Diversity and ecosystem services of natural enemies in sustainable smallholders' oil palm plantations in West Kalimantan and Riau

Dewi Caesaria Oktaviani[1*], *Dewi* Sartiami[2], and *Nina* Maryana[2]

[1]Postgraduate Student of Program Study Entomology, Plant Protection Department, Faculty of Agriculture, IPB University, Bogor, Indonesia
[2]Plant Protection Department, Faculty of Agriculture, IPB University, Bogor, Indonesia

Abstract. Sustainable oil palm plantation practices can have a positive impact on production, biodiversity, and the ecosystem. The management of oil palm plantations influences farmers' cultivation techniques, which play a crucial role in maintaining the habitat of natural enemies in oil palm plantations. The presence of these natural enemies in oil palm is important for maintaining ecosystem stability. This study aims to examine the relationship between sustainable oil palm plantations and the diversity of natural enemies. Understanding the interaction of insect pests with parasitoids and predators in oil palm plantations. The research was carried out from December 2023 to August 2024. Insect sampling method was conducted using a beating sheet and sweep net. The number of caterpillar pests found was 16 species from 21 morphospecies that attack oil palms in West Kalimantan and Riau. Predators found in oil palm plantations are *Sycanus* sp. (Reduviidae), ants *Oecophylla* sp. (Formicidae), robber fly (Diptera: Asilidae), (Tachinidae), wasps (Hymenoptera: Vespidae), (Coleoptera: Carabidae and Coccinellidae), and spiders (Araneae). Parasitoids found include (Braconidae), (Aphelinidae), (Eulophidae), *Telenomus* sp. (Scelionidae), and *Brachymeria* sp. (Chalcididae). Agricultural techniques prohibit the use of pesticides such as paraquat, and the prohibition on not clearing vegetation in oil palm plantation areas and is requires to have a high conservation area (HCV). Ecosystem services of natural enemies (parasitoids and predators) are important for maintaining environmental stability in both sustainable and non-sustainable oil palm plantations.

1 Introduction

Oil palm (*Elaeis guineensis* Jacq) is the largest vegetable oil-producing commodity in the world; global production reached 79.5 million metric tons of total production. Indonesia became the largest crude palm oil (CPO) producer by contributing 59% globally, equivalent to 47 million metric tons [1]. The islands of Sumatra and Kalimantan are still the central

* Corresponding author: oktavianidewi@apps.ipb.ac.id

concentration of oil palm plantations. Sumatra has 6.1 million hectares, and Kalimantan has 3.84 million hectares of oil palm plantations [2].

The concept of sustainable agriculture is applied not only to oil palm plantations, therefore, several oil palm farmers participate in realizing sustainable plantations through the certification of Indonesia Sustainable Palm Oil (ISPO) and Roundtable Sustainable Palm Oil (RSPO) [3]. Sustainable oil palm plantation management is required to have a conservation area called High Conservation Value, as well as more environmentally friendly farming cultivation techniques, due to the prohibition on using several herbicide products such as paraquat, and the prohibition on clearing weeds in the pagaran area [4].

This environmentally friendly cultivation practice is an important effort in maintaining the habitat of natural enemies. Natural enemies such as predators and parasitoids can reduce the use of chemical pesticides that are detrimental to the environment and farmers' health [5]. Parasitoids such as *Euplectrus* sp. (Eulophidae), *Apanteles* sp. (Braconidae), and *Trichogrammatoidea thoseae* (Trichogrammatidae) are known to parasitize major oil palm pests, including *Birthamula chara*, *Darna trima*, *D. Deducta*, *D. Bradleyi*, and caterpillars: (Lepidoptera) [6].

The existence of natural enemies in oil palm plantations is important to maintain ecosystem stability. This study aims to study the relationship between oil palm plantation certification and the diversity of natural enemies. This study also seeks to uncover the potential ecosystem services of natural enemies to be developed in sustainable oil palm plantations. Research on the impact of RSPO certification through sustainable practices on the diversity and effectiveness of the role of natural enemies in oil palm plantations is still limited. Therefore, this study is expected to provide the benefits of RSPO certification and its implications for sustainable oil palm plantations management strategies.

2 Materials and methods

2.1 Research design

The sampling consisted of two groups of smallholder oil palm farmers, namely the Rimba Harapan Cooperative oil palm farmer group in Sintang Regency, West Kalimantan, and the Amanah Swadaya Farmers Association in Pelalawan Regency, Riau. From each region, 10 oil palm plantations were selected (5 plantations with a sustainable certificate and 5 plantations that are not sustainable), and two criteria of plantations were also carried out (riparian river and non-riparian). Observations were made on oil palm trees aged 5-10 years with a land area of 1 and 2 hectares, with a planting distance of about 9 x 9 m. In each land area, 9 oil palm trees were observed.

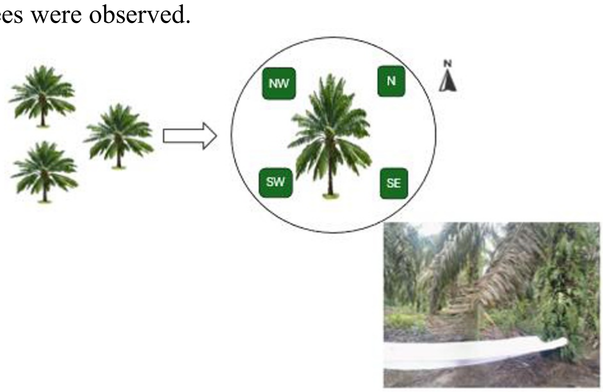

Fig. 1. Design of observation plot on oil palm land

2.2 Insect collection using beating sheet

This beating sheet uses a white muslin cloth that is stretched under the oil palm fronds, with dimensions of Length x width = (7 m x 1,5 m). The oil palm fronds on the cloth are shaken so that the caterpillars and Lepidoptera larvae fall onto the cloth. Each oil palm tree was observed to have as many as 8 fronds divided into 4 cardinal directions, and each cardinal direction was determined to have as many as 2 fronds to be observed. Each oil palm land was observed with as many as 3 trees by looking for fronds that were still easy to reach. The sampling method was carried out by purposive sampling, which was carried out on each observation plot. Three oil palm trees were observed by looking for leaf fronds that were still safe and easy to reach. The insect pests that fell were then taken and put into clear plastic boxes, and maintenance is carried out.

2.3 Insect collection using sweep nets

Insect collection using sweep nets was conducted based on a 10 m transect distance, with 3 repetitions on each transect by swinging the insect net 10 times in double swings. Insect retrieval using nets was carried out around the oil palm trellis area, near the HCV area, and in the understorey. The insect net used had a diameter of 30 cm with a stick length of 80 cm, and was made of organdie cloth [7]. Insects trapped in the net were then put into a glass bottle containing cotton, which was given ethyl acetate liquid with a concentration of 100%. Then the insect sample was transferred into a film bottle containing 70% alcohol.

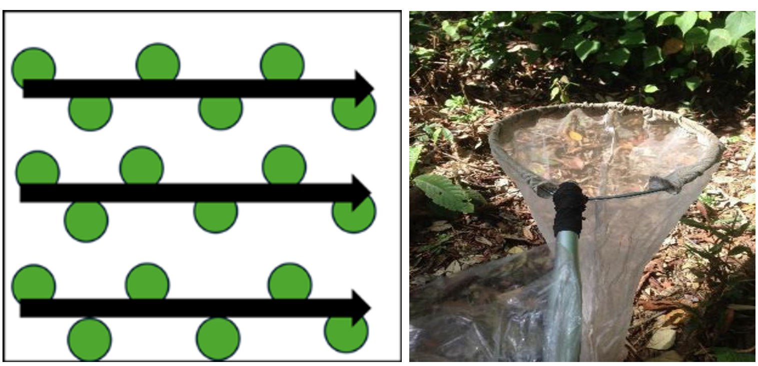

Fig. 2. Transect line with *sweep net*

2.4 Rearing of Lepidoptera Larvae

Oil palm leaf-eating larvae or caterpillars obtained from oil palm fields are kept in clear thin-wall boxes measuring P = 17 ml × W = 4 ml, and are given oil palm leaves for food. Parasitoids that come out of the host's body are then taken and put into a microtube containing 70% alcohol, then labelled and identified.

2.5 Insect Identification

Insects found from field observations were sorted and identified at the Insect Biosystems Laboratory, Department of Plant Protection, Faculty of Agriculture, IPB University. Identification was carried out based on identification keys compiled by Study of Insects [8], Hymenoptera of the world: An Identification Guide to families [9], The Insects of Australia [10], A guide to the ants of Jambi (Sumatra, Indonesia): Identification key to ant genera and images of the EFForTS collection [11], Manual of the New World Genera of the Family Braconidae (Hymenoptera) [12], and other relevant references.

2.6 Data Analysis

The data obtained were compiled using Microsoft Excel version 365. Analysis of variance (ANOVA) was used to determine the differences in natural enemy diversity between the two landscape types and RSPO and Non-RSPO treatments, using the General Linear Model (GLM procedure) with the R-studio vegan package. Then insect diversity was calculated using the Shannon-Wienner index (diversity), Simpson (dominance) [13]. Interactions between natural enemies and hosts with the R-studio bipartite package [14]. All analyses were performed using R-studio software version 4.4.1.

3 Results and Discussion

Based on research that has been carried out, at least 16 species of caterpillars from 21 morphospecies were found that attack oil palm plants in West Kalimantan and Riau. The types of caterpillars found were *Amanthusia phidippus*, *Arctornis* sp., *Metisa plana*, *Darna trima*, *Dasychira inclusa*, *Elymnias panthera*, *Paleacrita* sp., *Hidari irava*, *Mahasena corbetti*, *Spilosoma* sp., *Spodoptera litura*, *Chrysodeixis* sp., and *Orygia antiqua*. Predators found in oil palm plantations as pest controllers are *Sycanus* sp. ladybugs (Reduviidae), weaver ants *Oecophylla* sp. (Formicidae), robber fly (Diptera: Asilidae), (Tachinidae), wasps (Hymenoptera: Vespidae), (Coleoptera: Carabidae and Coccinellidae), and spiders (Araneae). Parasitoids found are larvae parasaitoid (Braconidae), (Aphelinidae), (Eulophidae), egg parasitoid *Telenomus* sp. (Scelionidae), and *Brachymeria* sp. (Chalcididae). *Oecophylla* ants have been shown to be effective in suppressing pest populations in cocoa and coconut plants in Asia and Africa. This makes *Oecophylla* ants an important predator for these plants [15]. The presence of predatory insects in an ecosystem will be higher in more complex and diverse habitat structures [16].

Figure 3 shows the interaction between natural enemies and oil palm pests. Some of the natural enemies found in this research include *Sycanus* sp., which preys on *Darna trima* fire caterpillars, *Alsophila* sp., and *Dasychira inclusa*. Parasitoid *Brachymeria* sp. parasitize *Hidari irava*. Aphelenidae, which parasitize *Dasychira inclusa*, *Actornis* sp., and *Paleacrita* sp. Eulophidae, which parasitize *Alsophila* sp., and *Actornis* sp. Braconidae, which parasitize the caterpillar *Elymnias* sp. and Erebidae caterpillars. Pest-parasitoid in smallholder oil palm plantations in Riau is more complex than in smallholder oil palm plantations in West Kalimantan.

The number of caterpillar pests in sustainable oil palm plantations in Riau is less than in non-sustainable ones. The parasitization rate in Riau is higher because the more complex habitat structure can support a higher diversity of natural enemies. Several factors, such as the age of the oil palm, cause changes in the surrounding vegetation pattern. The canopy becomes denser, reducing the intensity of incoming light. This has an impact on changes in the microclimate, the composition of vegetation types, and the availability of food for parasitoids will also change [17]. Then, in Kalimantan, the number of caterpillars in sustainable oil palm plantations is higher than in non-sustainable ones. This decrease in habitat complexity can cause the loss of parasitoid species that are unable to adapt, thereby increasing the possibility of insect pests avoiding parasitization [18].

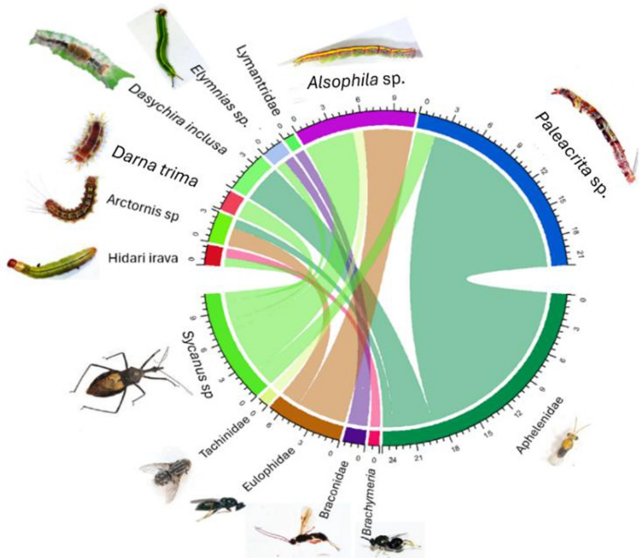

Fig. 3. Interaction between pest with natural enemies.

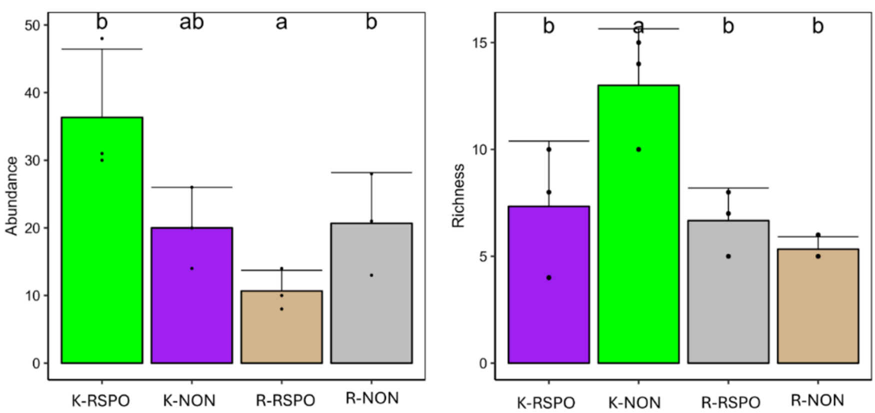

Fig. 4. Abundance and richness of pests in smallholders' oil palm

Based on the data distribution shown in the boxplot diagram, individuals from K-RSPO were higher compared to other locations, and caterpillar morphospecies in K-Non were higher (Figure 4). The abundance and richness of pests in smallholder oil palm plantations differ significantly from the estimated abundance of caterpillar pests in sustainable smallholder oil palm plantations in Kalimantan is higher than in non-sustainable oil palm plantations. This is thought to be because the use of insecticide applications is more widely used on non-sustainable oil palm lands compared to sustainable oil palm lands, so that fewer caterpillar pests are found. The use of insecticides and herbicides in sustainable oil palm plantations is carried out routinely. As a result, the caterpillar found on sustainable plantations is higher.

Efforts made to implement Good Agricultural Practices (GAP) for sustainable agriculture through several important aspects that must be considered include maintaining the sustainability of ground cover plants (understory vegetation), reducing pesticide use according to the recommended doses, managing riparian areas around rivers, and utilizing empty bunches as compost [19]. Through sustainability certification that takes into account the health and welfare of oil palm farmers, as well as the sustainability of palm oil production efforts at the global level, which is expected to reduce environmental issues related to deforestation [20].

Table 1. Diversity indices of pests in smallholders' oil palm

Location	Abundance	Richness	H2	invsimpson
Kalimantan RSPO	36	13	2.28	8.45
Kalimantan Non-RSPO	61	22	2.69	11.07
Riau RSPO	28	12	2.09	5.49
Riau Non-RSPO	26	7	1.82	5.68
Total	151	33		

Based on the Shannon-Wienner index (H'), the diversity of insect pests in sustainable and non-sustainable smallholder oil palm plantations is at a moderate to low level (H': 2.28 – 1.82) (Table 1). The diversity of caterpillars in the land is classified as moderate because the attack of fire caterpillars found in sustainable and non-sustainable smallholder oil palm plantations is less, compared to hairy caterpillars and inchworms.

This is because the age of the oil palm used ranges from 5 to 10 years, which refers to the results of Sahari's research [21] which states that the Lepidoptera pest community in oil palms less than 3 years old is mostly dominated by fire caterpillars, while in oil palms that are 6 years old, bagworms and hairy caterpillars are more dominant. Oil palm plantations adjacent to horticultural crops are greatly influenced by the interaction of the two types of plants, the presence of horticultural plants can affect the dynamics of insect populations around oil palm plantations. *Spodoptera litura* pests are often found on horticultural plants and can move to oil palm plantations adjacent to their habitat [22].

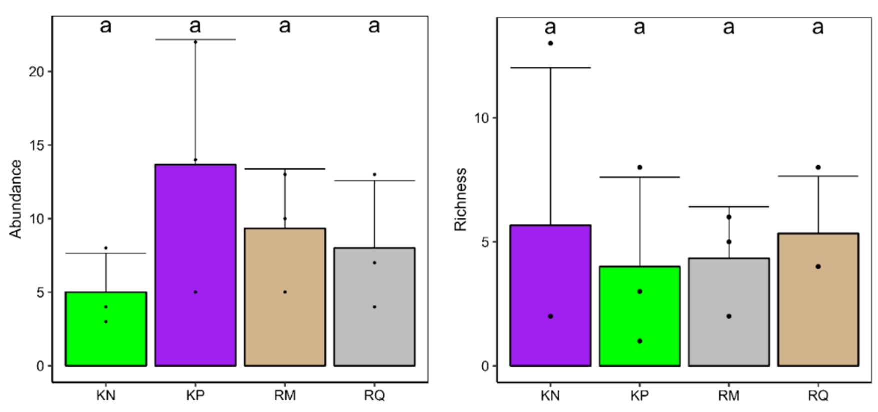

Fig. 5. Abundance and richness of natural enemies in smallholders' oil palm. Abundance (K-N) Kalimantan-RSPO, (KP) Kalimantan-Non, (RM) Riau-RSPO, and (RQ) Riau-Non. Richness (KN) Kalimantan-RSPO, (KP) Kalimantan-Non, (RM) Riau-RSPO, and (RQ) Riau-Non.

The diversity of natural enemies of parasitoids and predators in smallholder oil palm plantations in both Riau and Kalimantan did not produce significantly different results. The presence of natural enemies found in smallholder oil palm plantations does not differ between sustainable and non-sustainable land. This is because the landscape of both locations is almost the same, as is the condition of the understory vegetation. Decreased habitat complexity can cause the loss of natural enemy species, one of which is parasitoids that are unable to adapt to these changes, causing insect pests to be unable to be parasitized.

Planting flowering plants around the land in agroecosystems is expected to support the survival and development of parasitoids [23]. Oil palm plantations by planting refugia plants such as *Turnera subulate,* which are expected to be able to become a habitat for natural enemies such as parasitoids. Previous studies have reported that the presence of flowering plants plays an important role in maintaining parasitoid communities in the field [24]. The presence of flowering herbaceous plants in a habitat can be an abundant food source for parasitoids. Flowers provide nectar, which is an important source of energy for natural enemies of parasitoids and predators [25].

Table 2. Diversity indices of natural enemies in smallholders' oil palm

Location	Abundance	Richness	H2	invsimpson
Kalimantan RSPO	93	33	1.99	3.82
Kalimantan Non-RSPO	86	18	1.89	4.78
Riau RSPO	83	23	2.30	8.47
Riau Non-RSPO	156	30	2.11	6.22
Total	418	67		

Based on the results of the Shannon-Wienner diversity index of natural enemies (parasitoids and predators) in Riau, the sustainable species index value is 2.30, and in Kalimantan, the sustainable species index value is 1.82. The moderate diversity value approaching 1 indicates that there are many species with almost the same number of individuals. Low value approaching 0 indicates that species diversity is low, where one or several species can dominate in a population. Natural enemies in oil palm plantations as biological agents that can control pests. The ecosystem in sustainable smallholder oil palm plantations is more stable in carrying out its role and function optimally. This shows that sustainable oil palm plantations can provide a habitat that is very suitable for natural enemies to survive in the understory vegetation and flowering plants, as plants are planted for conservation.

Flowering plants planted for natural enemy conservation and optimization have received significant attention from various researchers in the world [26]. The use of flowering plants to increase the diversity and effectiveness of natural enemies of parasitoids and predators in agricultural areas has been widely carried out, because flowering plants have a source of nectar that is used as an energy source for animals or natural enemies [27]. The more diverse the diversity of predators in an ecosystem, the more able it is to suppress yield losses due to attacks by insect pests [28]. Predatory insects also need a lot of prey or pests to fulfill their survival and continue to grow [29].

Oil palm plantations need high conservation value land to maintain animal and insect habitats, so that the presence of oil palm plantations does not reduce the rate of deforestation. so that biodiversity in a plantation is not lost. [30] Research found that conservation areas in oil palm plantations can be habitats for wildlife such as birds, reptiles, monkeys, and insects.

4. Conclusion

Sustainable oil palm plantation practices have a positive impact on the diversity of natural enemies. The relationship between sustainable oil palm plantations and the diversity of natural enemies, both in Riau and Kalimantan, is no different. The applications of environmentally friendly agricultural techniques by prohibiting the use of pesticides such as paraquat and maintaining plant vegetation in oil palm plantation areas are necessary in order to have high conservation areas (HCV). This is important in maintaining the habitat of natural enemies in oil palm plantations and maintaining ecosystem stability. Future research needs to examine the role of plant vegetation in attracting natural enemies, while sustainable plantations should be planted with a variety of flowering plants as habitats for parasitoid and predator populations.

References

1. USDA Foreign Agricultural Services. Top producing countries of palm oil production 2023/2024 U.S. Department of Agriculture. (2023). https://fas.usda.gov/data/production/commodity/4243000
2. Ditjenbun Directorate General of Plantations. Status of Indonesia plantations of palm oil commodities 2015-2017. (2023). http//ditjenbun.pertanian.go.id.
3. RSPO 2023. Rspo Independent Smallholder Standard For the Production of Sustainable Palm Oil. Roundtable on Sustainable Palm Oil (RSPO) https://rspo.org/certification/rspo-independent-smallholder-standard
4. Veriasa TO, Nurrunisa M, Fadhli N. 2024. Revisiting the Implications of RSPO Smallholder Certification Relative to Farm Productivity in Riau, Indonesia. For Soc. **8**, 123 (2024). https://doi:10.24259/fs.v8i1.26964
5. Naranjo SE, Ellsworth PC, Frisvold GB. Economic value of biological control in integrated pest management of managed plant systems. Annu Rev Entomol. October 60, 621–645 (2015). https://doi:10.1146/annurev-ento-010814-021005
6. Sahari B, Buchori D, Manuwoto S, Nurmansyah A. Pattern of Lepidopteran pest community attacking oil palms and their associated hymenopteran parasitoid. IOP Conf Ser Earth Environ Sci. **325**(1) (2019). https://doi:10.1088/1755-1315/325/1/012010
7. Noyes JS. A study of five methods of sampling Hymenoptera (Insecta) in a tropical rainforest with special reference to Parasitica. J of Natural History. **23** 285-298 (1989).
8. Johnson CA dan Triplehorn NF. Boror and DeLong's Introduction to The Study of Insects 7th Edition. (USA, Thomson Books Cole, 2005)
9. Goulet H, Huber JT. Hymenoptera of the World: an Identification Guide to Families. (Ottawa (CA), Agriculture Canada, 1993)
10. CSIRO. The Insects of Australia, 2nd edn. (Melbourne, Melbourne University Press, 1996)
11. Nazarreta R, Buchori D, Hashimoto Y, Hidayat P, Scheu S, Drescher J. A guide to the ants of Jambi (Sumatra, Indonesia): Identification key to ant genera and images of the EFForTS collection. e-Publishing, Penerbit BRIN, ISBN-**13**(15) 2021. http://doi.org/10.14203/press.273

12. Wharton RA, Marsh PM, Sharkey MJ. Manual of the New World Genera of the Family Braconidae (Hymenoptera). (Washington DC, Internasional Society of Hymenopterists, 1997)
13. Magurran AE. Measuring Biological Diversity. (Malden, Blackwell Science Ltd., 2004)
14. Dormann CF, Freud J, Grubber B, Becket S, Devoto M, Felix GMF, Oriondo JM, Opshal TO, Pinheiro RBP, Straus R, Diego PV. 2022. Package 'bipartite'. CRAN.
15. Peng R, Christian K. Ants as biological-control agents in the horticultural industry. Di dalam: Lach L, Parr CL, Abbott KL, editor. Ant ecology. Ke-1. (New York (US), Oxford University Press Inc., 2010)
16. Rusch A, Valantin-Morison M, Sarthou JP, Roger-Estrade J. Biological control of insect pests in agroecosystems: effects of crop management, 19 20 farming systems, and seminaturalhabitat at the landscape scale: A review. Advances in Agronomy. **109**, 219-259, (2010)
17. Perovic DJ, Gurr GM, Raman A, Nicol HI. Effect of landscape composition and arrangement on biological control agents in a simplified agricultural system: a cost-distance approach. Biol Control **52**, 263-270, (2010)
18. LaSalle J, Gauld ID. Hymenoptera: Their diversity, and their impact on the diversity of other organisms. Di dalam: LaSalle J, Gauld ID, editor. Hymenoptera and Biodiversity. London: CAB International. hlm 1-26, (1993)
19. Darussamin A, Astuti M, Rahadian D, Prihantono E, Siregar LT, Husnawati, Hikman. Guidebook for the Aplication of RSPO Principles and Criteria for Palm Oil. Ministry of Agriculture., ready to be published. (2012) https://rspo.org/publications/download/fd26d49fec7ade9.
20. Tacconi, L., Rodrigues, R. J., & Maryudi, A. Law enforcement and deforestation: Lessons for Indonesia from Brazil. Forest Policy and Economics, **108**(May), 101943, (2019). https://doi.org/10.1016/j.for pol.2019.05.029
21. Sahari B. Struktur komunitas parasitoid Hymenoptera di perkebunan kelapa sawit, Desa Pandu Senjaya, Kecamatan Pangkalan Lada, Kalimantan Tengah. Dissertation Thesis, Institut Pertanian Bogor, Indonesia, 2012.
22. Manikome N. Keragaman Jenis Dan Populasi Serangga Pada Tanaman Cabai Di Wilayah Tobelo. Seri Ilmu-Ilmu Alam Dan Kesehat. **2**(2015), 69–77, (2018)
23. Gillespie M, Wratten S, Sedcole R, Colfer R. Manipulating floral resources dispersion for hoverflies (Diptera: Syrphidae) in a California lettuce agro-ecosystem. Biol Control **59**, 215-220, (2011)
24. Basri MW, Kamarudin N. Cassia cobanensis as a beneficial plant for sustenance of parasitoids in bagworm control. MPOB TT No. 132. (2002)
25. Hogg BN, Bugg RL, Daane KM. Attractiveness of common insectary and harvestable floral resources. Biol Control **56**, 76-84, (2011)
26. Wratten SD, Lavandero BI, Tylianakis J, Vattala D, Çilgi T, Sedcole R. Effects Of Flowers On Parasitoid Longevity And Fecundity. New Zealand Plant Protection **56**, 239-245, (2003)
27. Freeman CE, Worthington RD, Jackson MS. Floral nectar sugar compositions of some South and Southeast Asian species. Biotropica. **23**(4b), 58-574, (1991)
28. Furlong MJ, Zalucki MP. Exploiting predators for pest management: the need for sound ecological assessment. Entomologia Experimentalis et Applicata. **1**(35), 225-236, (2010)
29. Price PW, Denno RF, Eubanks MD, Finke DL, Kaplan I. Insect Ecology, Behavior, Populations and Communities. (Cambridge (GB), Cambridge University Press, 2011)
30. Kissinger, Pitri RMN, Violet. Vegetaton and Fauna Diversity of High Conservation Value (HCV) Swamp Areas in Oil Palm Plantation. IOP Publishing Earth and Environmental Science. 2020. https://doi:10.1088/1755-1315/499/1/012017.