Ecosystem Services in Coffee (*Coffea arabica* L.) Production System in The District of West Bandung, West Java: The Community Structure and Diversity of "Direct and Indirect" Pollinator Insects

Parikesit[1,2,3]*, A Paramita[1], S Withaningsih[1,2,3] and H Kasmara[1]

[1]Department of Biology, Faculty of Mathematic & Natural Sciences, Universitas Padjadjaran, Jl. Raya Bandung-Sumedang Km. 21 Jatinangor Sumedang 45363, West Java, Indonesia. Tel. +62-22-7796412 ext. 104, Fax. +62-22-7795545
[2]Institute of Ecology – Universitas Padjadjaran, Jl. Sekeloa Selatan I Bandung 40213, West Java, Indonesia
[3]Graduate School of Environmental Science & Sustainability Science, Universitas Padjadjaran. Jl. Dipatiukur No. 35 Bandung, West Java Indonesia.

*E-mail: parikesit@unpad.ac.id

Abstract. Many biological production systems depend on regulating services performed by insects for economic benefits, and coffee (*Coffea arabica* L.) production system is one of them. On the other hand, coffee plantation makes a good habitat for insects communities, especially direct and indirect pollinator insects. A study focused on the community structure and the diversity of "direct and indirect"pollinator insects has been carried out in coffee plantation located in West Bandung Regency, West Java. The main objectives of the study were to elucidate pollinator insect community's structure,diversity, and relationship between insects distribution along some measured environmental factors. A field survey combining a number of transects and sampling techniques were performed using netting, pan traps, and Malaise traps. Fifty species of 30 families and four ordersofinsects directly and indirectly involved in flower pollinationwere identified. The Diversity and Species Richness Indices indicatedhigh value (H'= 3,30; R=8,18). Species Evenness Indexshowed an evenly distributed species (E'= 0,84);Species Similarity Index showed a moderate diversity (Cs=0,58). The ordination analysis suggested that some abiotic parameters such as altitude, wind, air temperature, air humidity, and light intensity were importantenvironmental factors affecting the occurrence of pollinator insects in coffee plantation.
Keywords : *coffea arabica*, diversity, environmental factors, pollinator insects, regulating services

1. Introduction

Agricultural landscapes in wet tropical area, as Indonesia, are highly depending on ecosystem services to maintain their productivity. One of the common ecosystem services found in the agricultural landscapes is pollination, which acting as the regulating service [1]. In pollination, the presence of pollinators is considered as the main factor aside from flowers quantity and fertility. In this regard, insects are the main pollinators compared to others, in most plants species across the globe [2,3]. They

pollinated two third of the entire plant species, including 400 crop species. More than 100,000 species of insect are identified as pollinators; bees, moths, butterflies, beetles, and flies are among them [4].

The insect communities are also important factor, aside from their diversity, to maintaining the agricultural productivity, therefore, pollinators have major role from ecological and economic perspectives. Many studies show that pollination done by insects could significantly increase the crop fruits production [5]. They are also able to increase crop's genetic diversity, adaptability, seedling quality and quantity, and maintaining the nature of crop quality and its ability to regenerate. Thus, pollinator conservation has becoming a need and consideration in many places [6].

Coffee (*Coffea* spp.) is one of the crops that require insect pollination. Pollination rate has a positive correlation with pollinators diversity [7]. A natural pollination might increase the pollination rate and leads to higher quality and quantity of coffee fruits produced. In Central Sulawesi, Indonesia, showed that pollination efficiency carried out by bees on Robusta coffee (*Coffea canephora*), was significantly increased the fruit sets and coffee beans production (86.5% sets by solitary bees and 70.4% sets by social bees)[8].

Today, coffee is the main agricultural product from many agriculture-based countries. In the global trade, coffee is a valuable commodity after oils [9]. In Indonesia coffee is considered as one of the main products, and merging as third largest coffee production country in the world [10]. The coffee plantation spreads in main islands, such as Sumatera, Java, Bali, Nusa Tenggara, Sulawesi, Maluku, and Papua. The Indonesian coffee becomes a well-known coffee because of its quality and distinctive flavor.

Therefore, a study for the insect pollinator's structure and diversity on coffee production is prominent issue. This study is related, not only for maintaining the coffee productivity, but also describing how the coffee production related to the biodiversity conservation. Biodiversity conservation might also increase the coffee brand value, as more global issues persuade people to tend their natural environments.

This paper aims to describe the community structure and diversity of insects that directly (pollen-bearing insects) and indirectly (nectar-feeding insects) involved in pollination in coffee plantation managed by local people in one of the production sites in West Java. Insect abundances, distribution, andtheir relation with some measured environmental factors would also be elucidated.

2. Study sites and methods

2.1. Study sites

The study was conducted at one of the Arabica coffee production areas in West Bandung Regency during flowering season. Geographically, the coffee plantation is located at Lembang District at coordinate 6°45'30" - 6°51'59" S and 107°35'00" - 107°43'59" E. The coffee plantation is located within the forest area of Perum Perhutani, at the foot of Mt. Tangkuban Perahu on 1000 meters above sea level with sloping topography >15%. According to the forest area management, coffee plantation at *Resor Pemangkuan Hutan* (Forest Management Resort) Lembang is part of *Bagian Kesatuan Pemangkuan Hutan* (Forest Management Unit Division) spreading over 4,103.4 ha, which registered under the management of *Kesatuan Pemangkuan Hutan* (Forest Management Unit) Bandung Utara. The canopy of forest vegetation was not too dense, however the floor vegetation cover was quite dense. Insect specimen identification was conducted at Laboratory of Entomology of Zoological Museum -Indonesian Institute of Science *(LIPI)*, Cibinong.

2.2. Data collection and analysis

The insect's composition and community structure survey was acquired by netting, pan traps, and Malaise traps [11,12]. These three techniques were conducted along 500 m transect with 20 m width placed crossing the contour line [13,14] of coffee plantation. Transects were placed within 1-2 ha area in order to maximize the catch rate possibility of flying insects [13].

Netting method was conducted by exploring the area randomly within 10 meters width of transect belt [14] around plot and transect line for 10 minutes [15]. Samples collected through netting, were recorded based on species, number of individuals, time of presence, and the nearest plot location when the sample was collected. The collected samples using pan traps and Malaise traps were recorded based on species and number of individuals collected in each plot traps. For the pan traps method, the minimum number of bowls set was 20 [12] with minimum distance 10 meters [15] and placed at about 1 meter above soil surface at for 24 hours [16]. For the Malaise trap, according to the preliminary study of 500 m transect lines; the Malaise traps laid were three with 150 meter of gap from one another. Every Malaise trap was expected to effectively trapping pollinator from two opposite directions.

Dried specimens made from trapped insect for the identification based on its species, category (pollinators and non-pollinators), and its feeding guilds. The specimen identification was conducted at Laboratory of Entomology of Zoological Museum -Indonesian Institute of Science *(LIPI)*, Cibinong.

The environmental factors measured and recorded were the biotic parameters including plant species composition (other than coffee crops) found within the site study, phenology, and canopy condition. Abiotic parameters measured were site altitude, wind speed, temperature and humidity, and light intensity.

The data analysis was focused on the insect pollinators, while the non-pollinators were for supplementary data. Data analysis conducted was based on the data collection during the coffee flowering season, such as Relative Species Richness (KR); Relative Frequency (FR); Simpsons Dominance Index (C); Shanon-Wiener Species Diversity Index (H'); Margalef species Richness Index (R); Species Evenness Index (E'); and Sorenson Species Similarity Index (Cs). The ordination analysis of Canonical Correspondence Analysis (CCA) was also conducted in order to synthesize a hypothesis to reveal the distribution of pollinator species along a complex of measured environmental factors [17,18]. The environmental factors analyzed by CCA were the abiotic parameters (site altitude, wind speed, temperature and humidity, and light intensity).

The results of CCA are eigenvalues, raw correlation and interset correlation illustrated in an ordination diagram. The eigen values suggest the species and plot distribution along the axis in ordination diagram. This value ranged from 0 to 1; the eigenvalues larger than 0.5 is interpreted as meaningful.

3. Results and discussion

3.1. Species composition and diversity

The total number of captured insects that directly and indirectly involved in flower pollination was 50 species of 30 families and 4 orders (Coleoptera, Diptera, Hymenoptera, and Lepidoptera). Figure 1 shows the number of orders, families, and species found in the study site. The highest species number was Diptera, with total of 17 species (around 34% of total species found) of 11 Families. This order has species members considered as the main pollinator and has a major role, second after Hymenoptera order, particularly for agriculture crops and flowering plants subtropical area [19].

Table 1 shows the direct and indirect pollinator species found in coffee plantation based on each insect collecting method. Table 1 shows that one of Diptera's species was caught by the three collecting methods, i.e., *Homoneura (Homoneura) trispina* (Lauxaniidaefamily) suggesting that this species was commonly found in the coffee plantation. The genus of *Homoneura*is microspore eating flies and also feed on nectar found on Gnetaceae family, which emits strong flower aroma [20]. The pollen stuck on *Homoneura* flies mostly found at their antenna and tarsi. *Homoneura (Homoneura) trispina* is one of the 350 species belongs to Lauxaniidae family and spreading over the East Asia region [21].

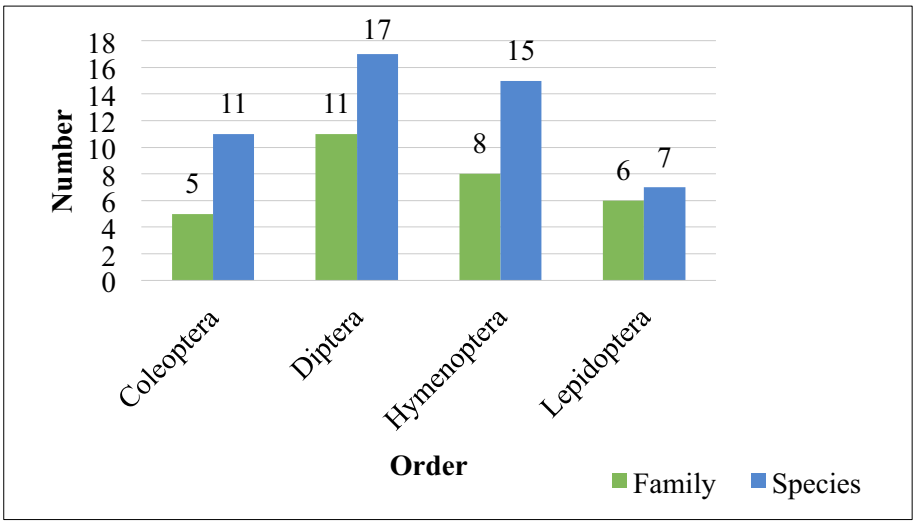

Figure 1. Number of families and species of direct and indirect pollinator insects from four orders found in the study site.

There were 15 species of 8 families belong to order of Hymenoptera; about 30% of total species found. Pollinators belong to this order consist of 5 species of bees community (family of Apidae and Halictidae), 8 species of wasps (family of Mutillidae, Pompilidae, Scoliidae, Tenthredinidae, and Vespidae), and 2 species of ants (family of Formicidae). Bees community is the most important community based on its diversity and the plant pollinated [2]. The bees' pollination services on Arabica coffee crop contributes in increasing 12.3% of fruit set production in Central Sulawesi [22] and 20-25% in Java (Ferwerda, 1948 *cited in* [23]).

The order of Coleoptera found consists of five families with 11 species or about 22% of the total species found. Beetle (order of Coleoptera), is the third important pollinator, after bee and wasp, which acting as pollen vector on some pollinated vegetation in rainforest [2]. The members belong to Coleoptera order mostly feed on nectar and pollen, thus they were adapted themselves in terms of behavior as in bees community [19].

The other order found during this study was the order of Lepidoptera that found as many as seven species belongs to six Families or 14% of the total species found. The pollinators belong to this order are five species of moths (Familyof Erebidae, Noctuidae, Pyralidae, and Roeslerstammiidae), and two species of butterflies (Family Nymphalidae: Satyrinae ann Pieridae). Butterflies and moths are the common visitors for vegetation where species of Rubiaceae family are found because of the flower morphology that has a bright color crown [2], and Arabica coffee has a bright white color.

The pollinators found by netting method were as many as 23 species from 18 families or 46% of total pollinator found by all method (figure 2). The Species Diversity Index (*H'*) measured was 2.77 categorized as moderately diverse. The pollinators found by pan traps were as many as 19 species from 13 families or 38% of total pollinators found, with Species Diversity Index (*H'*) value of 2.47, which also fall into the category of moderately diverse. There were 29 species of pollinators belong to 23 Families caught by Malaise traps, equivalent to about 58% of the total pollinators found in the study site, with Diversity Index (*H'*) of 2.99 or moderately diverse.

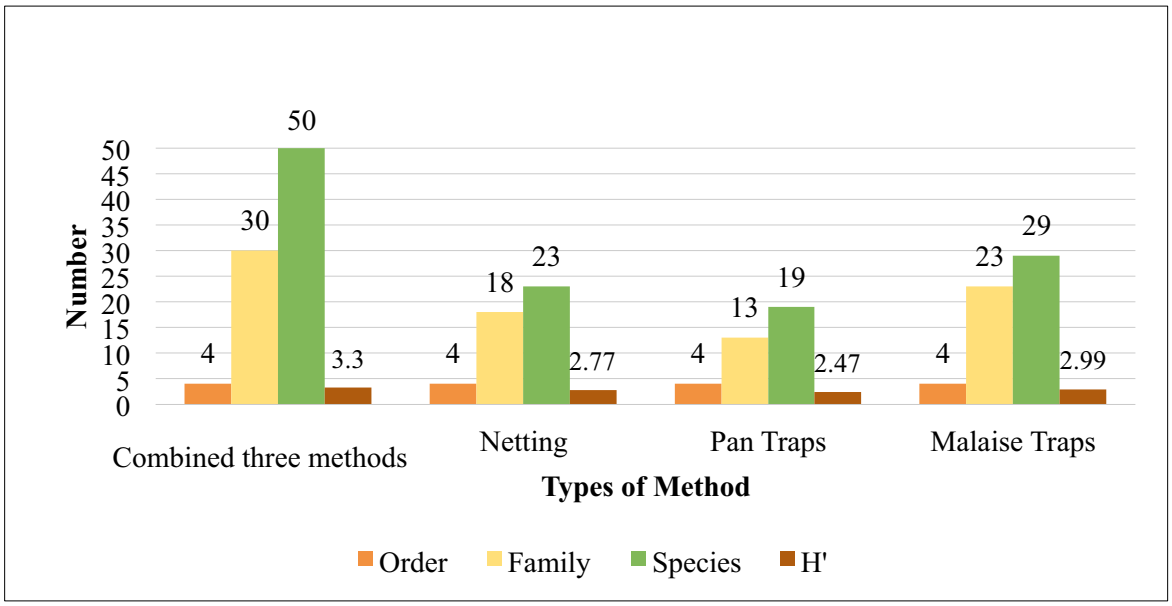

Figure 2. Numbers of order, family, species, and species diversity index of direct and indirect pollinators caught in the study site using three methods.

3.2. The abundance and presence of pollinator insects in coffee plantation

The highest individual abundance was shown by *Distichona* sp. (Diptera: Tachinidae), 55 individuals were recorded with Relative Density of 13.75%; these flies (Famili Tachinidae) were one of the important families of flies pollinator. They actively visit flowers to feed on nectar, thus, they are considered as effective pollinator because of their hairy body morphology.

There was strong interaction between some flies belonging to Tachinidae family and some flowering plants [24]. However, studies are lacking with regard to the relation of flowering pattern or plant morphology that affects tachinid flies to visit flowering plants, therefore, the main host of these flies is still unknown. This fact asserting that the tachinid flies is feeding from wide variety of flowers, which make these flies as an effective pollinator.

The highest Relative Frequency was shown by *Chymomyza* sp. (Diptera: Drosophilidae) with 9.42%. The occurrence of Drosophilidae fly family might be due to the fact that this family is a phytophagous fly, an insect groups that feed on almost every part of plant parts including root, branch, leaves, flower and fruits. It even has the role as decomposer in the food chain [25]. Drosophilidae family or the fruit flies, are included as pollinator for Arabica Coffee (*C. arabica*) [26]. Drosophilidae family was able to actively increase the pollination and also the seedling and fruit formation on Arabica coffee. Figure 3 illustrates the Relative Abundance and Frequencies of pollinators found in the study site.

Table 1. Direct and IndirectPollinator Insects found in the study site based on three catching methods.

No.	Order	No.	Family	No.	Species	Method Code					
						N Bh	N Bg	PT Bh	PT Bg	MT Bh	MT Bg
1	Coleoptera	1	Cantharidae	1	*Drilonius* sp.			●			
				2	*Laemoglyptus* sp.						●
		2	Curculionidae	3	*Eugnamptus* sp.	●	●				
				4	*Metialma ignorata*						●
		3	Elateridae	5	*Adelocera* sp.					●	
				6	*Cardiophorus* sp.				●		●
				7	*Elaterid* sp.					●	
		4	Mordellidae	8	*Mordella* sp.					●	●
				9	*Apogonia* sp.						●
		5	Scarabaeidae	10	*Microserica* sp.			●	●		●
				11	*Neoserica* sp.			●	●	●	●
2	Diptera	6	Anthomyiidae	12	*Chirosia* sp.	●					
		7	Calliphoridae	13	*Lucilia silvarum*	●	●	●			
				14	*Chymomyza* sp.	●	●	●	●		
		8	Drosophilidae	15	*Drosophila (Drosophila) brachynephros*			●	●		
				16	*Drosophila immigrans*			●	●	●	●
				17	*Drosophila* sp.			●			
		9	Lauxaniidae	18	*Homoneura (Homoneura) trispina*	●	●	●	●	●	●
		10	Muscidae	19	*Neomyia* sp.		●				
				20	*Thricops* sp.			●	●		
		11	Phoridae	21	*Aenigmatias* sp.	●				●	
		12	Sarcophagidae	22	*Boettcheria dumoga*	●		●	●		●
		13	Simulidae	23	*Simulium (Eusimulium)* sp.					●	
		14	Syrphidae	24	*Episyrphus viridaureus*	●	●				
		14	Syrphidae	25	*Paragus (Pandasyopthalmus) haemorrhous*						●
2	Diptera	15	Tachinidae	26	*Distichona* sp.	●	●	●	●		●
				27	*Peleteria* sp.	●	●	●	●		

No.	Order	No.	Family	No.	Species	Method Code							
						N Bh	N Bg	PT Bh	PT Bg	MT Bh	MT Bg		
		16	Tephritidae	28	*Oedicarena* sp.					●	●		
				29	*Amegilla* sp.		●						
		17	Apidae	30	*Amegilla (Zonamegilla) calceifera*		●						
				31	*Apis cerana*		●				●		
				32	*Xylocopa caerulea*		●						
		18	Formicidae	33	*Dolichoderus* sp.		●				●		
				34	*Dolichoderus tuberifer*		●			●	●		
		19	Halictidae	35	*Lasioglossum pectinatum*		●	●		●			
3	Hymenoptera	20	Mutillidae	36	*Mickelidia* sp.						●		
				37	*Auplopus* sp.						●		
		21	Pompilidae	38	*Dipogon* sp.			●	●				
				39	*Homonotus* sp.				●				
		22	Scoliidae	40	*Campsomeris limbata*	●	●						
		23	Tenthredinidae	41	*Aglaostigma* sp.		●						
				42	*Tenthredo* sp.						●		
		24	Vespidae	43	*Vespa velutina*	●	●	●					
		25	Erebidae	44	*Nyctemera regularis*				●				
		26	Noctuidae	45	*Conservula indica*						●		
		27	Nymphalidae: Satyrinae	46	*Ypthima pandocus*		●			●	●		
4	Lepidoptera	28	Pieridae	47	*Eurema blanda*		●						
				48	*Herculia* sp.						●		
		29	Pyralidae	49	*Pyralid* sp.						●		
		30	Roeslerstammiidae	50	*Roeslerstammiid* sp.					●	●		

Table 2 shows some insect pollinator community indices; the Dominance Species Index (*C'*) of pollinator measured is considered low (0.06); Species Diversity Index (*H'*)shows a high diversity index (3.30); the Species Richness Index (*R*) also shows a high richness level (8.18); and for the Species Evenness Index (*E*') suggests that all species tend to be evenly abundant (0.84).

As shown in table 2, there was not any dominant species found in the coffee plantation. This suggests that the abundance of each species within the pollinator community occurred in almost evenly numbers of individuals. The high score of species richness and diversity index indicate that coffee plantation in the study site was able to provide suitable habitat for insect pollinator community, because of the abundance of feeding resources.

The coffee plantation in the study site is located adjacent to the remnant natural forest, and this has resulted in frequent visitation by bees and other pollinators. Such condition could eventually resulted in higher productivity of fruit set by 20%, compared to coffee plantation located more than one km from forest [7,8,22].

Table 2. Some indicesof direct and indirect pollinator insect community in coffee plantation of the study site.

Index	Score	Category
Dominance (*C*)	0,06	Low
Diversity (*H'*)	3,30	High
Richness (*R*)	8,18	High
Evenness (*E'*)	0,84	Spread evenly

3.3. Insect pollinator distribution along environmental gradient: Ordination Analysis

The presence and distribution of pollinator species is closely related to its biotic environmental factors like feeding source (pollen and/or nectar) and also some physical environmental factors [27]. The ordination analysis using CCA conducted in the present study resulted eigenvalues 0.459 and 0.336, for axes 1 and 2, respectively. These eigenvalues suggest that axis 1 could explain to some extent the distribution of insect pollinator along the measured environmental gradient. Although, this result also indicates that not all abiotic parameters measured, giving a significant effect toward the pollinator species distribution.

Table 3 shows the correlation between measured environmental parameters. This table indicates that there is a positive correlation between wind velocity and air temperature, and a negative correlation between air humidity and temperature.

Table 3. Raw correlation score among measured environmental parameters.

	Altitude	Wind Speed	Light Intensity	Air Temperature	Air Humidity
Altitude	1	-0,245	-0,352	-0,170	0,113
Wind Speed	-0,245	1	0,393	**0,872**	-0,815
Light Intensity	-0,352	0,393	1	0,640	-0,604
Air Temperature	-0,170	**0,872**	0,640	1	**-0,962**
Air Humidity	0,113	-0,815	-0,604	**-0,962**	1

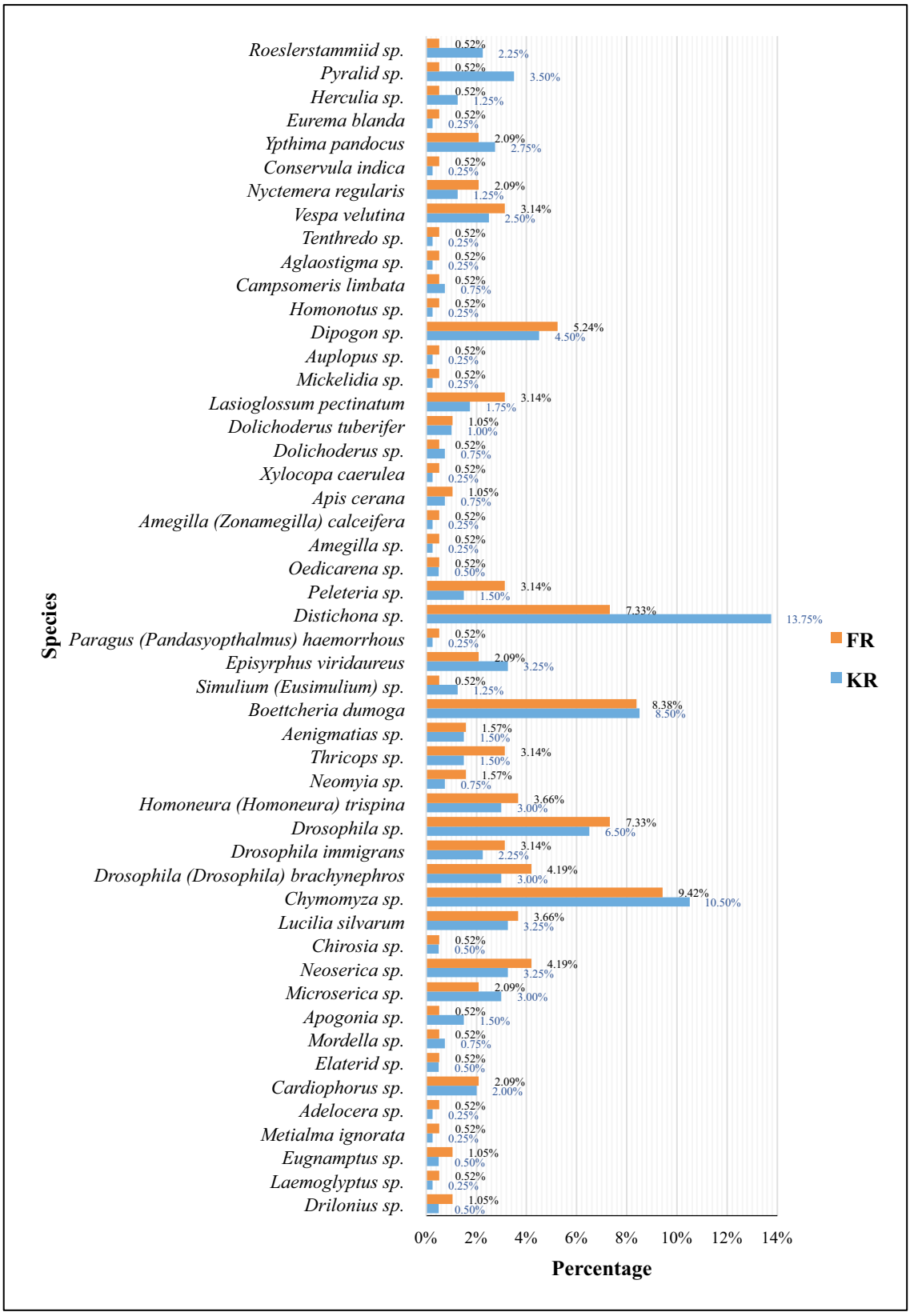

Figure 3. Relative Abundance and Frequency of each pollinator species found in the study site.

The correlations of the measured environmental parameters in ordination axis (interset correlation) are shown in table 4. The highest interset correlation in axis 1 is light intensity followed by location altitude, 0.628 and -0.522. In axis 2, the highest interset correlation score is shown by wind speed and air humidity, i.e. 0.728 and -0.608. These results indicate that light intensity, location altitude, wind speed, and humidity are the measured environmental factors affecting pollinator species distribution.

Table 4. Interset correlation score of environmental parameters.

Variable	Correlation		
	Axis 1	Axis 2	Axis 3
Location altitude	**-0.522**	0.027	0.569
Wind speed	0.416	**0.728**	-0.042
Light intensity	**0.628**	0.074	-0.184
Air temperature	0.236	0.530	-0.260
Air humidity	0.086	**-0.608**	0.264

Based on the line length and angle formed with the axes 1 and 2 in ordination diagram, the environmental factors associated to axis 1 are light intensity and altitude (figure 4). Whereas the environmental factors associated to axis 2 are wind speed and air humidity. Insect utilizes sunlight during feeding time, molting, reproduction or events related to its lifetime. Sunlight affects local distribution of an insect species, thus, this insect would do activity based on the signal response from the sunlight [28]. The activity of insects with nocturnal, diurnal, matinal or krespuskular behaviour is highly affected by light activity. Honey bees become more active during light intensity of 500 lux or more, and their activity would diminish and then stop when the light intensity reach 10 lux. In the morning, honey bees starttheir activity at lower light intersity as compare to when they stopat night. The average score of measured light intensity is 10927 lux, which a suitable condition for pollinators to do their activity and searching for food.

Wind affects particularly on feeding activity when insect is flying. Fast wind would make feeding activity of pollinator decrease or even stop, particularly when the wind speed reaches 30 km/hour or 8.3 m/s (Chagnon, 2008 *cited in* [29]). The average of wind speed 0.35 m/s is still considered as optimum speed for pollinator to do their activity and to search for a food. Wind speed and pressure in forest area is much lower than in the grassy or bushes area, due to trees and vegetation resistance against highwind current [30].

Pollinator activity is heavily affected by temperature change when they are searching for food. The optimum temperature for pollinator to carry out feeding activity is between 16-32^{o}C. There is no activity conducted when the temperature dropped below 8^{o}C, some activity might be performed between 8-16^{o}C, and feeding time will also be stopped when the temperature reaches above 32^{o}C. When the environment temperature drops, the reserved energy in insect would also decrease, which lead to a more number of flowers are required and more calories derived from flower is needed. An average temperature 24.79 ^{o}Cis still considered as optimum temperature for pollinators to search for food.

Pollinator's activity when searching for food would increase as the air temperature increases and humidity decreases. Under dry environment or low air humidity, the sugar concentration in nectar will increase (Beismeijer *et al*., 1999 *cited by* [29]). The average air humidity recorded at the study site was 74.84% or high humidity area (above 60%). This might be caused by the altitude of study site, which is located 1408-1554 above sea level.

The distribution of insect pollinator along the measured environmental gradient is shown in ordination analysis (figure 4)**.** Five parameters of abiotic parameters were identified as affecting factors for pollinator distribution. These environmental factors show a varying effect on pollinator distribution in coffee plantation. The species found on the first quadrant (top right side on the

ordination diagram in figure 4) is the common species found in open vegetation where sunlight penetrated the floor vegetation. These species tend to survive in high temperature and wind velocity. Some of these species are *Neoserica* sp., *Eugnamptus* sp. and *Ypthima pandocus.*

Ordination diagram shows that species of *Boettcheria dumoga*tend to be encountered in higher air humidity and altitude. Other species like *Vespa velutina*, *Drosophila (Drosophila) brachynephros,* and *Lucilia silvarum* were found in higher air humidity. The species of *Lasioglossum pectinatum, Distichona* sp., and *Drosophila immigrans* were found in higher altitude.

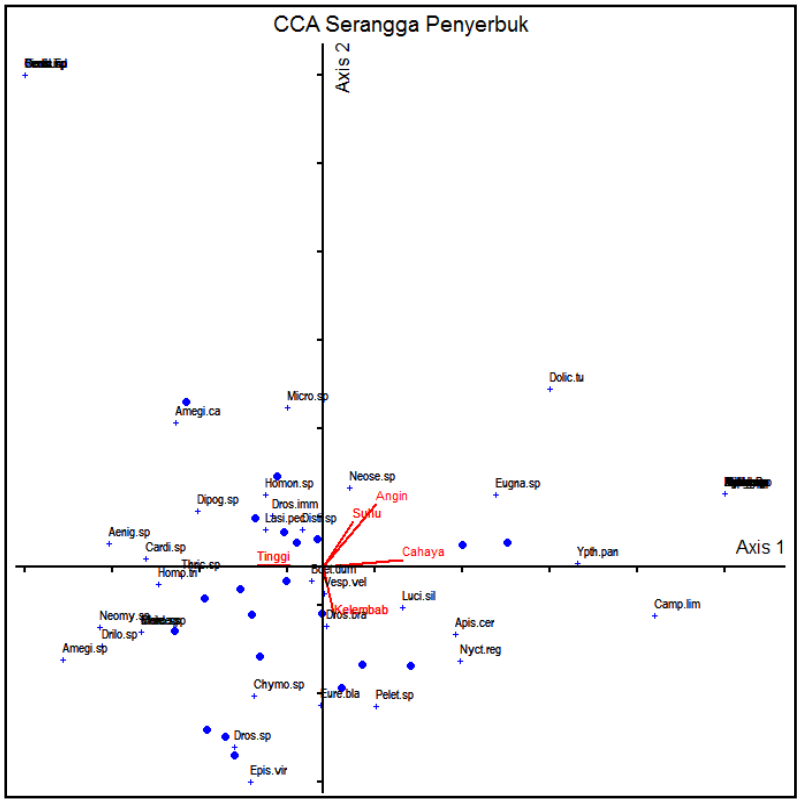

Figure 4. Distribution of direct and indirect pollinator insects along some measured environmental gradient in the coffee plantation (using CCA technique).

4. Conclusion

Based on the result described above, it can be concluded that: 1) coffee production system is able to provide a suitable habitat for direct and indirect pollinator insect community indicated by high species richness and diversity index, including the presence of diverse main pollinator species; there is no dominant species found within the community, 2) the presence of diverse pollinator species in coffee production system indicates that the regulating ecosystem services is underwent well, and 3) the ordination analysis indicates that pollinator's presence and distribution along environmental gradient is affected by some environmental parameters, namely light intensity, altitude, wind velocity, air temperature and humidity.

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