriptive methods, and the results were presented as figures, tables, diagrams, and distribution maps. The analysis was performed using standardized software, including Microsoft Excel Office 2019 (pie chart, average, standard deviation), PAST version 4.09 (venn diagram), and QGIS 3.30 (spatial distribution map) (Hammer *et al*. 2001; Emil *et al*. 2024).

3. Results

3.1. Species Diversity of Stingless Bees Along the Krueng Woyla River

During the study, samples collected from each stingless bee nest along the Krueng Woyla River were successfully identified as a single species, namely *Tetragonula fuscobalteata*. According to taxonomic classification, this species belongs to the Kingdom Animalia, Phylum Arthropoda, Class Insecta, Order Hymenoptera, Family Apidae, Genus *Tetragonula*, and Species *Tetragonula fuscobalteata* (Figure 1). These findings are further supported by the morphological characteristics observed in all examined samples, as presented in Table 1.

As supporting evidence for the morphological identification, the samples were examined using three basic morphometric characters as comparative data, revealing similar body size measurements among samples collected from three different sampling areas. Body length was recorded as 3.52±SD 0.230 mm (Woyla Barat), 3.61±SD 0.197 mm (Woya Induk), and 3.35±SD 0.207 mm (Woyla Timur). In addition, head width varied at 1.47±SD 0.068 mm (Woyla Barat), 1.46±SD 0.165 mm (Woyla Induk), and 1.4±SD 0.105 mm (Woyla Timur), while forewing length measured 3.91±SD 0.218 mm (Woyla Barat), 3.68±SD 0.294 mm (Woyla Induk), and 3.77±SD 0.216 mm (Woyla Timur). The morphometric measurements are summarized in Table 2.

3.2. Distribution of Stingless Bees Along the Krueng Woyla River

A total of 47 nests of *T. fuscobalteata* were successfully identified during the study. The highest number of nests was recorded along the Krueng Woyla River in Woyla Induk District (the middle river section), with 31 nests accounting for 65.96% of the total. Woyla Barat District (downstream) ranked second with 9 nests (19.15%), while the lowest number was observed in Woyla Timur District (upstream), where 7 nests were recorded (14.89%) (Figure 2).

Nests of *T. fuscobalteata* recorded along the Krueng Woyla River in Woyla Barat District were distributed across two villages: Peulekung Village, with five nests, and Karak Village, with four nests. In Woyla Induk District, *T. fuscobalteata* nests were found in five

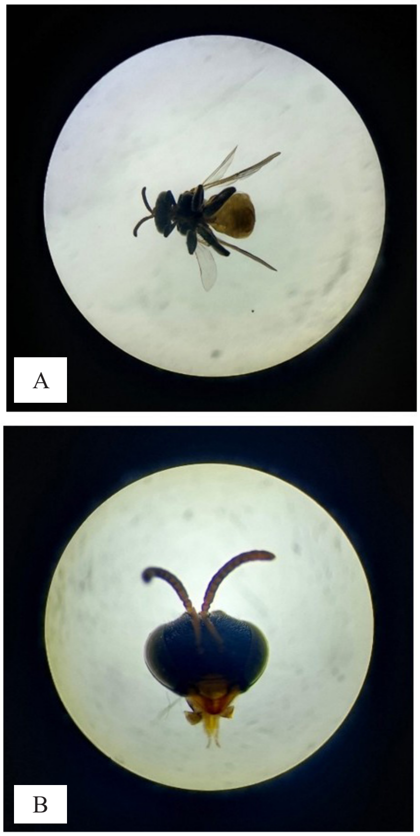


Figure 1. Stingless bees were recorded in a semi-natural ecosystem surrounding the Krueng Woyla River, West Aceh, Aceh, Sumatra, Indonesia. Species identification confirmed that all collected specimens belonged to *Tetragonula fuscobalteata*. Descriptions of body characteristics and morphometric measurements are presented in Tables 1 and 2: A. General appearance of the whole body at 1× magnification, B. Frontal view of the body at 3× magnification. If readers or researchers are interested in examining the specimens used in this study, they may contact the corresponding author via the following email address: muhammadfarhan@utu.ac.id

villages: Paya Dua Village (16 nests), Paya Luah Village (two nests), Lung Buloh Village (five nests), Tingkeum Panyang Village (two nests), and Pasi Aceh Village (six nests). Meanwhile, nests along the Krueng Woyla River in Woyla Timur District were recorded exclusively in Tangkeh Village, with a total of 7 nests. Detailed information on nest codes, geographic coordinates, discovery dates, colony behavior, and the frequency of nest entrance and exit activity within a five-minute interval is presented in Table 3 as distribution data.

3.3. Nesting Ecology of Stingless Bees Along the Krueng Woyla River

During the study period, four types of nesting substrates utilized by *T. fuscobalteata* were identified. The majority of nests were found on wooden walls,

Table 1. Morphological characteristics of the identified samples observed under a Nikon SMZ745 stereo microscope, confirming that all examined specimens belong to *Tetragonula fuscobalteata*

Measured body characteristics	Observation results
Body color	Bicolored, black with a yellowish abdomen
Head and antennae	Head black, entirely covered with fine white hairs. Scape, pedicel, and flagellum brown
Mandibula	Mandibles with two teeth
Mesoscutum	Black with six hair bands
Scutellum	Scutellum large
Propodeum	Propodeum glabrous and shiny
Wing	Semi-transparent membranous wings
Number of hamuli	Five hamuli on the hind wing
Hind tibia	Hind tibia with hairs on the posterior edge
Basitarsus	An elliptical disc on the posterior part of the basitarsus

Table 2. Body size of *Tetragonula fuscobalteata* across sampling locations around the Krueng Woyla River, Sumatra, Indonesia. St.dev: standard deviation

Sample	Body length (mm)		Head width (mm)		Forewing length (mm)	
	Average	St.dev	Average	St.dev	Average	St.dev
WB (nc = 9, ni = 10)	3.52 (3.3-3.9)	0.230	1.47 (1.4-1.6)	0.068	3.91 (3.5-4.2)	0.218
WI (nc = 31, ni = 10)	3.61 (3.3-3.8)	0.197	1.46 (1.3-1.8)	0.165	3.68 (3.2-4.1)	0.294
WT (nc = 7, ni = 10)	3.35 (3.1-3.6)	0.207	1.4 (1.2-1.5)	0.105	3.77 (3.5-4.2)	0.216

WB: Woyla Barat, WI: Woyla Induk, and WT: Woyla Timur. nc = number of colonies and ni = number of individuals measured

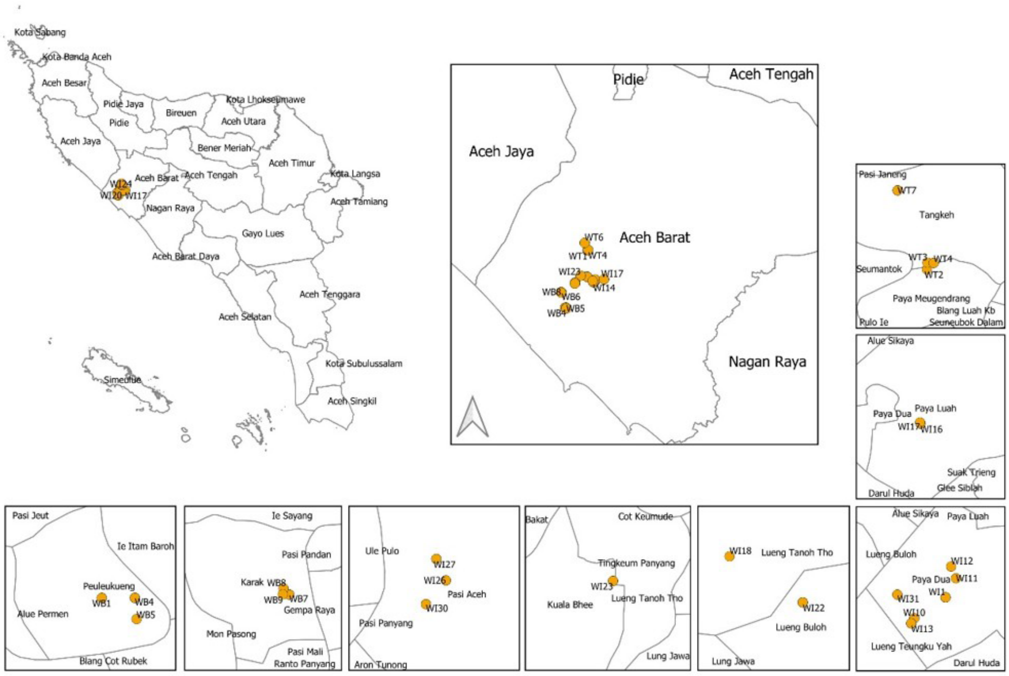


Figure 2. The distribution of *Tetragonula fuscobalteata* nests in a semi-natural ecosystem surrounding the Krueng Woyla River, West Aceh, Aceh, Sumatra, Indonesia. All areas along the river course were confirmed to contain nests, including Woyla Barat, Woyla Induk, and Woyla Timur Districts

Table 3. Codes, coordinates, administrative locations (village names), time of detection, frequency of colony member ingress and egress, and colony behavior of *Tetragonula fuscobalteata* in a semi-natural ecosystem surrounding the Krueng Woyla River, West Aceh, Aceh, Sumatra, Indonesia. Data are arranged alphabetically by sampled districts

Location	Code	Coordinate	Village	Time of detection	Frequency/5 minutes (combined individual)	Behavior
WB	WB1	4°19'58.5"N-96°01'28.2"E	Penluekung	08/11	189	A
	WB2	4°19'58.5"N-96°01'35.7"E	Penluekung	08/11	160	C
	WB3	4°19'58.5"N-96°01'35.7"E	Penluekung	08/11	140	C
	WB4	4°19'58.5"N-96°01'35.7"E	Penluekung	08/11	210	A
	WB5	4°19'53.7"N-96°01'36.1"E	Penluekung	08/11	180	C
	WB6	4°21'27.5"N-96°01'08.4"E	Karak	15/11	260	A
	WB7	4°21'27.5"N-96°01'08.4"E	Karak	15/11	86	C
	WB8	4°21'30.9"N-96°01'05.3"E	Karak	15/11	98	C
	WB9	4°21'27.6"N-96°01'04.9"E	Karak	15/11	96	C
WI	WI1	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	53	A
	WI2	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	60	A
	WI3	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	43	C
	WI4	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	51	A
	WI5	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	60	A
	WI6	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	39	A
	WI7	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	46	A
	WI8	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	30	C
	WI9	4°22'35.9"N-96°04'26.0"E	Paya Dua	11/10	37	C
	WI10	4°22'29.9"N-96°04'17.0"E	Paya Dua	17/10	79	C
	WI11	4°22'41.4"N-96°04'29.0"E	Paya Dua	17/10	93	A
	WI12	4°22'44.8"N-96°04'27.6"E	Paya Dua	17/10	87	A
	WI13	4°22'28.4"N-96°04'16.1"E	Paya Dua	17/10	80	A
	WI14	4°22'28.4"N-96°04'16.1"E	Paya Dua	17/10	36	A
	WI15	4°22'28.4"N-96°04'16.1"E	Paya Dua	17/10	70	A

Table 3. Continued

Location	Code	Coordinate	Village	Time of detection	Frequency/5 minutes (combined individual)	Behavior
	WI16	4°22'46.2"N-96°05'20.0"E	Paya Luah	18/10	91	A
	WI17	4°22'46.9"N-96°05'19.7"E	Paya Luah	18/10	88	A
	WI18	4°23'03.1"N-96°03'36.7"E	Lung Buloh	19/10	78	A
	WI19	4°23'00.2"N-96°03'41.3"E	Lung Buloh	19/10	52	A
	WI20	4°23'00.2"N-96°03'41.3"E	Lung Buloh	19/10	46	C
	WI21	4°23'00.2"N-96°03'41.3"E	Lung Buloh	19/10	76	C
	WI22	4°23'00.2"N-96°03'41.3"E	Lung Buloh	19/10	87	C
	WI23	4°23'07.3"N-96°03'01.3"E	Tingkeum Panyang	19/10	103	A
	WI24	4°23'07.3"N-96°03'01.3"E	Tingkeum Panyang	19/10	100	A
	WI25	4°22'24.4"N-96°02'29.5"E	Pasi Aceh	20/10	58	C
	WI26	4°22'24.4"N-96°02'29.5"E	Pasi Aceh	20/10	106	A
	WI27	4°22'27.1"N-96°02'28.3"E	Pasi Aceh	20/10	96	A
	WI28	4°22'27.1"N-96°02'28.3"E	Pasi Aceh	20/10	88	A
	WI29	4°22'21.4"N-96°02'27.0"E	Pasi Aceh	20/10	108	A
	WI30	4°22'21.4"N-96°02'27.0"E	Pasi Aceh	20/10	90	C
	WI31	4°22'36.7"N-96°04'12.1"E	Paya Dua	24/10	260	A
WT	WT1	4°25'36.8"N-96°03'42.0"E	Tangkeh	02/11	150	A
	WT2	4°25'36.8"N-96°03'42.0"E	Tangkeh	02/11	197	A
	WT3	4°25'40.6"N-96°03'42.3"E	Tangkeh	02/11	187	A
	WT4	4°25'40.4"N-96°03'45.9"E	Tangkeh	02/11	176	A
	WT5	4°25'40.4"N-96°03'45.9"E	Tangkeh	02/11	163	A
	WT6	4°26'22.3"N-96°03'25.1"E	Tangkeh	02/11	108	C
	WT7	4°26'22.3"N-96°03'25.1"E	Tangkeh	02/11	110	A

WB: Woyla Barat, WI: Woyla Induk, and WT: Woyla Timur. A: Aggressive, C: Calm. A and C show colony behavior

totaling 29 nests (61.70%), followed by concrete walls with 9 nests (19.15%), concrete fences with 7 nests (14.89%), and metal poles with 2 nests (4.26%) (Figure 3). Wooden walls constituted the most dominant substrate, with nests distributed across three locations: 9 nests along the Krueng Woyla River in Woyla Barat District, 14 nests in Woyla Induk District, and 6 nests in Woyla Timur District. Nests attached to concrete walls were predominantly recorded in Woyla Induk District (8 nests), with a single nest observed in Woyla Timur District. In addition, all seven nests found on concrete fences were located along the Krueng Woyla River in Woyla Induk District. Within the same area, two additional nests were also observed on metal pole substrates (Figure 4).

Quantitative data showed that nest entrances ranged from 1.0 to 15.0 cm in length, 0.5 to 2.0 cm in horizontal width, and 0.5 to 2.5 cm in vertical height (Table 4). Nests were constructed in unique locations, at heights of 40.0-302.2 cm above the ground and at distances of 50.0-4,900 m from the Krueng Woyla River, the main water source (Table 5). Variations were observed in five aspects of *T. fuscobalteata* nest entrances: color, cavity shape, texture, presence of pores, and sticky resin. Three color types were identified, with dark-toned and brownish shades being the most common (each 46.81%). The entrances were predominantly oval, among three recorded cavity shapes (57.45%). Most entrances had a soft texture (61.70%), lacked pores (93.62%), and contained sticky resin (63.83%). Variations across the 47 nest entrances are illustrated in Figure 5.

3.4. Environmental Conditions Recorded During the Study

Environmental conditions recorded at the study sites showed minor variations. Temperature ranged from 29.0 to 29.67°C, air humidity from 73.0 to 77.33 %, visibility from 14.33 to 15.0 KM, and air pressure from 1006.7 to 1008.0 hPa across the three locations (Table 6).

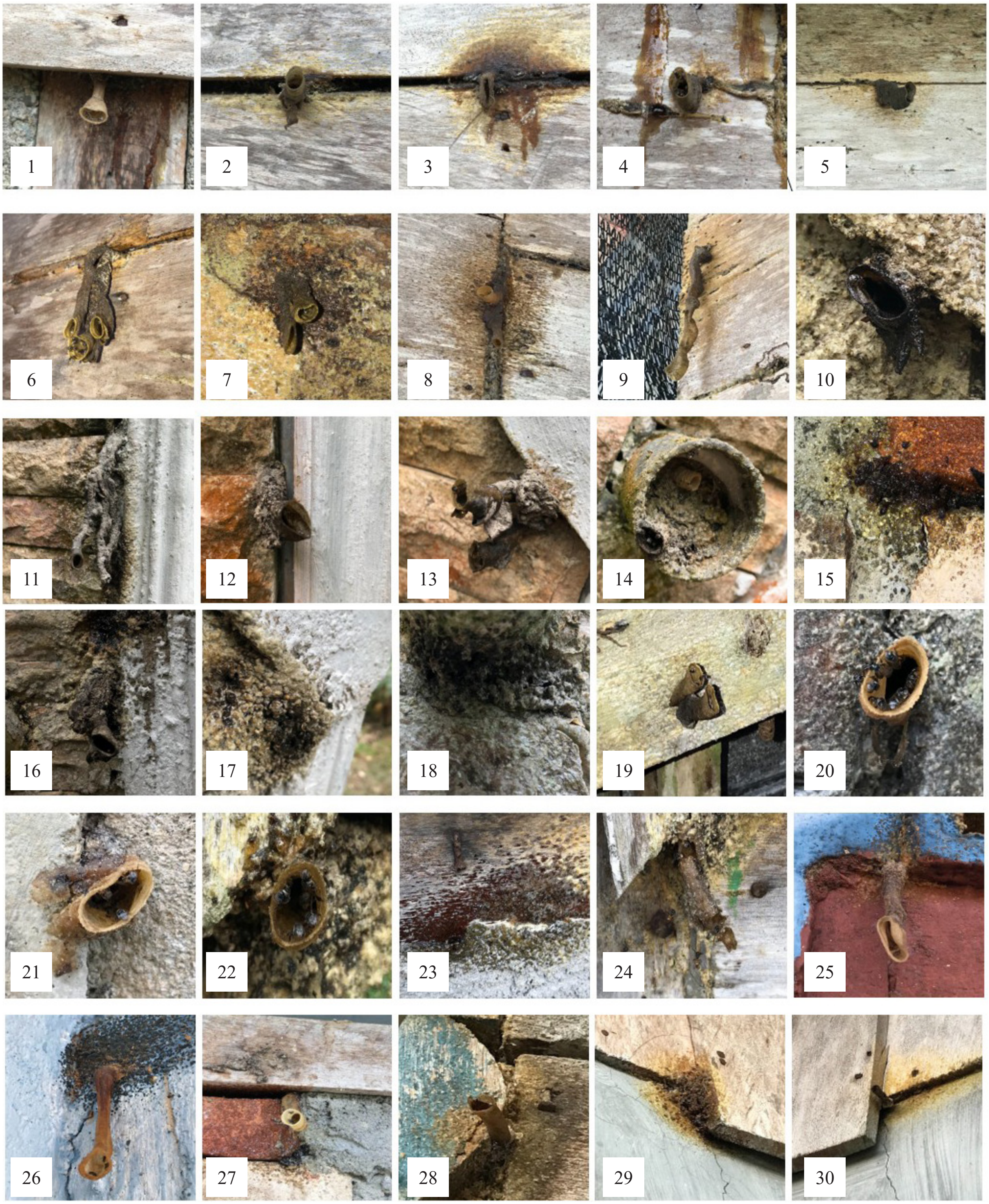
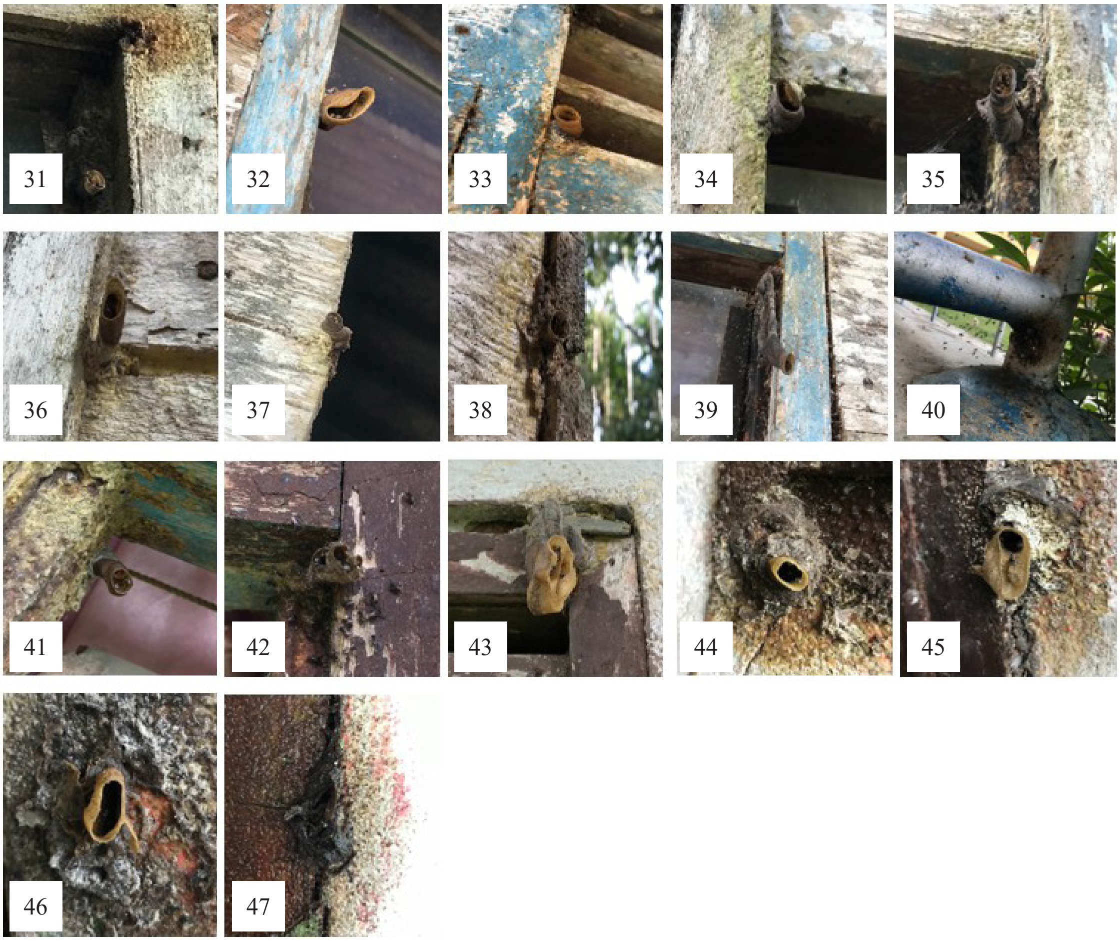


Figure 3. The appearance and nesting locations of *Tetragonula fuscobalteata* recorded during the study: 1. WB1 (ww), 2. WB2 (ww), 3. WB3 (ww), 4. WB4 (ww), 5. WB5 (ww), 6. WB6 (ww), 7. WB7 (ww), 8. WB8 (ww), 9. WB9 (ww), 10. WI1 (cf), 11. WI2 (cf), 12. WI3 (cf), 13. WI4 (cf), 14. WI5 (mp), 15. WI6 (cw), 16. WI7 (cf), 17. WI8 (cf), 18. WI9 (cf), 19. WI10 (ww), 20. WI11 (cw), 21. WI12 (cw), 22. WI13 (ww), 23. WI14 (ww), 24. WI15 (ww), 25. WI16 (cw), 26. WI17 (cw), 27. WI18 (cw), 28. WI19 (ww), 29. WI20 (cw), 30. WI21 (cw), 31. WI22 (ww), 32. WI23 (ww), 33. WI24 (ww), 34. WI25 (ww), 35. WI26 (ww), 36. WI27 (ww), 37. WI28 (ww), 38. WI29 (ww), 39. WI30 (ww), 40. WI31 (mp), 41. WT1 (ww), 42. WT2 (ww), 43. WT3 (ww), 44. WT4 (ww), 45. WT5 (cw), 46. WT6 (ww), 47. WT7 (ww). Ww: wooden wall, Cw: concrete wall, Cf: concrete fence, Mp: metal pole



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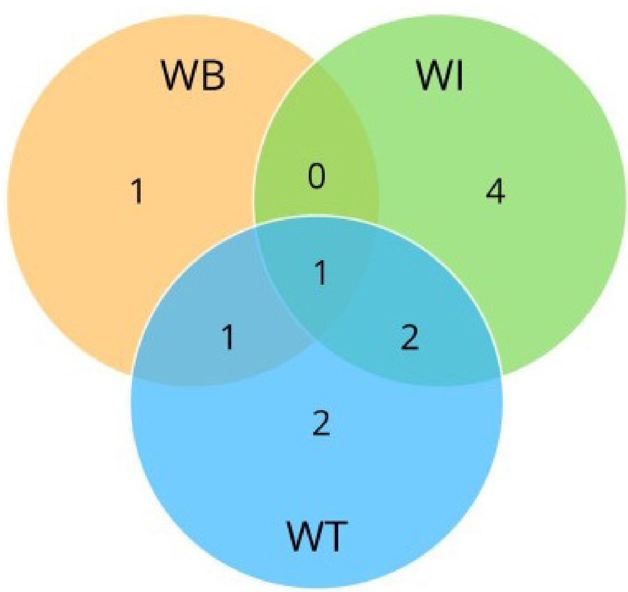

Figure 4. Four nesting sites of T*etragonula fuscobalteata* were recorded in semi-natural ecosystems along the Krueng Woyla River. One nesting site was found in Woyla Barat (WB), four in Woyla Induk (WI), and two in Woyla Timur (WT). The values 0, 1, 2, and 4 represent the number of nest substrate types recorded in each study area

Table 4. The entrance size of *Tetragonula fuscobalteata* nests was recorded during the study. Data are presented as the mean, minimum-maximum range, and standard deviation

Location	Nest entrance size (cm)					
	Length		Horizontal diameter		Vertical diameter	
	Average	St.dev	Average	St.dev	Average	St.dev
WB (n = 9)	5.04 (2.5-15.0)	4.16	1.06 (0.5-1.4)	0.33	1.17 (0.7-1.5)	0.27
WI (n = 31)	4.20 (1.0-14.0)	3.37	1.12 (0.5-2.0)	0.39	1.19 (0.5-1.8)	0.29
WT (n = 7)	2.84 (1.0-5.4)	1.77	1.16 (1.0-1.5)	0.22	1.64 (1.1-2.5)	0.50

WB: Woyla Barat, WI: Woyla Induk, and WT: Woyla Timur. n denotes the number counted (colonies)

Table 5. The nesting locations of *Tetragonula fuscobalteata* relative to the ground (cm) and the water body of the Krueng Woyla River (m). Data are presented per nest in the order of encounter, along with the mean and minimum-maximum range

Nest location	WB	WI	WT
Nest height from ground (cm)	100; 80; 90; 91; 200; 150; 120; 102; 208	120; 40; 50; 120; 55; 120; 125; 123; 120; 201; 105; 58; 66; 54; 68; 156; 150; 200; 302; 300; 301; 200; 150; 180; 203; 203; 200; 290; 230; 208; 50	206; 196; 211; 60; 70; 100; 150
	Average: 126.78 Min-Max : 80-208 SD : 54.21	Average: 153.16 Min-Max : 40-302 SD : 92.83	Average: 141.86 Min-Max : 60-211 SD : 64.55
Distance from the Krueng Woyla River (m)	350; 50; 50; 50; 150; 350; 350; 450; 455	3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 3600; 4900; 4900; 2700; 2700; 2700; 2700; 2700; 1300; 1300; 180; 180; 150; 150; 90; 90; 3600	150; 150; 180; 290; 290; 1096; 1096
	Average: 250.56 Min-Max : 50-455 SD : 185.85	Average: 2720.65 Min-Max : 90-4900 SD : 1589.73	Average: 464.57 Min-Max : 150-1096 SD : 397.27

WB: Woyla Barat, WI: Woyla Induk, and WT: Woyla Timur

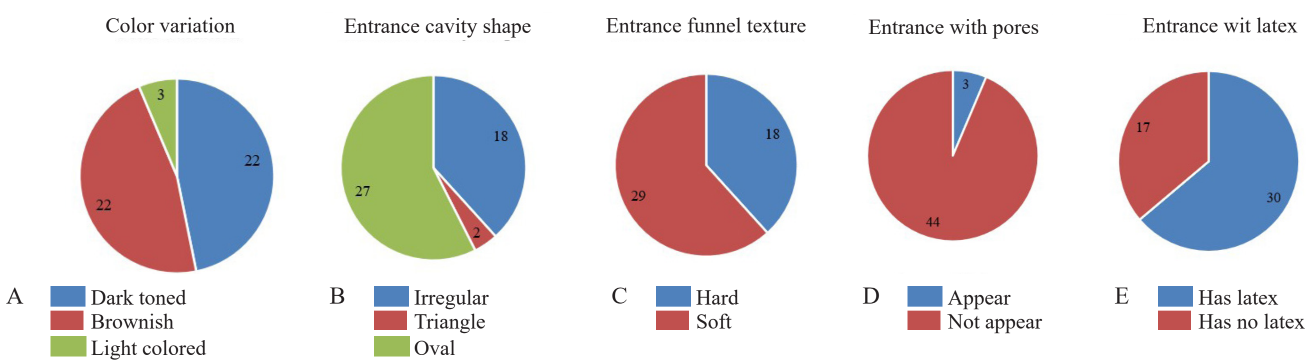

Figure 5. Variations in the entrance structures of *Tetragonula fuscobalteata* nests observed during the study period included several aspects, namely: A. Color spectrum, B. Cavity shape, C. Texture, D. Presence of pores, and E. Presence of sticky resin

Table 6. Environmental conditions recorded during the study, data on daily mean values for each observation date at the same location

Location	Environmental conditions			
	Temperature (°C)	Air humidity (%)	Visibility (km)	Air pressure (hPa)
WB	29.33	77.33	14.67	1,006.7
WI	29.0	76.33	14.33	1,007.3
WT	29.67	73.0	15.0	1,008.0
Range of the three locations	29.0-29.67	73.0-77.33	14.33-15.0	1,006.7-1,008.0

WB: Woyla Barat, WI: Woyla Induk, and WT: Woyla Timur

4. Discussion

4.1. Species Diversity of Stingless Bees Along the Krueng Woyla River

Based on morphological, morphometric, and ecological characteristics verified using a zoogeographical approach, the collected samples were identified as *T. fuscobalteata*. This species was previously reported in Aceh Besar Regency, Aceh Province, approximately 266 km from the present study site (Emil *et al*. 2024), and is known to have a wide distribution in Indonesia within the Indo-Malayan biogeographical region (Engel *et al*. 2023). The presence of *T. fuscobalteata* has also been widely documented in studies on stingless bees in Sumatra and other parts of Southeast Asia, including Thailand and Malaysia (Sakagami *et al*. 1990; Salim *et al*. 2012; Wayo *et al*. 2020; Herwina *et al*. 2021). The genus *Tetragonula* is recorded to have a wide geographical distribution across Indonesia (Engel *et al*. 2018; Engel *et al*. 2023; Emil *et al*. 2024; Atmowidi *et al*. 2024). Study locations are predicted to offer limited space for multiple species; this is further supported by reports of high stingless bee species richness in Aceh, where ecosystem conditions are more diverse (Emil *et al*. 2024).

In this study, *T. fuscobalteata* from Woyla Induk exhibited a larger body size than those from the other sites (3.61±SD 0.197 mm). In contrast, the maximum head width (1.47±SD 0.068 mm) and longest forewing length (3.91±SD 0.218 mm) were recorded in samples from Woyla Barat. All specimens were confirmed as belonging to the genus *Tetragonula* based on morphometric ranges reported by Rachmawati *et al*. (2022), with maximum values of 4.37 mm for body length, 1.41 mm for head width, and 3.60 mm for forewing length, and by Efin *et al*. (2019), who reported corresponding maxima of 4.58 mm, 1.60 mm, and 4.26 mm. The morphometric values observed in this study are comparable to those reported by Trianto *et al*. (2024) for ten stingless bee species in Sulawesi but remain smaller than those documented for *T. fuscobalteata* from Aceh Besar, Aceh Province (Emil *et al*. 2024). The observed morphological characteristics of the species exhibited complete congruence with those of *T. fuscobalteata* reported from South Kalimantan (Purwanto *et al*. 2022). Morphometric differences across study regions need to be examined in greater depth in future studies. In addition, vegetation studies are required, as vegetation is presumed to play an important role in influencing variations in bee body size or weight across regions.

4.2. Distribution of Stingless Bees Along the Krueng Woyla River

A total of 47 nests of *Tetragonula fuscobalteata* recorded in this study were exclusively associated with the Krueng Woyla River area, with all nests found in residential zones (100%) and none observed in garden areas (0%) or residential yards (0%). This pattern indicates that riparian environments are among the primary habitats for this species. Consistent with these findings, Emil *et al*. (2024) reported that, out of ten stingless bee species documented, six nests of *T. fuscobalteata* were an important component of ecosystems in residential environments. The presence of nests across the three sub-districts along the Krueng Woyla River indicates that *T. fuscobalteata* is abundant and well adapted to local environmental conditions. However, no nests were found associated with trees.

The occurrence of nests representing only a single stingless bee species is likely attributable to ecosystem characteristics that tend to be less accommodating of species diversity due to limited availability and heterogeneity of floral resources. The genus *Tetragonula* is widely recognized as one of the most commonly encountered stingless bee taxa, whereas a higher diversity and abundance of stingless bees are typically associated with forest ecosystems (Hamid *et al*. 2016; Mayes *et al*. 2019). The predominance of nests in Woyla Induk is presumably linked to the greater diversity of forage vegetation in this area; however, further investigations, including comprehensive vegetation assessments, are required to substantiate this inference. Colonies exhibiting aggressive behavior, along with high frequencies of nest entrance and exit activities during observation intervals, indicate a colony defense strategy in response to external disturbances to the nest (Shackleton *et al*. 2019; Miharja *et al*. 2024). Differences in behavior and the number of individuals entering and exiting the nest were not the main parameters of this study. Still, they were included as supplementary data for future research development. Aggressive and calm behaviors are likely influenced by the level of environmental risk that threatens the colony (Rudin *et al*. 2018).

4.3. Nesting Ecology of Stingless Bees Along the Krueng Woyla River and Environmental Conditions Recorded During the Study

During the study period, four types of nesting substrates utilized by *T. fuscobalteata* were identified. The majority of nests were found on wooden walls, totaling 29 nests (61.70%), followed by concrete walls with 9 nests (19.15%), concrete fences with 7 nests (14.89%), and metal poles with 2 nests (4.26%), this finding is consistent with the report by Emil *et al*. (2024), which noted that *T. fuscobalteata* constructs its nests on residential structural elements, such as door and window frames, as well as on metal poles. The distinctive characteristic of *T. fuscobalteata* lies in its highly restricted nesting-site preference, as this species is rarely encountered nesting outside residential areas and is seldom found constructing nests beyond houses. Within the genus *Tetragonula*, this species exhibits a specialized nesting preference that differs from other congeners, as reported in studies of stingless bees in Aceh (Indo-Malayan region) and Sulawesi (Wallacea) (Suhri *et al*. 2022; Emil *et al*. 2024). In Southeast Asia, bamboo is one of the nesting substrates used by *T. fuscobalteata*, along with residential structures (Starr and Sakagami 1987). The predominance of wooden walls as nesting substrates (29 nests) across all study sites is likely influenced by the local community's dominant housing structures, which continue to use wooden boards as the primary building material.

The size of the nest entrance is closely associated with the body size of individuals within the colony. In this study, nest entrances ranged from 1.0 to 15.0 cm in length, 0.5 to 2.0 cm in horizontal width, and 0.5 to 2.5 cm in vertical height. Consistent with this, Emil *et al*. (2024) reported that *T. fuscobalteata* has the smallest nest entrance size compared to nine other stingless bee species recorded in Aceh Province. Notably, this species also exhibits the smallest nest entrance among congeners in the genus (Emil *et al*. 2024). Nests were located in varied positions at heights ranging from 40.0 to 302.2 cm above the ground, likely representing a colony strategy to mitigate external disturbances (Rivaldy *et al*. 2023; Emil *et al*. 2024). In addition, nests were located at distances ranging from 50.0 to 4,900 m from the Krueng Woyla River, the main water source. This proximity to water is consistent with observations by Lorenzon and Matrangolo (2005), who reported abundant floral and non-floral resources around water bodies frequently visited by foraging worker bees. Furthermore, Noorahya *et al*. (2023) highlighted that water is an essential component in honey production, explaining why nests in the present study were located within a radius of less than 5 km from the Krueng Woyla River.

Dark-toned and brownish nest entrance funnels were the most frequently observed, a pattern closely associated with the resin-producing vegetation exploited by the colonies (Emil *et al*. 2024). In addition, dark-colored entrance funnels are presumed to represent older nests, as prolonged exposure to air and contamination by external organisms gradually alters their coloration (Miharja *et al*. 2024). In this study, brightly colored entrance funnels were rarely encountered, which may indicate a dominance of older nests and a low rate of colony fission in the area, or reflect the limited availability of light-colored plant resins in the study region. Four types of entrance cavity shapes were recorded, consistent with the findings of Sayusti *et al*. (2021) on stingless bees in Sulawesi. The soft texture of the nest entrance suggests newly established nests or entrances that have not yet hardened (Miharja *et al*. 2024), and it also serves an adaptive function by enabling colonies to seal the entrance during disturbance events (Emil *et al*. 2024). The presence of pores and sticky resin on the entrance funnel facilitates air exchange and acts as a defensive mechanism against intruding organisms (Emil *et al*. 2024). The predominance of entrances with sticky resin further indicates an environment rich in associated organisms, highlighting the need for further investigation in future studies. Multiple factors influence variation in nests. Environmental factors, such as rainfall and predation pressure, play a key role in shaping differences in nest entrance characteristics. In general, both internal colony conditions and external environmental factors determine this variation, as reported by Emil *et al*. (2024) and Sayusti *et al*. (2021).

In conclusion, This study shows that stingless bees along the Krueng Woyla River are represented by a single species, *Tetragonula fuscobalteata*, which is widely distributed across the three study regions (upstream, middle, and downstream) and exhibits a high adaptive capacity to riparian and residential environments. A total of 47 nests were recorded, with the highest number in Woyla Induk, followed by Woyla Barat and Woyla Timur, all of which were associated with residential areas; no nests were found in gardens or trees. This species demonstrates a specific nesting preference for various artificial substrates, such as wooden walls, concrete structures, fences, and metal poles, with a predominance of wooden structures, reflecting local housing characteristics. Variation in nest entrance characteristics, including size, shape, color, texture, presence of pores, and resin occurrence, reflects adaptations to microhabitat conditions, proximity to water sources, and surrounding environmental factors, such as forage vegetation availability and environmental pressures. Overall, *T. fuscobalteata* exhibits strong dominance and high adaptive flexibility in utilizing the Krueng Woyla riparian landscape, highlighting this area as an important potential habitat for stingless bees that should be sustainably managed and conserved.

Conflict of Interest

The authors declare no conflict of interest.

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