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RESEARCH PAPER

Species diversity of fruit flies in three different habitats in Central Sulawesi, Indonesia

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ABSTRACT

Fruit flies (Diptera: Tephritidae) are major pests in the horticultural sector. However, comprehensive information on their distribution across different habitats in Central Sulawesi is still lacking. This study aimed to assess the species diversity of fruit flies in three habitat types—urban, agricultural, and forest areas—in Central Sulawesi, Indonesia. Collections were conducted from November 2022 to May 2023 using Steiner traps baited with cue lure (CUE) and methyl eugenol (ME). Fruit fly specimens were identified to the species level, and diversity, dominance, and evenness indices were calculated. A total of 32 species and 10,393 individual fruit flies were collected across the three habitat types. The forest habitat exhibited the highest diversity and evenness indices, followed by agricultural and urban areas. In contrast, the urban habitat showed a higher dominance of certain species. The most dominant species were *Bactrocera dorsalis* (ME trap) and *B. albistrigata* (CUE trap). Notably, the presence of rare species found exclusively in forest habitats contributed significantly to the higher species richness observed there.

Key words: forest, plantation, Tephritidae, urban, Wallacea region

INTRODUCTION

Sulawesi is one of the islands in Indonesia that belongs to the Wallacea region, which is a sanctuary for tropical biodiversity. Wallacea is a unique biogeographical region located between the Asian and Australian-Papua New Guinea realms. Sulawesi hosts a remarkable diversity of endemic flora and fauna, with distinctive of ecosystems and habitat types, including tropical rainforests and orchards (Sapta et al., 2015; Reilly et al., 2019; Doorenweerd et al., 2020). Central Sulawesi, a major province on the island, features varied landscapes including farmland, forests, national parks, and urban areas. According to BPS Sulteng (2024), Central Sulawesi produced 2.1 million fruits and vegetables in 2023, with the highest production being durian, pineapple, and banana. The region has high fruit tree diversity, including guava, Indian almond, chili, bitter gourd, sapodilla, pumpkin, watery rose apple, pineapple, starfruit, mangosteen, jackfruit, rambutan, papaya, breadfruit, banana, durian, and mango. The majority of these serve as hosts for fruit flies (Suputa et al., 2010; Fitrah et al., 2020; Aryuwandari et al., 2020). This affects the distribution and diversity of fruit fly species, particularly in the Palu City, Sigi, and Donggala regencies.

Fruit flies (Diptera: Tephritidae) are among the most economically important pests worldwide (Qin et al., 2015), and are significant quarantine pests (Almeida et al., 2016). They have been reported to cause damage ranging from 5% to 100% of fruit production in Asia (Rauf et al., 2013). The most economically important genera of fruit flies include *Anastrepha, Bactrocera, Ceratitis, Dacus*, and *Rhagoletis* (Jiang et al., 2018). In Indonesia, key species include *Atherigona orientalis, Bactrocera* spp., and *Dacus longicornis* (Suputa et al., 2010). However, host range and climatic conditions influence fruit flies diversity and distribution (Salazar-Mendoza et al., 2021).

The types of flowering plants in a habitat influence insect species composition (Jihadi et al., 2021). For example, fruit fly genera *Bactrocera* and *Zeugodacus* feed on *Bulbophyllum* spp. and *Dendrobium* spp. in Southeast Asian rainforests (Tan & Nishida, 2013). Fahrig et al. (2011) also reported that greater vegetation variety in forests creates favorable environments for fruit flies, even in small amounts. Therefore, fruit fly diversity is closely linked to habitat type.

The agricultural sector in Central Sulawesi

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holds potential for significant fruit production. This could influence fruit fly diversity due to the availability of host plants, which are cultivated year-round. This condition affects population levels and distribution of fruit fly species (Linda et al., 2018). Sulawesi also has extensive forests with healthy ecosystems, which may support both pest and non-pest fruit fly species. Habitat variation is considered a key factor in determining fruit fly diversity. Fruit flies depend on plant materials for nutrition, reproduction, and shelter. The suitability of a habitat is associated with specific host plants. Host specificity can vary depending on the resources used by each species (Grimbacher et al., 2013). Environmental conditions and host plant architecture significantly influence the abundance and behavior of phytophagous insects (Gaëlle et al., 2014).

Fruit fly species have been collected using attractants and host rearing methods in West Sulawesi (Khaeruddin et al., 2015), Central Sulawesi (Jusmanto et al., 2019), South Sulawesi (Daud et al., 2019; Doorenweerd et al., 2020), and North Sulawesi (Doorenweerd et al., 2020). The collected fruit flies belong to three genera: *Bactrocera, Dacus,* and *Zeugodacus* (Khaeruddin et al., 2015; Daud et al., 2019; Jusmanto et al., 2019; Doorenweerd et al., 2020). In Central Sulawesi, four fruit fly species have been reported: *B. albistrigata*, *B. carambolae*, *B. cucurbitae,* and *B. umbrosa* (Jusmanto et al., 2019). However, there is currently a lack of comprehensive information on fruit fly distribution across different habitats—such as forests, plantations, and urban areas—in Central Sulawesi. This study provides information on species diversity, dominance, and evenness of fruit flies in urban, agricultural, and forest habitats in Central Sulawesi, which is essential for understanding their potential as pests.

MATERIALS AND METHODS

Research Site. The research was conducted from November 2022 to May 2023 across three habitat types in Central Sulawesi, Indonesia: urban (Palu City), agricultural (Donggala Regency), and forest (Sigi Regency) (Figure 1, Table 1).

The urban habitat in Tondo, Mantikulore District, Palu City, is an area with various trees, mostly fruit trees, intentionally planted for shading in home gardens and parks. The dominant plants in this area include ivy gourd, star fruit, sapodilla, water apple, mango, and Jamaica cherry, cultivated around residential areas. Mantikulore is classified as tropical humid, with an average annual rainfall of 56.39 mm and a mild dry season. The annual relative humidity ranges from 67% to 78%, and temperature vary between 27.1 ºC and 29.9 ºC. The topography consists mainly of lowland, with about 10% classified as mountainous (BPS Palu, 2024).

The agricultural habitat was located in Nupa Bomba, Tanantovea District, Donggala Regency. The observation site consisted of a heterogeneous ecosystem with various types of fruit and vegetable plants including ambarella, avocado, banana, bitter gourd, breadfruit, chilies, coffee, cucumber, dragon fruit, durian, grapefruit, guava, Indian bael, jackfruit, Jamaican cherry, langsat, lime, longan, mango, noni fruit, papaya, passion fruit, pineapple, pumpkin, rambutan, soursop, star fruit, strawberries, and water apple. Donggala is also classified as tropical humid, with an average annual rainfall of 148.25 mm, average humidity of 76.2%, and temperature ranging from 20 ºC to 38 ºC. The topography is more mountainous, with approximately 60% of the land situated at 86 m a.s.l. (BPS Donggala, 2023; BPS Donggala, 2024).

The forest habitat was located in Beka, Marawola District, Sigi Regency, specifically in the Ranjuri forest (Figure 1). It is a secondary forest dominated by tree species such as argus pheasant trees (*Dracontomelon dao* and *D. mangiferum*), sea almond (*Terminalia catappa*), sugar palm (*Arenga pinnata*), weeping fig (*Ficus benjamina*), India rubber tree (*F. elastica*), fishtail palm (*Caryota mitis*), *Pothos* sp., false rattan (*Flagellaria indica*), Siamese rough bush (*Streblus asper*), and caper-thorn (*Capparis micracantha*). Marawola also has a tropical humid climate, with a lower average annual rainfall of 48.9 mm, average humidity around 74%, and a temperature of approximately 28.4 ºC. The topography of this district is entirely mountainous (100%) (BPS Sigi, 2024).

Fruit Fly Collection. Fruit flies were collected using Steiner traps. Each habitat contained three observation plots, and each plot was equipped with three Steiner traps placed 10 m apart. Traps were installed on tree branches at 1–1.5 m above the ground during the rainy and fruiting season.

Steiner traps were made from transparent cylindrical plastic jars, 20 cm height and 10 cm in internal diameter, with both height covered by wire mesh (Figure 2). The traps were modified following the FAO and IAEA (2023) guidelines. An iron hook was used to hang each trap from a tree branch. Inside, a piece of cotton was suspended and saturated with 0.50 mL of attractant—either cue lure (CUE) or methyl

Table 1. The observation sites of urban, agriculture and forest habitats in Central Sulawesi, Indonesia

Habitats	Research locations	Coordinates	Altitudes (m a.s.l.)
Urban	Tondo, Mantikulore District, Palu City	0°50’19.1”S 119°53’08.6”E	44.3
		0°50’00.2”S 119°53’12.7”E	30.4
		0°49’58.6”S 119°53’13.6”E	31.1
Agricultural	Nupa Bomba, Tanantovea District, Donggala Regency	0°42’51.1”S 120°00’12.7”E	765.5
		0°42’50.5”S 120°00’17.1”E	741.8
		0°43’05.6”S 120°00’18.5”E	849.9
Forest	Beka, Marawola District, Sigi Regency	0°59'26.0"S 119°51'38.0"E	25.9
		0°59'26.9"S 119°51'30.6"E	93.0
		0°59'27.1"S 119°51'31.5"E	71.5

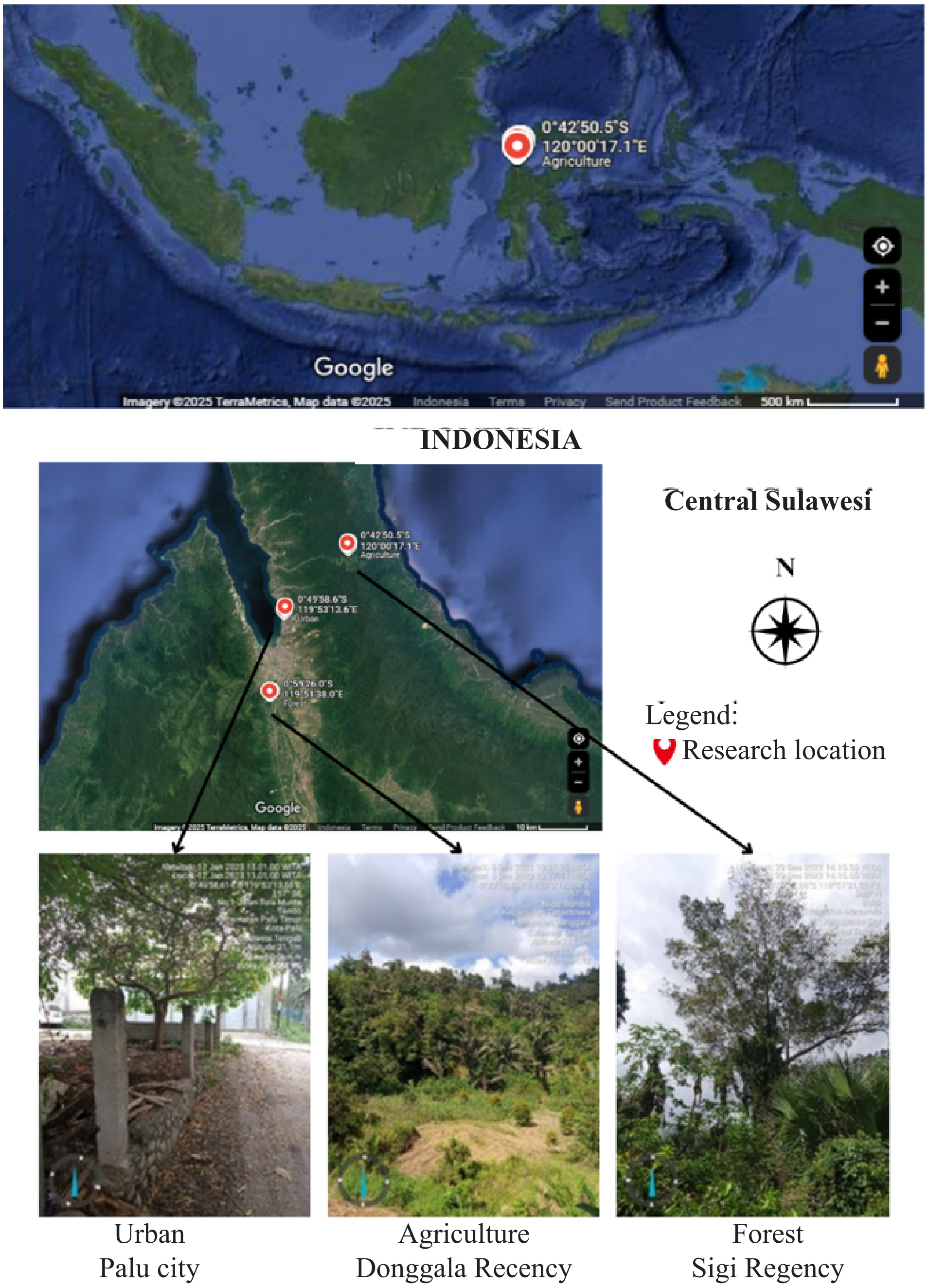

Figure 1. The location sites of urban, agriculture, and forest areas in Central Sulawesi, Indonesia.

eugenol (ME). Fruit flies were collected weekly, and the cotton was also replaced at that time. Collected specimens were wrapped in tissue paper and stored in collection bottles containing silica gel and camphor for identification.

Identification. All collected fruit flies were identified based on morphological characteristics using a USB Portable Digital Microscope (Supereyes® Model A005+, Shenzhen Supereyes Co. Ltd., China) at the Laboratory of Entomology, Department of Plant Protection, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Species-level identification was conducted following the diagnostic characteristics outlined in Keys to the Tropical Fruit Flies (Tephritidae: Dacinae) of South-East Asia: Indomalaya to North-West Australasia (Drew & Romig, 2013).

Data Analysis. A dichotomous key for fruit fly identificiation was constructed based on: (1) Statements of character traits and their observable variations; (2) Morphological features distinguishing each taxon. Character states used in the key were derived from identification guides by Drew & Romig (2013) and Pratyadhiraksana et al. (2020). Updates regarding species names, authorship, and geographic distribution were accessed from Drew & Romig (2013). Identification of each species was achieved by comparing dichotomous morphological features specific to that species.

Data on fruit fly diversity and abundance from each habitat type were compiled into a single table. Several ecological indices were adopted in this research. The following ecological indices were calculated:

(i) Shannon-Wiener Diversity Index (H′):

$$H' = -\sum \left(\frac{n_i}{N}\right) \ln\left(\frac{n_i}{N}\right)$$

H’= Shannon-Wiener Diversity Index;
ni = Number of individual of species;
N = Total number of individuals.

(ii) Shannon Evenness Index (E):

$$E = \frac{H'}{\ln(S)}$$

E = Shannon-Evennes Index;
H’= Shannon-Wiener Diversity Index;
S = Total number of individuals.

(iii) Simpson’s Dominance Index (D):

$$D = \sum (P_i)^2 \rightarrow P_i = n_i \frac{n_i}{N}$$

D = Simpson’s Dominance Index;
p_i = Total sample proportion to species i;
n_i = Number of individuals to species i;
N = Total number of individuals collected.

RESULTS AND DISCUSSION

A total of 32 fruit fly species were collected from three distinct habitat types in Central Sulawesi, Indonesia, namely urban areas (Palu City), agricultural areas (Donggala District), and forest areas (Sigi District). The species belonged to three genera: *Bactrocera* (23 species), *Dacus* (3 species), and *Zeugodacus* (6 species). The morphological differences among the fruit fly species are presented in the identification key below.

The identification key was developed using a dichotomous approach to guide users from genus to species level based on specific morphological characteristics. The key consists of paired contrasting statements, starting from general features (genus) to more specific traits (species). In this study, the dichotomous key was based on male morphological characters such as the scutum, scutellum, wings, and

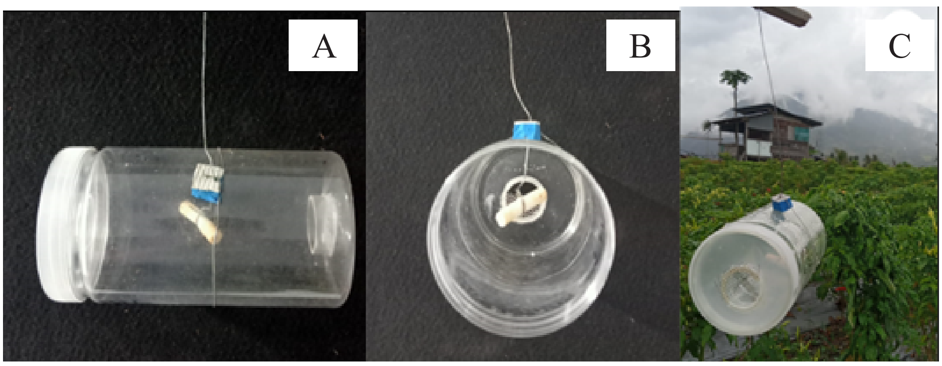

Figure 2. Steiner trap. A. Outside part; B. Inside part; C. Installed on the field.

1	A. Abdomen terga fused and strongly petiolate [***Dacus*** (**Wiedemann**)] 2
	B. Abdomen terga not fused and oval to elongate, oval in shape 4
2	A. Lateral and medial post sutural yellow vittae absent 3
	B. Lateral absent and medial post sutural yellow vittae present .... ***Dacus infernus*** **(Hardy)**
3	A. Scutum dark red-brown without distinct dark patterns .... ***D. longicornis*** **(Wiedemann)**
	B. Scutum black .... ***D. pullus*** **(Hardy)**
4	A. Medial postsutural vittae present **[*Zeugodacus*** **(Hendel)]** **5**
	B. Medial postsutural vittae absent **[*Bactrocera*** **(Macquart)]** **10**
5	A. Colour pattern on wing membrane as a large apical spot that recurves back along dm-cu crossve in .... ***Zeugodacus emittens*** **(Walker)**
	B. Colour pattern on wing membrane as bands only along both r-m and dm-cu crossveins (may be pale on r-m crossvein) **6**
6	A. Lateral and medial postsutural yellow vittae present **7**
	B. Seta; cells bc and c colorless .... ***Z. cucurbitae*** **(Coquillett)**
7	A. Abdominal terga III-V light **8**
	B. Abdominal terga III-V dark **9**
8	A. Abdominal terga III-V mostly orange-brown with at most, a black spot on anteriolateral corners of tergum III and a medial black stripe on tergum V .... ***Z. persignata*** **(Hering)**
	B. Abdominal terga III-V fulvous with a broad medial and two broad lateral longitudinal dark fuscous to black bands joined along the anterior margin of tergum III .... ***Z. exornata*** **(Hering)**
9	A. Face fulvous with a pair of small circular black spot.......... ***Z. neoflavipilosa*** **(Drew & Romig)**
	B. Face entirely fulvous.......... ***Z. abnormis*** **(Hardy)**
10	A. Costal band just overlapping R2+3, mesopleural stripe not reaching to postpronotal lobe dorsally......**11**
	B. Costal band confluent R4+5, two transverse fuscous bands across wing running from costal band to hind **margin12**
11	A. Postpronotal lobes black; lateral postsutural yellow vittae very short and narrow and ending just posterior of a.sa. seta .... ***Bactrocera frauenfeldi*** **(Schiner)**
	B. Postpronotal lobes yellow; lateral postsutural yellow vittae of medium width, elongate and ending just before ia. Seta .... ***B. albistrigata*** **(de Meijere)**
12	A. Colour pattern on wing membrane as three broad red-brown bands from costal band to hind margin **13**
	B. Colour pattern on wing membrane as dark not bands **14**
13	A. A broad fuscous costal band confluent with R4+5 and overlapping this vein at its apex .... ***B. umbrosa*** **(Fabricius)**
	B. A broad fuscous costal band confluent with R4+5 and two transverse fuscous bands across wing running from costal band to hind margin .... ***B. bifasciata*** **(Hardy)**
14	A. Abdominal tergum dark, T pattern absent **15**
	B. Abdominal tergum light, T pattern absent **16**
15	A. A narrow dark fuscous costal band slightly overlapping R2+3 .... ***B. nigrotibialis*** **(Perkins)**
	B. A broad costal band almost with R4+5 ....***B. enigmatica*** **(Hardy)**
16	A. Terga III-V orange-brown with a dark T pattern narrow **17**
	B. Terga III-V dark with a dark T pattern wide **18**
17	A.Two broad lateral postsutural vittae narrowing posteriorly to end just before ia. Seta .... ***Bactrocera nanoarcuata*** (Drew & Romig)
	B.Two moderality broad paralel-sided lateral postsutural vittae ending at ia. seta ...... ***B. bryoniae*** **(Tryon)**

18	A. Face fulvous with a pair of medium-sized circular to slightly oval black spots **19**
	B. Face fulvous with a pair of small-sized circular black spots **20**
19	A. Costal band confluent with R4+5 and overlapping .... ***B. beckerae* (Hardy)**
	B. Costal band almost confluent with R4+5 .... ***B. pseudobeckerae* (Drew & Romig)**
20	A. Scutum base colour black **21**
	B. Scutum base red-brown **24**
21	A. Costal band confluent with R2+3 .... **22**
	B. Costal band overlapping R2+3 .... **23**
22	A. Abdominal tergum T pattern absent **25**
	B. Abdominal tergum T pattern present **26**
23	A. Abdominal terga IV-V red-brown with a narrow black T pattern **27**
	B. Abdominal terga III-V entirely black **28**
24	A. Scutum orange-brown with broad lateral longitudinal black bands running from inside lateral postsutural vittae .... ***B. trifasciata* (Hardy)**
	B. Scutum red-brown with pale fuscous patterning posteriorly .... ***B.* sp1 (unidentified)**
25	A. A narrow dark fuscous costal band with R2+3 and remaining narrow around apex of wing .... ***B. nationigrotibialis* (Drew & Romig)**
	B. A narrow pale fuscous costal band confluent with R2+3 and remaining narrow before widening very slightly across apex of R4+5 .... ***B. angustifinis* (Hardy)**
26	A. A narrow fuscous costal band confluent with R2+3 and remaining very narrow around apex of wing .... ***B. dorsalis* (Hendel)**
	B. A narrow dark fuscous costal band confluent with R2+3 and widening gradually across apex of R4+5 .... ***B. affinidorsalis* (Hardy)**
27	A. Anterolateral corners of terga IV and V dark fuscous **29**
	B. Anterolateral cornes of terga III or IV dark fuscous **30**
28	A. A broad fuscous costal band confluent with R4+5 and overlapping this vein at its apex .... ***B. umbrosa* (Fabricius)**
	B. A broad fuscous costal band confluent with R4+5 and two transverse fuscous bands across wing running from costal band to hind margin .... ***B. bifasciata* (Hardy)**
29	A. a broad dark fuscous costal band usually confluent with R4+5 and expanding slightly across apex of this vein .... ***B. limbifera* (Bezzi)**
	B. A narrow dark fuscous costal band just overlapping R2+3 where it is very pale and expanding slightly across apex of R4+5 .... ***B. bimaculata* (Drew & Hancock)**
30	A. A narrow dark fuscous costal band distinctly overlapping R2+3 .... ***B. musae* (Tryon)**
	B. A narrow fuscous confluent with costal band slightly overalpping R2+3 .... ***B. carambolae* (Drew & Hancock)**
31	A. A very broad fuscous coastal band overlapping R4+5 in the center of the wing and M at apex of wing and merges as a pale tin across cell M .... ***B. eurylomata* (Hardy)**
	B. Broad dark fuscous costal band confluent with R4+5 and expanding into a large spot across apex of a wing to form a large spot .... ***B. transversa* (Hardy)**

abdomen (Drew & Romig, 2013; Pratyadhiraksa et al., 2020).

Fruit fly species composition varied among the three habitat types, influenced by habitat-specific characteristics. In the urban habitat, which included six types of plant flora, 12 fruit fly species were found. In agricultural areas with 50 types of plant vegetation, 23 species were identified. In forest habitats, with 12 types of plant vegetation, 17 species were recorded. Our study showed that species richness was highest in the agricultural habitat, followed by the forest and urban areas (Table 2). These results suggest a strong

Table 2. Abundance of fruit flies collected in Steiner trap with Cue-Lure (CUE) and methyl eugenol (ME) from urban, agriculture, and forest area, Central Sulawesi, Indonesia

Species	Urban		Agriculture		Forest		Total	
	CUE	ME	CUE	ME	CUE	ME	CUE	ME
Bactrocera albistrigata	698	-	6	-	1157	-	1861	0
B. affinidorsalis	-	-	577	-	-	-	577	0
B. angustifinis	-	-	47	-	-	-	47	0
B. beckerae	-	-	-	-	3	-	3	0
B. bifasciata	-	-	7	-	-	-	7	0
B. bimaculata	-	-	-	-	11	-	11	0
B. bryoniae	-	-	-	-	3	-	3	0
B. carambolae	-	783	-	117	-	475	0	1375
B. dorsalis	-	1743	-	147	-	1688	0	3578
B. enigmatica	-	-	3	-	-	-	3	0
B. eurylomata	-	-	1	-	-	-	1	0
B. frauenfeldi	378	-	-	-	878	-	1256	0
B. limbifera	2	-	589	-	343	-	934	0
B. linduensis	-	-	12	-	-	-	12	0
B. musae	-	15	-	-	-	139	0	154
B. nanoarcuata	-	-	22	-	-	-	22	0
B. nationigrotibialis	-	11	-	-	-	8	0	19
B. nigrotibialis	-	-	9	-	-	-	9	0
B. pseudubeckerae	-	-	4	-	-	-	4	0
B. transversa	-	-	14	-	-	-	14	0
B. trifasciata	-	-	3	-	-	-	3	0
B. umbrossa	-	25	-	3	-	88	0	116
B. sp1 (unidentified)	-	-	-	-	-	5	0	5
Dacus longicornis	2	-	-	-	17	-	19	0
D. infernus	-	-	3	-	-	-	3	0
D. pullus	-	-	1	-	-	-	1	0
Zeugodacus abnormis	6	-	5	-	7	-	18	0
Z. cucurbitae	223	-	-	-	19	-	242	0
Z. emittens	-	-	1	-	-	-	1	0
Z. exornata	-	-	3	-	4	-	7	0
Z. neoflavipilosa	-	-	7	-	-	-	7	0
Z. persignata	29	-	44	-	7	-	80	0
Total fruit flies	1338	2577	1358	267	2449	2403	5145	5247
Total species	7	5	20	3	11	6	26	6

correlation between plant diversity and fruit fly species richness across different habitat types.

The diversity and availability of host plants significantly influenced fruit fly species richness. The agricultural habitat, which was formerly protected forest land, may have experienced changes in fruit fly populations due to land-use conversion. The findings aligns with Manrakhan (2020) and Samways et al. (2020), who reported that converting forests to plantations can lead to major environmental changes that create new habitats for fruit flies, expanding their breeding grounds and interactions with host plants. Astriyani et al. (2016) and Susanto et al. (2017) found that high host plant density in agricultural areas ensures a continuous food supply, promoting fruit fly feeding and reproduction. The continuous presence of suitable host plants supports stable populations, resulting in increased species diversity. Senior et al. (2016) noted that fruit flies are drawn to plants offering food and shelter. Mendes et al. (2013) and Silva et al. (2019) also found that plantations often feature diverse fruit trees cultivated by local communities, offering ample resources for fruit fly development.

The increased availability of host plants in plantations supports higher species richness. Horticultural plantations in agroecosystems create favorable environments for fruit flies, while urban areas contribute to the dispersal of tephritid pests (Prokopy et al., 2000; Malacrida et al., 2006). Additionally, human agricultural activities, such as pesticide use and crop management, may inadvertently favor certain fruit fly species by reducing natural predators and competitors (Ovruski et al., 2018).

Our findings are consistent with Susanto et al. (2017) and Sayuthi et al. (2019), who emphasized that host plant availability is a key factor influencing the presence and diversity of fruit flies. The agricultural habitat in our study had 50 types of fruit and vegetable plants, offering numerous host options. Some fruit fly species are host-specific; thus, greater host diversity increases the likelihood of suitable hosts for more species, resulting in higher overall species richness. The results of our study followed the research of Diaz et al. (2016) also found that greater plant diversity leads to more fruit fly species due to the availability of host plants, creation of microhabitats, and resource stability. Similar findings by Benelli et al. (2015) and Yao et al. (2017) showed that diverse vegetation provides a wide range of resources and environmental conditions for fruit flies. Thompson et al. (2017) and Martin et al. (2023) also reported that variation in plant phenology (flowering and fruiting) results in stable and continuous food supplies throughout the year, enhancing species richness.

A total of 4,852 fruit fly individuals were collected from forest habitats, 3,915 from urban areas, and 1,625 from agricultural habitats (Table 2). This indicates the highest abundance was found in forest habitats. However, the distribution of individuals among species was not even, indicating species dominance in some habitats. Our study showed that *B. dorsalis, B. albistrigatra,* and *B. frauenfeldi* were the most abundant in forest habitats; *B. limbifera, B. affinidorsalis,* and *B. dorsalis* dominated agricultural areas; and *B. dorsalis, B. carambolae,* and *B. albistrigata* were dominant in urban areas. Habitat type and tree species availability determined the abundance of fruit flies. *B. dorsalis* and *B. umbrosa* were mostly attracted to methyl eugenol (ME), while *Z. cucurbitae* and *B. limbifera* responded to cue lure (CUE) (Hasinu et al. 2020; Supratiwi et al., 2020). Overall, *B. dorsalis* was the dominant species attracted to ME (Figure 3), and *B. albistrigata* was the most attracted to CUE (Figure 4).

The diversity index of fruit flies in the three habitat types was categorized as moderate. The forest habitat showed the highest Shannon-Wiener diversity index (H′) and evenness index (E), followed by agriculture and urban areas (Table 3). Species richness and the relative abundance of individuals affect diversity index values. According to Magurran (2004), when a single species dominates a habitat, species evenness and diversity values decrease.

The high diversity and abundance of fruit flies in forest habitats may be due to the presence of non-seasonal host plants that provide a year-round food source, such as weeping fig (*Ficus benjamina*), argus pheasant tree (*Dracontomelon dao*), and sugar palm (*Arenga pinnata*). This finding agrees with Córdova-García et al. (2021) and Brown (2013), who stated that non-seasonal plants provide consistent resources for fruit flies. Novotny et al. (2005) and Vayssières et al. (2009) also reported that stable forest vegetation ensures the continuous availability of fruit hosts. Drew & Romig (2013) highlighted that forest ecosystems offer optimal environments for pest species like *B. dorsalis* and *B. fraunfeldi*, which tend to dominate due to abundant hosts. Similarly, Tarno et al. (2022) and Hudiwaku (2021) found that *Bactrocera* species dominated in tropical forests and orchards.

Fruit fly abundance in urban habitats was higher than in agricultural areas, possibly due to deliberate planting of fruit trees like guava, mango, and starfruit in residential yards. These trees are well-known hosts (Gesmallah et al., 2017; Adnyana et al., 2019; Fitrah et al., 2020; Aryuwandari et al., 2020). The high abundance of *B. dorsalis* and *B. carambolae* in urban areas may be linked to the abundance of host plants (Supratiwi et al., 2020). Larasati et al. (2013) and Manrakhan (2020) noted that these species are polyphagous and capable of infesting a wide range of fruits. Saputra et al. (2019) also reported that *B. carambolae* and *B. dorsalis* are widely distributed and highly competitive in areas with abundant host plants. Lamba et al. (2021) found that disturbed habitats like plantations support fewer fruit flies compared to undisturbed forests. According to Suputa et al. (2010) and Aryuwandari et al. (2020), *B. dorsalis* primarily infests several crops including chili, orange, starfruit, guava, water rose apple, and mango.

Environmental factors such as humidity, temperature, sunlight, and wind affect fruit fly population dynamics. Temperature, in particular, plays a major role in development (Solomon et al., 2018). During the study, forest temperatures ranged from 28.8 ºC to 29.7 ºC, agriculture from 26.6 ºC to 28.8 ºC, urban area from 31.2 ºC to 31.9 ºC. Lamba et al. (2021) also noted that temperature, rainfall, and seasonal fruit availability influence fruit fly populations and their habitat distribution. Seasonal changes in host fruit

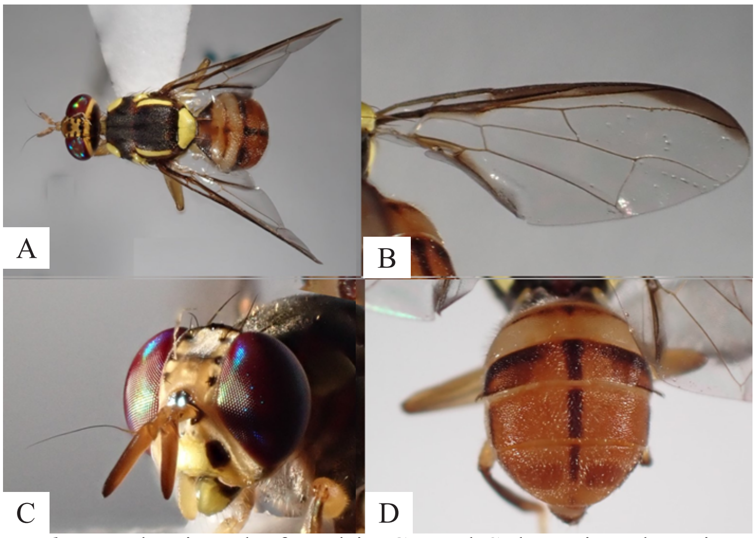

Figure 3. *Bactrocera dorsalis*, predominantly found in Central Sulawesi, Indonesia was responded to ME. A. scutum and scutellum; B. Wing; C. Head: facial spot; D. Terga.

Figure 4. *Bactrocera albistrigata*, predominantly found in Central Sulawesi, Indonesia was responded to CUE. A. Scutum and scutellum; B. Wing; C. Head: facial spot; D. Terga.

Table 3. Diversity of fruit fly's species

Parameter	Habitat			
	Urban	Agriculture	Forest	Total
∑ individu	3915	1625	4852	10,392
Relative (%)	37.7	15.6	46.7	100
Total species	12	23	17	32
Shannon-Weiner (H')	1.50	1.68	1.71	
Dominance-Simpson (D)	0.28	0.27	0.23	
Shannon-Evennes (E)	0.60	0.54	0.61	

availability may cause fluctuations in abundance and diversity, potentially increasing rare species at certain times.

CONCLUSION

This research recorded 32 fruit fly species belonging to three genera: *Bactrocera*, *Dacus*, and *Zeugodacus* in Central Sulawesi, Indonesia. Species richness was highest in agricultural areas, followed by forests, and then urban areas. The diversity index indicated that overall fruit fly diversity across all habitats was moderate, with the highest diversity observed in forest habitats. These findings emphasizes the critical role of vegetation diversity in shaping fruit fly species richness and abundance. The more diverse the habitat, the more resources are available to support biodiversity. This insight is valuable for the sustainable management of fruit fly populations and for conserving biodiversity in both agroecosystems and natural habitats.

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AUTHORS' CONTRIBUTIONS

D conducted the field research, including the collection of fruit fly species data. NSP and RFS contributed to the analysis of species diversity, development of the identification key, and manuscript preparation. DP coordinated the study design and performed statistical analyses. A provided critical insights into habitat ecology and its influence on species diversity. S, as the corresponding author, supervised the research process, ensured the accuracy of the results, and coordinated revisions and communication among authors. All authors interpreted the results, reviewed the manuscript, and approved the final version for publication.

COMPETING INTEREST

The authors declare no conflict of interest—financial, non-financial, professional, or personal—that could influence or bias the content of this paper. All research activities, including data collection and analysis, were conducted independently and transparently, with no potential conflicts of interest related directly or indirectly to this study.

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