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WEATHER-BASED FORECASTING MODEL FOR THE PRESENCE OF BAGWORM (Metisa plana Walker) IN OIL PALM PLANTATION USING REGRESSION ANALYSIS AND ARTIFICIAL NEURAL NETWORK

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Metisa plana is one of the top leaf-eating insect pests in oil palm plantation. A moderate level of infestation could significantly reduce yield for over two years and causes a severe economic loss to the industry. The devastating losses that *Metisa plana* bring about is one of the reasons the execution of control method should be properly planned. Most of the conventional control method does not associate *Metisa plana* with weather parameters. Therefore, it is important to elucidate the relationship between these two prior to development of an early warning system so that the pest can be controlled efficiently. Hence, the objectives of this study were i) to examine the population density of bagworm under field condition and weather parameters, ii) to investigate the most dominant weather parameters at different time-lags that influence changes in bagworm population density, and iii) to develop a prediction model for bagworm population density by using regression models and artificial neural network (ANN). This study was conducted in Estate Sungai Mengah owned by Tabung Haji Plantation located in Muadzam Shah, Pahang from July 2016 to June 2017. Two fields were selected: Block 16 and Block 21, and these fields have severe and mild bagworm infestations, respectively. Bagworm censuses were done by identifying *Metisa plana*'s larval stage 1 (L1) to 7 (L7) from 13 random palms by cutting off frond number 17. The larval stages were then recorded and summed up biweekly. A Davis Vantage Pro 2 weather station was installed in each block to acquire weather data i.e., temperature, rainfall, relative humidity, solar radiation, wind speed, wind direction and heat index. The weather data were then averaged or summed up biweekly to produce mean temperature (MT), total rainfall (RF), mean relative humidity (RH), mean solar radiation (SR), mean wind speed (WS), and mean heat index (HI). The time-lags used in the analysis consisted of lag two weeks (T2), four weeks (T4), six weeks (T6), eight weeks (T8), ten weeks (T10) and twelve weeks (T12). The relationship between bagworm and weather parameters were analysed using Shapiro-Wilk's test, Spearman's Rank correlation, multiple linear regression

(MLR) and ANN. For the ANN, two models were developed particularly i.e., ANN based on correlation analysis and feature selection. The results showed that bagworm population in Block 16 was higher because the field was significantly hotter, less humid and received more solar radiation than Block 21. Bagworms were negatively correlated with mean temperature, mean heat index, and mean wind speed while positively correlated with total rainfall and mean relative humidity. Most of the interactions between bagworm and weather parameters occurred frequently at time-lag 2 weeks in Block 16 and time-lag 12 weeks in Block 21. The results showed that highest R^2 values were obtained through ANN-Correlation ranging from 0.329 to 0.989, followed by ANN-Feature selection ranging from 0.266 to 0.995, and multiple linear regression ranging from 0.000 to 0.798. The best models were obtained through ANN-Correlation method i.e., for L1 larval stages utilizing mean temperature, mean relative humidity, mean wind speed, and mean heat index at time-lag 2 and 4, mean temperature, mean relative humidity, and mean heat index at time-lag 6, and mean solar radiation at time-lag 12 with 99.58% accuracy. This was followed by the L2 larval stage model utilizing mean temperature, total rainfall, mean relative humidity, mean wind speed, and mean heat index at time-lag 2, mean temperature, mean wind speed, and mean heat index at time-lag 4, mean temperature, total rainfall, mean wind speed and mean heat index at time-lag 6, and mean solar radiation at both time-lag 8 and 12 with 99.91% accuracy. A query performed using both models suggested that the favourable weather condition for *Metisa plana* under field condition was 20 to 24°C mean temperature, 15 to 20 mean heat index and 138 to 210 Wm^{-2} mean solar radiation. Prediction of *Metisa plana's* L1 and L2 larval stages could be achieved with high accuracy using ANN by incorporating weather parameters and time-lag analysis.

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

MODEL RAMALAN BERDASARKAN CUACA BAGI KEHADIRAN ULAT BUNGKUS (*Metisa plana* Walker) DI LADANG KELAPA SAWIT MENGGUNAKAN ANALISIS REGRESSI DAN RANGKAIAN KECERDASAN BUATAN

Oleh

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Metisa plana adalah salah satu serangga perosak pemakan daun yang utama di ladang kelapa sawit. Tahap serangan yang sederhana dapat mengurangkan hasil secara signifikan selama lebih dari dua tahun dan menyebabkan kerugian ekonomi yang teruk kepada industri. Kerugian dahsyat angkara *Metisa plana* adalah salah satu sebab pelaksanaan kaedah kawalan harus dirancang dengan betul. Sebilangan besar kaedah kawalan konvensional tidak mengaitkan *Metisa plana* dengan parameter cuaca. Oleh itu, adalah penting untuk menjelaskan hubungan antara kedua-duanya sebelum membangunkan sistem amaran awal agar perosak dapat dikawal dengan cekap. Oleh itu, objektif kajian ini adalah i) untuk mengkaji kepadatan populasi ulat bungkus di bawah keadaan ladang dan parameter cuaca, ii) untuk menyelidik parameter cuaca yang paling dominan pada jeda waktu yang berbeza yang mempengaruhi perubahan kepadatan populasi ulat bungkus, iii) untuk membangunkan model ramalan kepadatan populasi ulat bungkus dengan menggunakan model regresi dan rangkaian kecerdasan buatan (ANN). Kajian ini dilakukan di Ladang Sungai Mengah yang dimiliki oleh Tabung Haji Plantation yang terletak di Muadzam Shah, Pahang antara tahun 2016 dan 2017. Dua kawasan dipilih: Blok 16 dan Blok 21, dan masing-masing mengalami serangan ulat bungkus yang teruk dan ringan. Bancian ulat bungkus dilakukan dengan mengenal pasti peringkat larva *Metisa plana* 1 (L1) hingga 7 (L7) dari 13 pokok kelapa sawit secara rawak dengan memotong pelepah ke-17. Peringkat larva kemudian direkodkan dan dijumlahkan dua minggu sekali. Stesen cuaca Davis Vantage Pro 2 dipasang di setiap blok untuk memperoleh data cuaca iaitu purata suhu (MT), jumlah kelimpahan hujan (RF), purata kelembapan relatif (RH), purata sinaran suria (SR), purata kelajuan angin (WS), dan purata ukuran indeks haba (HI). Data cuaca kemudian dipuratakan atau dijumlahkan setiap dua minggu. Jeda waktu yang digunakan dalam analisis terdiri dari jeda dua minggu (T2), empat minggu (T4),

enam minggu (T6), lapan minggu (T8), sepuluh minggu (T10) dan dua belas minggu (T12). Hubungan antara ulat bungkus dan parameter cuaca dianalisis menggunakan ujian Shapiro-Wilk, korelasi susun taraf Spearman, regresi linear berganda (MLR) dan ANN. Dua model ANN dibangunkan terutamanya iaitu ANN berdasarkan analisis korelasi dan pemilihan ciri. Keputusan kajian menunjukkan bahawa populasi ulat bungkus di Blok 16 lebih tinggi kerana kawasan tersebut secara signifikan lebih panas, kurang lembap dan menerima lebih banyak sinaran suria daripada Blok 21. Ulat bungkus berkorelasi negatif dengan purata suhu, purata ukuran indeks haba, dan purata kelajuan angin, sebaliknya berkorelasi positif dengan jumlah kelimpahan hujan dan purata kelembapan relatif. Sebilangan besar interaksi antara ulat bungkus dan parameter cuaca sering berlaku pada jeda dua minggu di Blok 16 dan jeda dua belas minggu di Blok 21. Keputusan menunjukkan bahwa nilai R^2 tertinggi diperoleh melalui ANN-Korelasi bermula dari 0.329 hingga 0.989, diikuti oleh ANN-Pemilihan ciri bermula dari 0.266 hingga 0.995, dan regresi linear berganda antara 0.000 hingga 0.798. Model terbaik diperoleh melalui kaedah ANN-Korelasi iaitu untuk peringkat L1 yang menggunakan purata suhu, purata kelembapan relatif, purata kelajuan angin dan purata ukuran indeks haba pada jeda dua dan empat minggu, purata suhu, purata kelembapan relatif, dan purata ukuran indeks haba pada jeda enam minggu, dan purata sinaran suria pada jeda dua belas minggu, dengan ketepatan 99.58%. Model kedua adalah untuk peringkat L2 yang menggunakan purata suhu, jumlah kelimpahan hujan, purata kelembapan relatif, purata kelajuan angin, dan purata ukuran indeks haba pada jeda dua minggu, purata suhu, purata kelajuan angin, dan purata ukuran indeks haba pada jeda empat minggu, purata suhu, jumlah kelimpahan hujan, purata kelajuan angin, dan purata ukuran indeks haba pada jeda enam minggu, dan purata sinaran suria pada jeda lapan dan dua belas minggu masing-masing dengan ketepatan 99.91%. Analisis kepekaan yang dilakukan menggunakan kedua-dua model menunjukkan bahawa keadaan cuaca yang sesuai untuk *Metisa plana* ialah ketika keadaan ladang memiliki purata suhu 20 hingga 24 °C, 15 hingga 20 purata ukuran indeks haba dan 138 hingga 210 Wm^{-2} purata sinaran suria. Ramalan peringkat *Metisa plana* L1 dan L2 dapat dicapai dengan ketepatan yang tinggi menggunakan ANN dengan memasukkan parameter cuaca dan analisis jeda waktu.

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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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LIST OF ABBREVIATIONS

MPOB	Malaysian Palm Oil Board
HI	Heat Index
THI	Temperature-Humidity Index
AIPL	Animal Improvement Programs Laboratory
USDA	United States Department of Agriculture
T_{min}	Lower Threshold Temperature
T_{max}	Upper Threshold Temperature
T_{opt}	Optimum Temperature Threshold
ANN	Artificial Neural Networks
MLP	Multilayer Perceptron
DBM	Diamond Back Moth
PCA	Principal Components Analysis
BP	Back Propagation
GA	Genetic Algorithm
MIFS	Mutual Information Feature Selection
MRMR	Max-Relevance Min-Redundancy
SFS	Sequential Forward Selection
NB	Naïve Bayes
SVM	Support Vector Machine
KNN	K-Nearest Neighbor
LST	Land Surface Temperature
EVI	Enhanced Vegetation Index
Eta	Evapotranspiration
WNV	West Nile Virus

BI	Breteau Index
L1	First Larval Stage
L2	Second Larval Stage
L3	Third Larval Stage
L4	Fourth Larval Stage
L5	Fifth Larval Stage
L6	Sixth Larval Stage
L7	Seventh Larval Stage
UV	Ultraviolet
USB	Universal Serial Bus
MT	Mean Temperature
RF	Total Rainfall
RH	Mean Relative Humidity
MS	Mean Solar Radiation
WS	Mean Wind Speed
R	Coefficient of Correlation
R^2	Coefficient of Determination
SLR	Single Linear Regression
MLR	Multiple Linear Regression
RMSE	Root Mean Square Error
BPH	Brown Planthopper

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is well known for its production of palm oil. The tree, *Elaeis guineensis* is planted vastly in Malaysia. The oil derived from the fruits has many beneficial uses such as cosmetics, animal feed, and food products. Recently, palm oil has been chosen as the alternative fuel or biofuel due to the scarcity of petroleum (Mahmud & Cho, 2018). Palm oil is also healthy for human's consumption as demonstrated by (Absalome et al., 2020) where with palm oil-rich diets, thrombosis and atherosclerosis risk factors could be reduced. In 2013, the demand for edible oil has increased due to growing number of population and high world oil consumption that is about 52.1 million tons. To meet the demand, good agronomic practices especially pest and disease managements are important in oil palm industry as it is the foremost cause of reduction in crop yield.

Many pests found in oil palm plantations have become adapted to *Elaeis guineensis.* Most of the pests are defoliators that feed on leaves of oil palm. A wide attack of defoliators could cause a yield decline and the damage done could take several years for the palm to achieve full recovery. The major defoliators that have been considered important in oil palm plantation in Malaysia are rhinoceros beetles (*Oryctes rhinoceros*), nettle and slug caterpillars of family Limacodidae, and bagworm of family Psychidae. The adult *Oryctes* cut through leaves and bore holes into oil palm crown. According to Sulaiman et al. (2020), 50% defoliation by this pest could reduce yield by 12%. On the other hand, a 50% damage done on the upper crown by *Setora nitens* of Limacodidae family during its larval stage could cause a crop loss of over 40%. Kamarudin et al. (2019) mentioned that different species defoliate different parts of the crown. Of the Psychidae bagworm that are commonly found in oil palm plantation, three species are destructive: *Mahasena corbetti, Pteroma pendula* and *Metisa plana*. According to Halim et al. (2017), *Metisa plana* is the most dominant and dangerous species of bagworm. Its destructive larval stage is the main reason *Metisa plana* earns its reputation as one of the dangerous pests of oil palm. A 50% damaged by this pest will cause yield decline in the next two years of around 43% (Halim et al., 2017; Kamarudin et al., 2019; Ooi & Kamarudin, 2018). *Metisa plana* tops the other major oil palm defoliators given its the ability to reduce more yields with less infestation. This is a pest that needs to be taken seriously to lessen the reduction in crop yield and economic loss, and at the same time preventing widespread of it.

1.2 Problem Statement

Infestation by *Metisa plana,* if left untreated, can greatly affect the oil palm industry. The photosynthetic ability of the palms will be compromised due to the damage caused by *Metisa plana.* This will eventually translate into loss of crop yield. Priwiratama et al. (2019) stated that the yield of oil palm could be reduced up to 40% with a low level of damage of 10%. In addition, Kamarudin et al. (2019) also stated that 50% infestation by bagworm could cause the yield to decline about 30 to 40% for over 2 years. Assuming only 10% of oil palm area are infested by bagworm, with the recent price and yield statistics, oil palm sector will suffer a great loss per hectare annually.

The devastating losses that could be brought by *Metisa plana* is one of the reasons that the execution of mitigation system should be properly planned. However, the challenges arise in the mitigation systems' efficiency in terms of cost, time, and manpower, as well as sustainability. To overcome the challenges, ecological knowledge of *Metisa plana* should be well understood. Hence, the influence of ecological factors such as weather on the life cycle of bagworm must be studied (Mahadi et al., 2012).

The current conventional control practices are heavily dependent on in-situ data collection, which is destructive, less efficient, laborious, and costly (Ruslan et al., 2019). Therefore, it is wise to fully utilise the state of the art of technological advancement that could benefit the industry. Technological approaches that promote rapid, harmless, and cost-effectiveness such as automatic weather stations are necessary to overcome the challenges faced by the industry. Additionally, recently, many studies have incorporated machine learning analysis such as artificial neural network (ANN) in agricultural fields (Abiodun et al., 2019), especially in the development of pest prediction model.

To overcome the limitation of the conventional methods in controlling *Metisa plana,* this study attempted to develop a weather-based pest prediction model to facilitate the oil palm estate's operation via statistical analysis and ANN. The exploitation of these modern technologies could provide an efficient mitigation plan that could reduce cost, environmental pollution and improve sustainability.

1.3 Justification

Weather plays an important role in crop growth as well as development of pest and diseases. The pest remains active throughout the life cycle and has been observed feeding on oil palm foliage. The incidence and spread of bagworm are largely influenced by weather conditions. Hence, it is pertinent to assess the relative importance of weather variables in bagworm population dynamics due to the lack of information in bagworm in relation to weather condition. In addition, the current census practice is not able to forewarn and predict the possible bagworm outbreak in the future. Hence, there is a need for reliable and well-timed forecasts for bagworm outbreak utilizing both statistical analysis and ANN to appropriately plan for mitigation actions. A suitable control measure should be taken timely to efficiently suppress bagworms presence during their vulnerable stages and subsequently reduce economical loss brought upon by them.

1.4 General Objective

The overall objective of this study is to develop bagworm population model that can predict bagworm population density in oil palm plantation using weather parameters, regression models and artificial neural networks.

1.4.1 Specific Objectives

The specific objectives of this study are:

i. To examine the population density of bagworm under field condition and weather parameters.
ii. To determine the dominant weather parameters that influence changes in bagworm population density.
iii. To develop a prediction model for bagworm population density by using regression models and artificial neural network (ANN).

1.5 Organization of Thesis

The thesis comprised 6 chapters and outlined as follows:

Chapter 1 describes the general overview of the risk of *Metisa plana* infestation in oil palm industry. The problem statement, justification and research objectives are included in this chapter.

Chapter 2 reviews the literature on history of oil palm's insect pest. This chapter also encompasses the comprehensive reviews on *Metisa plana* as pest and the abiotic factors that might influence insect's population in general. The method of developing prediction models was also included followed by the literature of Artificial Neural Network, feature selection, and time-lag analysis.

Chapter 3 describes the general description of the study area, bagworm census and weather data collection. The details data analysis on how to achieve the research's objectives is also elaborated in this chapter.

Chapter 4 presents the results obtained and provides information on the interaction between *Metisa plana* and weather parameters along with the sensitivity analysis to provide information regarding their relationships. The performances of each model are also presented in this chapter.

Chapter 5 provides the findings on how the abiotic factors affected *Metisa plana*'s population. This chapter also discusses the relevancy of time-lag analysis and compares the differences between regression analysis and ANN.

Chapter 6 summarizes the findings obtained from the study and the recommendations for future work regarding bagworm prediction model.

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