UNIVERSITI PUTRA MALAYSIA

MEASURING PEST CONTROL SERVICES PROVIDED BY BIODIVERSITY IN MULTIPLE AGRICULTURAL LANDSCAPES

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By

NURADILAH BINTI DENAN @ ADNAN

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Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

MEASURING PEST CONTROL SERVICES PROVIDED BY BIODIVERSITY IN MULTIPLE AGRICULTURAL LANDSCAPES

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Chairman : Badrul Azhar Md. Sharif, PhD
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Non-selective pesticides have caused extensive loss to animal biodiversity in the agro-ecosystem. Moreover, the loss of tropical forests due to agricultural activities and overuse of pesticides in homogenous habitat affects overall biodiversity and ecosystem functions. To provide solution, biological control is alternatives to chemical pesticides. The main issues were how different types of agricultural landscape (oil palm, rubber tree plantation and fruit orchard) and the interior and edge effect of different ages of oil palm contributes to predation by natural enemies on pest insects. This research investigates the potential of birds, small mammals, and arthropods as natural enemies for pest insects in agricultural landscapes. The methodology was divided into two frameworks. First, a study was conducted in Pedas Negeri Sembilan to determine the predation rate within fruit orchards, oil palm, and rubber tree plantations using predation marks left on the artificial caterpillar. Local/site and landscape variables including understory vegetation structures, elevation, proximity to forest, and canopy cover from the three-agriculture landscape, were collected. The data were analyzed using Generalized Linear Mixed Models (GLMMs) with predation as the response variable. Binomial distribution was used and variables were fitted with plot as random effects. The effect between land-use type and predator type was significant. In all three land-use types, arthropods and mammals were important enemies of artificial caterpillars and there was little predation by birds. In fruit orchards and rubber tree plantations, mammal's predation was considerably higher likely due to the landscape ability to support higher abundances of insectivorous mammals. The second framework was conducted in Universiti Putra Malaysia Serdang Selangor to determine the predation on artificial caterpillar using variables comprising height and coverage of understory vegetation, elevation and, canopy cover from the edge and interior location of three different oil palm age stand. The binary regression was used to analyzed the relationship between the variables and complemented with Nagelkerke R^2 coefficient. The results revealed that mammals responsible for the highest levels of predation, followed by arthropods and birds. Arthropod predation was higher at edge locations, abandoned habitats, and elevated areas. Mammal predation was shown to increase with

understory coverage and decrease with elevation. Bird predation was not shown to be associated with any of the habitat quality characteristics studied. Overall predation was higher at the edge of plantations and positively correlated to understory vegetation coverage regardless of plot location. Throughout the research, types of habitat and habitat quality such as understory vegetation and edge location have distinct effect on the natural enemy population. The diversity and abundance of arthropods and mammals should be maintained by tolerating understory vegetation and minimizing the application of pesticides. A practical approach, such as reserving a semi-natural habitat of different types of vegetation within agricultural land to restore suitable foraging and refuge habitat for natural enemies. Besides, through the implementation of biodiversity-friendly management, there is real potential to improve the effectiveness of natural enemies within agricultural landscapes. The findings promote sustainable agriculture at the landscape level and offer an opportunity to increase crop yields.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan ijazah Master Sains

PENGUKURAN PERKHIDMATAN KAWALAN SERANGGA PEROSAK OLEH BIODIVERSITI DALAM PELBAGAI LANDSKAP PERTANIAN

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Racun serangga telah menyebabkan kehilangan biodiversiti yang meluas dalam agro-ekosistem. Selain itu, kehilangan hutan tropika akibat aktiviti pertanian dan penggunaan racun perosak yang berlebihan dalam habitat homogini sangat mempengaruhi keseluruhan biodiversiti dan fungsi ekosistem. Sebagai penyelesaian, kawalan biologi adalah alternatif kepada racun serangga perosak. Isu utama adalah bagaimana pelbagai jenis landskap pertanian (ladang kelapa sawit, getah dan kebun buah) serta kesan pinggir dan habitat dalam ladang kelapa sawit yang berbeza umur menyumbang kepada tahap pemangsaan oleh musuh semulajadi kepada serangga perosak. Kajian ini bertujuan untuk mengkaji potensi burung, mamalia kecil dan serangga sebagai musuh semulajadi bagi serangga perosak di dalam kawasan pertanian. Metodologi untuk mencapai matlamat ini dibahagikan kepada dua rangka kerja. Pertama, kajian yang dijalankan di Pedas Negeri Sembilan adalah untuk menentukan kadar predasi pada ulat buatan dalam kebun buah, kelapa sawit, dan ladang pokok getah. Data tempatan dan landskap termasuk struktur tumbuh-tumbuhan bawah semulajadi, ketinggian, jarak dekat dengan hutan, dan kanopi dari tiga landskap pertanian dikumpulkan. Data dianalisi sdengan menggunakan Model Campuran Linier Umum (GLMMs) dengan pemangsaan sebagai pembolehubah tindak balas. Regresi binomial digunakan dengan plot sebagai pemboleh ubah kesan rawak. Kesan antara jenis pertanian dan jenis pemangsa adalah penting. Dalam ketiga-tiga jenis pertanian, arthropod dan mamalia adalah musuh penting bagi ulat buatan dan terdapat sedikit pemangsaan oleh burung. Dapatan mamalia jauh lebih tinggi dalam kebun buah-buahan dan pokok getah daripada ladang kelapa sawit, mungkin disebabkan oleh keupayaan kebun buah dan lading pokok getah untuk menyokong lebih banyak mamalia. Rangka kerja kedua dijalankan di Universiti Putra Malaysia Serdang Selangor adalah untuk menentukan tahap pemangsaan pada ulat buatan dengan menggunakan pembolehubah yang terdiri daripada ketinggian dan liputan tumbuhan semulajadi, ketinggian dan kanopi dari lokasi pinggir dan pedalaman tiga umur sawit yang berbeza. Regresi binari digunakan untuk menganalisis hubungan antara pembolehubah dan dilengkapi dengan koefisien Nagelkerke R^2. Dapatan mendedahkan bahawa mamalia bertanggungjawab untuk tahap pemangsaan tertinggi, diikuti oleh serangga dan burung. Pemangsaan serangga adalah lebih tinggi di lokasi pinggir, habitat terbiar, dan di kawasan yang tinggi. Pemangsa mamalia dipengaruhi dengan peningkatan liputan vegetasi dan berkurang dengan ketinggian. Walaubagaimanapun, hasil pemangsa burung tidak dikaitkan dengan mana-mana ciri-ciri kualiti habitat yang dikaji. Tekanan pemangsaan secara keseluruhan adalah lebih tinggi di pinggir lading berbanding di dalam kawasan perladangan, dan pemantauan keseluruhan dikaitkan dengan peningkatan dalam liputan vegetasi tanpa mengira lokasi plot. Daripada keseluruhan penyelidikan, jenis habitat dan kualiti habitat seperti tumbuh-tumbuhan bawah dan lokasi pinggir mempunyai kesan yang berbeza terhadap populasi musuh semulajadi. Kepelbagaian dan kelimpahan arthropod dan mamalia harus dikekalkan dengan meningkatkan liputan vegetasi dan meminimumkan penggunaan racun perosak. Pendekatan praktikal, seperti memelihara habitat separa semulajadi atau melaksanakan perkongsian tanah bagi pelbagai jenis tumbuh-tumbuhan di dalam lading pertanian mungkin membantu memulihkan habitat dan tempat perlindungan bagi musuh semulajadi. Selain itu, pelaksanaan strategi pengurusan yang mesra biodiversity memberi potensi untuk memperbaiki keberkesanan musuh-musuh semulajadi dalam landskap pertanian. Penemuan dari hasil kajian ini mempromosi pertanian lestari di peringkat landskap dan menawarkan peluang untuk meningkatkan hasil tanaman.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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ASTM	American Society for Testing and Material
CBC	Classical Biological Control
FAO	Food and Agriculture Organization of the United Nations
IPM	Integrated Pest Management
MEA	Millennium Ecosystem Assessment
MPOB	Malaysian Palm Oil Board
MRB	Malaysian Rubber Board
MSPO	Malaysian Sustainable Palm Oil
RSPO	Roundtable Sustainable Palm Oil
TEEB	The Economics of Ecosystem and Biodiversity

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Southeast Asia represents a unique agroecosystem with complex landscape diversity in the tropics. Over the past decades, major landscape transformation has modified much of the original forest landscapes into human-modified landscapes in the region. These human-modified landscapes are either traditional mixed planting or modern monocultural systems. In Malaysia, traditional fruit orchards or home gardens are typical Malaysian agricultural landscape that includes various native fruit trees planted and managed by the local community (Sharifuddin and Zaharah, 1991; Peh et al., 2006; Salma et al., 2006; Shafie et al., 2011). It is a family or community's own property (Salma et al., 2006; Hussain and Byrd, 2012). Some area is involved in government projects where small-scale farmers developed the fruit orchard to plant fruit trees on their land for socio-economic benefits or some area are small-scale orchards for daily needs (Salma et al., 2006; Abdullah, 2011).

Apart from that, modern monocultural crop cultivation such as oil palm, *Elaeis guineensis*, and rubber tree, *Hevea brasiliensis* are other common agricultural landscapes in Malaysia (Murphy, 2014; Jackson et al., 2019). In 2017, Malaysian oil palm plantation reached an approximate area of 5.8 million hectares producing 19.8 million tonnes of crude palm oil (Malaysian Palm Oil Board, 2017). Specifically, Sabah and Sarawak were the major oil palm producers with 3.12 million hectares while Peninsular Malaysia has produced 2.72 million hectares. Unlike oil palm, rubber tree cultivation is cultivated in small to medium-scale plantations that are mainly managed by the smallholders. Higher global demand for rubber over the past decade has led to a major expansion of rubber plantation (Clay, 2004). In 2018, Malaysia had 1.01 million hectares of rubber tree smallholdings and 73,460 hectares' rubber tree estates that produced 603,329 tonnes of natural rubber (Malaysian Rubber Board, 2018).

Loss of tropical forests due to agricultural activities such as oil palm and rubber tree cultivation brings significant concerns on the loss of functional diversity in the tropical ecosystem (Laurance, 2007; Gibbs et al., 2010; Edwards et al., 2010; Foley et al., 2011; Hansen et al., 2013). Sundaland (Borneo, Malay Peninsula, Bali, and Java) is among the major global biodiversity hotspots under the pressure of massive land-use changes (Myers et al., 2000; Sodhi et al., 2004; Giam, 2017). Moreover, massive expansion of monoculture landscapes leads to poor communities of natural predators causing catastrophic outbreaks of herbivorous pest insects and diseases (Fitzherbert et al., 2008; Ewers et al., 2009; Azhar et al., 2014; Snyder, 2019). This situation has worsened in recent years, turning into a global concern that prompt conservation action worldwide (Crowder et al., 2010; Ghazali et al., 2016).

The control of pests by chemical pesticides is one of the most used methods for commercial crop production. Many of these agrochemicals have severe negative impacts on human and environmental health because of their hazardous toxicity and incorrect application. Modern oil palm and rubber tree agriculture, as well as a fruit orchard, rely heavily on external inputs, such as chemical pesticides and inorganic fertilizers to increase crop production (Le Roux et al., 2008; Simon et al., 2011). The overuse of pesticides in homogenous habitat affects overall biodiversity and ecosystem functions with severe health effects (Bianchi et al., 2013; Yadav et al., 2015). While the harmful impacts of pesticides are well known, alternative solution using natural predator is not well understood with most studies conducted in simplified environments or controlled conditions (Snyder et al., 2019). As the studies conducted under a controlled environment causing difficulties understanding the natural enemy in real-world agriculture, an alternative has been developed by researchers to overcome this matter. Gontijo (2019), noted that by providing beneficial floral plants to parasitoids and predators, and Torres and Bueno (2018) suggest reducing broad-spectrum insecticide usage, as a possible way to make hospitable agricultural landscape (Snyder et al., 2019). Thus, promoting a natural enemy as a biological control agent provides a potential and capable solution to reduce dependency on pesticides (Mason et al., 2008). Moreover, to strike a balance between ecological conservation and food production, conservation of natural enemies as biological agents has been widely recommended (de Groot, Wilson, and Boumans, 2002; Wood, 2002; Dudley et al., 2017). In a larger scale, conservation of natural enemies does succeed, however, there is still uncertainty on the ecology of its benefits and failures (Gurr et al., 2017; Karp et al., 2018)

Sustainable agriculture emphasizes building resilient agroecosystems and reducing the adverse impact of agricultural activities on the environment. It promotes agriculture that does not expand the agricultural frontier and helps restore ecosystems. Improving efficiency in the use of natural resources is critical to sustainable agriculture because food production depends to a large extent on the services provided by biodiversity. Local/site and landscape factors are essential in supporting biological control agents in agricultural landscapes (Seifert et al., 2015; Nurdiansyah et al., 2016; Milligan et al., 2016; Lindgren, Lindborg and Cousins, 2018). Predation on pests by the natural enemies is influenced by the presence of different vegetation that offers variability of resources and ecological niches (Azhar et al., 2015; Nurdiansyah et al., 2016; Denmead et al., 2017). In comparison to monoculture plantations such as oil palm and rubber tree plantations, tropical fruit orchard has complex perennial agroecosystems, which can promote the top-down food web cycle (Simon et al., 2017). Thus, in this study, it is expected that an agricultural area with considerable vegetation heterogeneity such as fruit orchard and the existence of other naturally grown vegetation within a plantation can provide effective pest control services compared to a monoculture plantation.

1.2 Problem Statement

The agricultural landscape is now many times more toxic to insects, and likely to other fauna, than it was decades ago, almost entirely because of the widespread use of chemical pesticides. The declining insect number, particularly those categorized as pollinators and natural enemies, can also have catastrophic ecological repercussions. In many parts of the world, biological control augmentation constitutes a major challenge to improve crop resilience (Coll and Wajnberg, 2017). Agrochemicals, particularly non-selective pesticides, have caused extensive loss of biodiversity in the agro-ecosystem as it exterminates not only targeted pests but also non-target fauna (Le Roux et al., 2008). Ecosystem function also can be affected by the long-term effect of pesticide application. Furthermore, residual impacts of pesticides also reported causing a major decline of arthropods population in natural habitats (Hallmann et al., 2017). Despite controlling pest populations, chemical pesticide application eliminates natural enemies from agricultural ecosystems leading to serious pest outbreaks (Wood, 2002; Dutcher, 2007; Kamarudin and Wahid, 2010). The dilemma of undesirable outcomes from the use of a chemical to mitigate pests has driven consumer's concerns (Bianchi et al., 2013). The contribution of natural enemies as biological control agents has attracted attention in the search for a more environmentally-friendly alternative (de Groot, Wilson, and Boumans, 2002; Wood, 2002). The strategy to use natural enemies as biological control, however, has increased in recent years (Landis et al., 2000). Moreover, biological control can reduce chemical usage and labor costs in various agricultural systems (Millenium Ecosystem Assessment, 2005; Cleveland et al., 2006; Kellermann et al., 2008; Sekercioglu, 2012).

Conventional farming is necessary to feed the world, but it relies heavily on the use of agrochemicals. This unsustainable practice can cause substantial environmental degradation, biodiversity loss and a progressive loss of agricultural productivity. Biological control research can shape sustainable agriculture in crop-producing countries (e.g., Malaysia, Indonesia, Thailand). This research is important to justify the conservation of biodiversity, particularly natural enemies such as arthropods, birds, and mammals in agricultural landscapes. The findings can be used to convince both major plantation businesses and smallholders to maintain biodiversity habitats on their farmlands and to reduce the use of chemical pesticides that can negatively affect human health and the environment in the long run. Crop health is the main factor to reach optimum levels of productivity and economic profitability in the agricultural system, as the pest outbreak severely affects the yields and quality. However, farming practices, especially in tropical countries, should depend on natural and sustainable resources that are readily available rather than depending on external inputs. Still, several ecological studies have reported that conventional oil palm and other non-forest habitats support lower fauna diversity compared to native forest landscapes (Koh, 2008; Azhar et al., 2011; Gillespie et al., 2012; Warren-Thomas et al., 2015).

The intensification of modern agriculture able to generate immense yield but biodiversity suffers the loss of habitats and affected important ecosystem function in the agricultural landscape (Landis, 2017). While it is well-known that a high level of disruption and ecological simplicity create an unfavourable environment in most agroecosystems for natural enemies (Landis et al., 2000). Therefore, it is essential to understand to what extent the natural enemies able to contribute to control pests in different land-use of agricultural landscapes. Studies looking at the factors that influence natural enemies are essential to strengthen biological control conservation within tropical agricultural landscapes (Maas et al., 2015; Nurdiansyah et al., 2016). The use of biological control agents is also aligned with sustainable crop certification schemes (e.g., Roundtable on Sustainable Palm Oil (RSPO) and Malaysian Sustainable Palm Oil (MSPO)). In general, the findings from this research can help the stakeholders in the agricultural sector to reconcile commodity crop production with biodiversity conservation.

1.3 Aim and Objectives

This research aimed to investigate the potential of birds, small/medium-sized mammals, and arthropods as natural enemies for pest insects in agricultural landscapes. The objectives of the research were as follows:

1. To measure the predation pressure of the natural enemies using artificial caterpillar as a pest in different agricultural landscapes (i.e., orchard, oil palm and rubber tree plantations) and at the interior and edge of oil palm plantation.
2. To identify the key environmental factors that determine the predation pressure of pest insects in different agricultural landscapes (i.e., orchard, oil palm and rubber plantations).

1.4 Significance of the Study

To date, this research is the first in Peninsular Malaysia to investigate pest control services provided by arthropods, birds, and mammals in multiple agricultural landscapes. The findings from this study highlight the important habitat quality characteristic that supports the natural enemy population. The present study showed that agricultural landscapes with higher habitat complexity can support better pest control services by natural enemies. The composition of natural enemy comprises of arthropods, small/medium-sized mammals, and birds are strongly affected by the condition of the environment. Within the agricultural landscape, anthropogenic disturbances are frequent that result in poor biodiversity and lower ecological resilience. The ecosystem needs a range of biodiversity that is important to deliver its services. For example, arthropods and birds are essential components in providing pollination and pest control in the ecosystem.

The present study also provides insights into the potential natural enemy that presence within different agriculture plantations. Furthermore, agricultural landscapes mixed with different crop species and planted with other beneficial non-crop plants aid in providing food resources, improve habitat quality and also provide refuge place for the natural enemy. Agricultural landscape surrounded by weedy plant strips or planted adjacent to different types of vegetation crop help to enhancing natural enemy establishment by providing a different source of food and habitat compared to a large monoculture plantation. Conserving biodiversity is essential as it provides biological control within agricultural landscapes. For example, the introduction of barn owl (e.g. *Tyto alba*) to control rodent pest. However, this research provides a framework for future studies on testing a range of suitable management tools that able to support the conservation of natural enemies and helps commercial and small-scale farmers to implement management practices that are wildlife- environmentally- friendly.

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