PREDICTIVE MODEL FOR RED PALM WEEVIL POPULATION IN COCONUT USING ENVIRONMENTAL VARIABLES AND REGRESSION METHOD

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

In Malaysia, coconut is one of the commercialized crops, and has become the most important industrial crop. Furthermore, Johor has the largest coconut plantation area in Peninsular Malaysia, which is 14,931.6 hectare. Johor was also the largest producer of coconuts in Malaysia in 2018, with the production number amounting to 112,122 hectares. However, the increasing population of Red Palm Weevil (RPW) in Malaysia is very worrying. RPW is known to be a very dangerous pest on coconut trees, especially found in the Middle East. This study was conducted to model the incident potential of RPW in coconut plantations. The first objective of this study is to examine temporal factors of RPW population. The second objective is to develop a model that can predict the occurrence population of RPW on a coconut plantation based on significant environmental variables. The third objective is to validate the model that has been developed in the second objective. The fourth objective is to produce a susceptibility map of RPW population. This study has been divided into eight phases. This phase includes a site visit to the coconut plantation attacked by RPW, and an interview session conducted with the plant biosecurity officer to address objective 1. A model linear model (GLM) was used to model events based on poisson regression. The model was then validated using root mean square error (RMSE) and mean absolute error (MAE) to address objectives 2 and 3. Finally, the location of the appropriate RPW population infestation was described using weighted Overlay analysis (WOA). Based on the model, five statistically significant variables were determined, which contributed to the total RPW. The variables are humidity, rainfall, wind direction, distance of the trap from the river and road. Based on the value of R squared, the most significant variable was distance from the river ($R=5.8$, $p<0.5$), followed by humidity ($R=2.9$, $p <0.5$), wind direction ($R=1$, $p<0.5$), rain ($R=0.2$, $p<0.5$), and distance from the road ($R=0.1$, $p <0.5$). This study shows that the places with the lowest probability of being infected by RPW in Mersing are Kg. Semaloi and Tg. Resang, because the two trap locations are far from roads and rivers. Meanwhile, the locations with the highest probability of being attacked by RPW are Kg. Penyabong and certain areas in Kg. Sungai Berbatu, Kg. Belukar Juling, and Kg. Semanyir, because all locations are close to roads and rivers. In conclusion, this model predicts the presence of RPW with errors of 4 (RMSE) and 3 (MAE) for each trap. This model can be developed further, which will assist the authorities in planning and providing an early warning system to identify areas that are likely to be attacked with RPW

ABSTRAK

Di Malaysia, kelapa adalah salah satu tanaman yang dikomersialkan dan telah menjadi tanaman industri terpenting. Tambahan pula, Johor mempunyai kawasan tanaman kelapa terbesar di Semenanjung Malaysia, iaitu 14,931.6 hektardan pengeluar terbesar di Malaysia pada tahun 2018, iaitu 112,122 hektar. Bagaimanapun, peningkatan populasi Kumbang Sawit Merah (RPW) di Malaysia amat membimbangkan. RPW dikenali sebagai perosak yang sangat berbahaya kepada pokok kelapa terutamanya di Timur Tengah. Matlamat kajian ini dijalankan untuk memodelkan potensi RPW di ladang kelapa. Objektif pertama kajian ini adalah untuk mengkaji faktor temporal populasi RPW. Objektif kedua adalah untuk membangunkan model yang boleh meramalkan kehadiran populasi RPW pada ladang kelapa berdasarkan pemboleh ubah persekitaran yang ketara. Objektif ketiga adalah untuk mengesahkan model yang telah dibangunkan dalam objektif kedua. Objektif keempat adalah untuk menghasilkan peta kerentanan populasi RPW. Kajian ini telah dibahagikan kepada lapan fasa. Fasa ini termasuk lawatan tapak di ladang kelapa yang diserang oleh RPW dan sesi temu bual dijalankan dengan pegawai biosekuriti tumbuhan untuk mengendalikan objektif 1. Model linear am (GLM) untuk memodelkan peristiwa berdasarkan regresi poisson telah digunakan. Selanjutnya, model disahkan menggunakan ralat punca min kuasa dua (RMSE) dan min ralat mutlak (MAE) untuk mengendalikan objektif 2 dan 3. Akhir sekali, lokasi populasi RPW yang sesuai untuk diserang, diterangkan menggunakan analisis tindanan berwajaran (WOA) untuk objek. Berdasarkan model, terdapat lima pemboleh ubah yang signifikan secara statistik menyumbang kepada jumlah RPW. Pembolehubah tersebut adalah kelembapan, hujan, arah angin, jarak perangkap dari sungai dan jalan raya. Berdasarkan nilai R kuasa dua, pemboleh ubah yang paling ketara ialah jarak dari sungai ($R=5.8$, $p<0.5$), diikuti kelembapan ($R=2.9$, $p<0.5$) arah angin ($R=1$, $p<0.5$), hujan ($R=0.2$, $p <0.5$) dan laluan terakhir ($R=0.1$,$p<0.5$). Kajian ini menunjukkan tempat yang mempunyai kebarangkalian paling rendah untuk dijangkiti RPW di Mersing ialah Kg. Semaloi dan Tg. Resang kerana dua lokasi perangkap tersebut jauh dari jalan raya dan sungai. Manakala lokasiyang mempunyai kebarangkalian paling tinggi untuk diserang RPW ialah Kg. Penyabong dan kawasan tertentu di Kg. Sungai Berbatu, Kg. Belukar Juling dan Kg. Semanyir kerana semua

lokasi berdekatan dengan jalan raya dan sungai. Kesimpulannya, model ini meramalkan kehadiran RPW dengan ralat 4 (RMSE) dan 3 (MAE) bagi setiap perangkap. Model ini dibangunkan agar dapat membantu pihak berkuasa dalam merancang dan menyediakan sistem amaran awal untuk mengenal pasti kawasan yang akan diserang RPW.

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LIST OF ABBREVIATIONS

RPW	-	Red Palm Weevil
H	-	Humidity
GLM	-	Generalized Linear Model
UTM	-	Universiti Teknologi Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Food security issues continue to grow over time. According to Jiang et al., (2019) in 2020, it was estimated that nearly 690 million people worldwide were undernourished and could exceed 840 million people in 2030 if current trends continue. Kogan et. al, (2019) indicate that almost 1 billion people are starving every year and one fourth of the world's population faced food deficiency. According to Care et al. (2020), food security reflected by global agricultural growth productivity has been slowing down. As indicated by Cox et al. (2019) and Peña-Lévano et al. (2019), the decrement in agricultural yield may be the consequence of climate change. Current studies confirmed that climate change causes low food production (Z. Jiang et al., 2019; Huong et al., 2019; Castro et al., 2019). Many types of crops are affected by climate change as indicated by DaMatta et al. (2019), Pironon et al. (2019) and Ray et al. (2019) and Lamichhane et al. (2019), which also takes coconut into account. (Vishweshwar et al., 2019 and Timon et al., 2019). Bosso et al., (2017) and Dong et al., (2019) indicate that there is a clear relation between climate change and the increase of plant pest. Therefore, this study focuses on how climate change had affected coconut production.

Coconuts (*Cocos nucifera L.*) are known due for its 3 multifarious uses, and it provides food for millions of people, especially in the subtropical and tropical regions. The tree grows in more than 93 countries, including Malaysia. The largest producers of coconut production are Indonesia, the Philippines, and India (Govindasamy, 2018). In Malaysia, coconut is one of the commercialized plantations and has become the most important industrial crop (DOA, 2018). In 2018, the agriculture sector accounted for 7.3% of employment in Malaysia (Indicators, 2020). Industrial crop statistics released by the Malaysian Department of Agriculture DOA (Jabatan Pertanian

Malaysia, 2017). shows that Johor has the biggest total area of coconut plantation in Peninsular Malaysia, which is 14,931.6 (ha), and is the biggest producer in Malaysia in 2018 with 112,122 (ha) (DOA, 2018). In tropical regions, it is widely planted for its versatility as each part of a coconut tree can produce domestic items, food, beverage (Joseph, 2017) and medicine purposes (Joseph, 2017; Manalo et al., 2017). Usually, the commercialized varieties of coconuts in Malaysia are MAWA (Malayan Dwarf X West African Tall), MATAG (MYD/MRD X Tagnanan Tall) and Aromatic Dwarf (commonly known as Kelapa Pandan).

Coconut and oil palms are classified in the family of *Arecaceae* and usually affected by pest infestation (Lee et al., 2017). Currently, coconut plantation is threatened by the most detrimental palm pest, which is *Rhnychophorus ferrugineus* or commonly known as the Red Palm Weevil (RPW) (Norhayati et al., 2016). RPW belongs to the *Dryophthoridae* family, *Curculionoidea* superfamily from the Order Coleoptera. The infestation of RPW in Malaysia was first detected by the DOA in 58 localities in seven districts of Terengganu, in which these infestations had given a huge loss in the local agriculture sector. The pest spreads very rapidly and causes serious damage to coconut palm plantations (Azmi et al., 2017). In 2011, about 550 000 RPW attacked over 800 ha of coconut plantation throughout Terengganu (Azmi et al., 2017). Later, in 2016, the weevil was found in Perlis, Kedah, Penang, and Kelantan, which showed a sharp increase and rapid spread of RPW population in Malaysia (Azmi et al., 2017). It is believed that the weevil was introduced by date palm trees which were brought in across the border either for date palm plantation or landscaping without proper quarantine (Norhayati et al., 2016). Since several years back, the Department of Agriculture has detected the activity of pests in coconut palm plantations in Johor. A progressive study and monitoring have been conducted to manage the pest. The pest has been abundantly trapped in coconut plantations around Johor, but there is no report from DOA showing symptoms of red palm weevil attacking coconut trees in Johor (DOA, 2018).

Red Palm Weevil (RPW) is an invasive tissue-boring pest and host range of 26 palm species worldwide belonging to 16 different genera (Dawadi et al., 2018; Mashal and Obeidat, 2019). There are 54 countries recognized to be infected by RPW infestation and the predicted financial losses hit multi-million dollars annually (Al-Megren et al., 2018). The occurrence of this invasive pest has been distributed widely from its native Southeast Asia to Asia (including China and India), Northern Africa, the Middle East, Europe, Oceania (Australia and Papua New Guinea), Caribbean (Aruba and Curacao) in 2008 and 2010 in California (Castillo et al., 2020). Asian Red Palm Weevil species include *R. ferrugineus* (Oliver), *R. vulneratus* (Panzer), *R. distinctus Wattanapongsiri*, *R. lobatus (Ritsema)* and *R. bilineatus* (Montrouzier). It is a large insect (more than 25mm long). In Johor, DOA has reported that the species captured from the installed trapped are from the species of *R. ferrugineus* and *R. vulneratus.* According to Thomas (2010), *R. ferrugineus* and *R. vulneratus* differ in terms of the pronotum shape or pronotal marking and the colour of the body. However, Sazali et al. (2019), conclude that both species are considered much the same according to their morphological, molecular-genetic and breeding characteristics. Meanwhile, Sadder et al., (2019) revealed high levels of genetic variation in the mitochondrial cytochrome oxidase subunit I (COI) gene sequences across 600 *R. ferrugineus* specimen and suggested both species are distinct. The true *R. ferrugineus* is native to the western and northern parts of Southeast Asia (Cinnirella et al., 2019).

Many factors influence the development of RPW. According to Ishfaq et al. (2017), Kumar et al. (2017), and González-Mas et al., (2019), abiotic parameters are known to have a direct impact on insect population dynamics. Climate would have a significant impact on the population dynamics of insect pests. Temperature, humidity, and rainfall play important roles in pest development (Raiten and Aimone, 2017). For example, changes in surrounding temperature regimes and humidity involve alterations in development rates of the survival of RPW (Metwally & Basheer, 2019). Moreover, Delaune (2019) and Claflin et al., (2019) show that landscape epidemiology has a significant impact on the development of pests. According to Raiten and Aimone, (2017) landscape epidemiology explains the interaction between temporal dynamics of host, vector, and pathogen populations within the non-restrictive environment to enable transmission.

Many ways to overcome and manage this invasive weevil have been applied by various stakeholders. Insecticide application is mainly used in managing the pest in the past (Massa et al., 2019), which may result in long-term damage to human health and the environment (Mashal & Obeidat, 2019). However, with the development of Integrated Pest Management (IPM), a new method with a better result has been found (Qayyum et al., 2019). The technique suppressed the populations using pheromone traps and biological control (Norton, 2017). DOA installs a pheromone trap using aggregation pheromone imported from Costa Rica in Malaysia's coconut plantations to control RPW infestations. However, the effectiveness of such control strategies is still unknown as the infestation has continued to increase in recent years (Azmi et al., 2017).

The use of a Geographic Information System (GIS) in agriculture plays an increasingly important role in crop production. It helps farmers increase production, reduce costs, and manage their land resources more efficiently (Rahman et al., 2019; Estigade et al., 2019; Machwitz et al., 2019). Geographical information systems (GIS) are computer-based systems designed specifically to facilitate the digital storage, retrieval, and analysis of spatially referenced environmental data. Coupled with geostatistical modelling, GIS can provide significantly increased opportunities for a better analysis on predicting the pest habitat (Al-Kindi et al., 2017; Jumaah et al., 2019 and Fu et al., 2014).

A recent study, Sanz-Aguilar et al. (2020) developed multievent model capture-recapture models using software E-SURGE. The model is used to investigate the dynamics of the infestation of *phoenix canariensis* by Red Palm Weevil in Mallorca Island, Spain). Emmert and Dehmer (2019) adopted generalised linear models to study the relationship between weevil captures and aggregation pheromone trials. The study was conducted to understand ways to increase the efficacy of pheromone trap in the Mediterranean basin. Next, Manzoor et al. (2020) applied simple linear regression to identify the relationship between environmental factors (weather) and the population fluctuation of RPW throughout the year in Sindh Province of Pakistan.

This study is to identify the environmental factors that have influenced the occurrence of RPW incidence and to model the relationship between the environmental factors and the incidence of RPW occurrence. Due to the capability of GIS in managing agricultural issues, this study is adopting spatial statistical modelling in controlling the occurrence of RPW on coconut trees in Mersing.

1.2 Problem Statement

Red Palm Weevil is known to be the deadliest pest on palm plantations especially in the Middle East (Azmi et al., 2017). In Malaysia, the population of RPW has continued to rise since firstreported in Terengganu in 2007and has dispersed into other states until first reported in Johor in 2016 (Azmi et al., 2017). The occurrence of Red Palm Weevil in coconut plantations around Johor is increasing (News, 2018). Today, the issue of Red Palm Weevil (RPW) or known as a destructive insect pest of a wide range of palm trees (Mahmud et al., 2015; Mozib, 2013) has become one of the major issues that is infesting and destructing the coconut trees in Malaysia.

Numerous studies have been conducted to overcome RPW occurrence. However, there is a lack of studies devoted to studying theenvironmental factors that can influence and predict the population of RPW in Malaysia, although previous studies have demonstrated the significant impact of the environment on the population and spread of pest activities (Jonsson et al., 2015; Gonçalves and de Moraes, 2017; Al-Kindi, et al., 2017). Vidyasagar et al. (2016) have stated that environmental factors can influence the density population of RPW. Manzoor et al., (2020) indicate that the change in climatic factors (temperature and humidity) influence on the oviposition and egg hatching of RPW. Barkan et al., (2018) state that RPW flight performances and dispersal potential depend on wind speed and temperature. According to González-Mas et al., (2019) state the impact of the abiotic factor (temperature, humidity, and UV-B radiation) on the spread of RPW. Besides that, Hussain et al. (2013); Azmi et al. (2017) have demonstrated that the types of soil and landscape are factors that can affect the population of RPW. However, the influence of other landscape features is disregarded, such as elevation, distance from the water bodies, and road. The spatio-temporal variations of biotic (e.g., microorganism interaction) and abiotic (e.g., soil, air temperature) factors that could be associated with the geographical dynamic of the disease might be different within and between regions. Existing models tend to be weighted towards climatic variables, underrepresenting the influence of other geographical factors that influence to disease occurrence.

Several studies have been conducted in other countries to model and predict the occurrence of RPW. For example, a recent study, Manzoor et al., (2020) applied simple linear regression to identify the relationship between environmental factors (climate) and the population fluctuation of RPW throughout the year in Sindh Province of Pakistan. Next, Kurdi et al., (2021) applied data mining algorithm from Naive Bayes (NB), KSTAR, AdaBoost, bagging, PART, J48 Decision tree, multilayer perceptron (MLP), support vector machine (SVM), random forest, and logistic regression to predict RPW infestation in its-early stages on palm tree at Riyadh, Saudi Arabia. Besides that, Farquad, (2018) applied machine learning algorithm to predict and early detection for RPW occurrence in Saudi Arabia. Emmert and Dehmer, (2019) applied generalised linear models to study the relationship between weevil captures and aggregation pheromone trials. Ju and Ajlan (2011) applied climatic mapping system, CLIMEX to predict the potential distribution of RPW in China. The sensitivity of the model, however, it is arguable because some species may be more sensitive to certain climatic factors, hence generic parameter-fitting in the model has a large impact (see Taylor and Kumar, 2012).

In Malaysia, numerous studies have been conducted to overcome the population of RPW. Azmi et al., (2017) demonstrated solutions to manage RPW by using biological prevention. (Wai et al., (2015); Yusuf et al., (2018) indicate method to overcome by using pheromone traps. Hazlina et al., (2015); Jalinas, (2019) and Lee et al., (2017) understand the pest morphology and study potential insect use as bio-insecticides to combat the pest. Hou et al., (2018) indicate ways to overcome the population of RPW by using microbial pathogen. Karh et al., (2019) illustrate the use of antifeedant activity of three eugenols based- compound as potential control agents to overcome population of RPW. Ahmad, (2020) study the efficiency sentinel data to detect coconut stress as an indicator of RPW attacks.

1.3 Aim and Objectives of the Study

The study aims to establish a spatial model using climate and to investigate variables to predict the number of RPW per site. This study develops a model to predict the occurrence of Red Palm Weevil in coconut plantation.

1. To examine temporal factors of RPW population.
2. To develop a model that can predict the incidence of RPW on a coconut plantation based on significant environmental variables.
3. To validate the model that has been developed in objective number two.
4. To produce a susceptibility map of the RPW population.

1.3.1 Research Questions

Objective 1

i. Are there any variations in the population of RPW between those three years?
ii. Do the variables that affect the RPW population vary among investigated years?

Objective 2

i. How can the environmental factors that will have impact on RPW occurrence be identified?
ii. Which factor will have a significant influence on RPW occurrence in Mersing?

Objective 3

i. How can the accuracy of the developed model be validated?
ii. To what extent can the accuracy of the developed model predict the RPW occurrence?

Objective 4

i. How can the prediction of RPW incidence be mapped?
ii. Where is the location predicted with a high population of RPW?

1.4 Significance of the Study

The study assists the stakeholders, including Plant Biosecurity Division and Agricultural Districts (Department of Agriculture), Integration Research and Extension Division (Malaysian Palm Oil Board), Federal Land Development (FELDA) and Federal Land Consolidation and Rehabilitation (FELCRA), in making an informed decision in combating coconut plantation from the invasive of Red Palm Weevil. By knowing the significant environmental factors, including landscape characteristics that cause the occurrence of RPW incidence, the early stages in preventing the pest epidemic could be taken before more suffering loss and damage occur. Researchers and stakeholders can now forecast which regions will be infested in the future using the susceptibility map generated in this study.

1.5 Scope of the Study

The scope of this study is described according to specific subsection as below:

i. Study area
ii. Data

1.5.1 Study Area

The study area is coconut plantations in Mersing, Johor where the total area is approximately 116.52 $km^{2.}$ Mersing is a part of Johor state, having a total area of 19102 km^2. The capital city of Mersing is Bandar Mersing, located at 2˚25’44.49”N and 103˚50’21.80”E. Mersing town is a particularly significant town situated in the eastern half of Johor state. It lies on the main trunk road that connects southern and eastern Johor with the east coast of Pahang, including Kuantan. According to Abdullahi et al., (2019) Mersing district varies in average elevation from 0 to 99.06 meters above sea level. Also, variations in the temperature and rainfall are high on average, with annual mean of 24°C – 32°C and 2828 mm/year rainfall.

Mersing is a town in Johor, Malaysia. It remains as a fishing village despite the developing city centre of Johor Bahru. It is the main departure spot for many islands, such as Rawa Island, Dayang Island, Aur Island, Pemanggil Island. It acts as the main port of departure to multiple islands in the South China Sea. Mersing is popular as a tourist spot since the location is near to the open sea. Also, plenty of coconut trees are planted here. Figure 1.1 shows the study area.

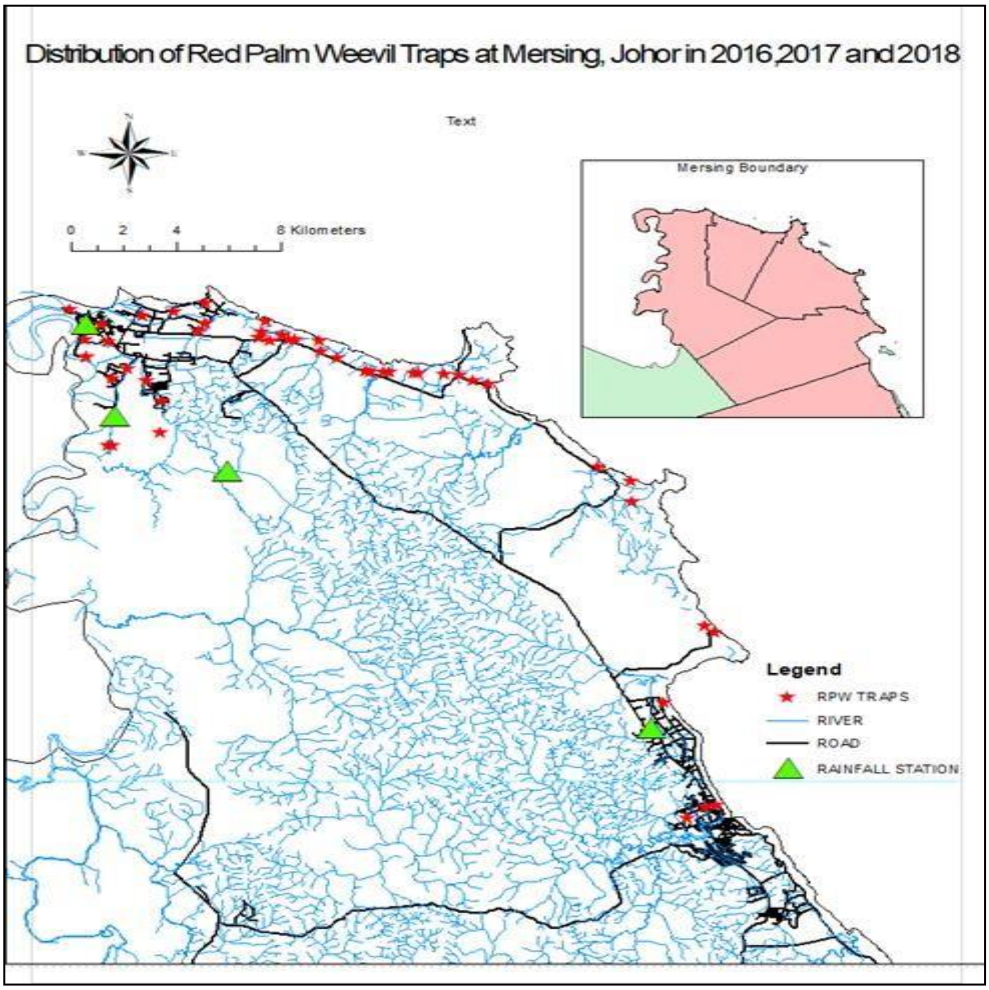

Figure 1.1 The boundary of study area

1.5.2 Data

The pest data used in this study were obtained from the Plant Biosecurity Division of Johor and data of RPW occurrence reports were collected by Plant Biosecurity of Johor. Data were within three years ranged from 2016 to 2018. Records of the RPW were taken from December 2016 to April 2018. According to the News (2018), there a few of districts in Johor infected by RPW such as Kulai, Batu Pahat, Mersing, Johor Bahru, Pontian, Muar, and Kota Tinggi. However, this study only focuses on Mersing district due to the high rate of RPW infestation compared to other districts.

Based on the records, there are about 51 places in Mersing infested by RPW. The location or trees to install the traps to track RPW distribution were decided by DOA. From the data set, Mukim Teriang, Mukim Padang Endau and Mukim Penyabong were infested by RPW. The environmental factors evaluated were limited to climate factors (temperature, humidity, rainfall, wind speed, and wind direction). The data was provided by authorised agencies. This study also uses elevation, and distance of pheromone traps to rivers and roads. A pheromone is a communication tool in the form of chemical used by insects and other animals to communicate to each other. According to Ni et al., (2019) and Massoud et al., (2011) pheromone trap is a trap that used pheromone to lure insects. Three years (2016 – 2018) weather related data were used, while elevation, road and river map features were collected in year 2017 because data is mostly from year 2017.

Geostatistical analysis, namely Kernel Density and generalized linear model, were applied in the analysis. To generate hot spot map of RPW distribution in Mersing, Kernel Density Estimation in ArcGIS 10.3 was used. For model to predict number of RPW per site according to environmental variable, Generalized Linear Model in SPSS 22 was used. Lastly, Weighted Overlay Analysis (crisp method) was used to generate susceptibility map.

1.6 Thesis Structure

The structure of the thesis is as below.

Chapter 1

This chapter illustrated in detail the introduction of the study, problem statement, objectives and aim of the study, the significance of the study and scope of the study including study area and data used.

Chapter 2

This chapter provides a detailed introduction of the literature review of coconut and environmental variables that impact the occurrence of RPW globally. It also presents the technologies and methods used to overcome the pests.

Chapter 3

This chapter provides the methodology to develop the predictive modelling to predict RPW occurrence. This chapter presents a research methodology from data collection, develops a predictive model by using Poisson regression, validates the model using RMSE and MSE and produces a suitability map.

Chapter 4

This chapter presents the result and discussion of the findings. This chapter presents the pattern of RPW distribution in Mersing, the significant environmental variables, the model using Poisson regression and demonstrated susceptibility map on the occurrence of RPW.

Chapter 5

This chapter sums up the findings according to each objective. This chapter presents the recommendations.

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