DEVELOPMENT OF GEOSPATIAL MODEL FOR** Metisa plana **(WALKER) OUTBREAK AND OUTBREAK PREDICTION IN OIL PALM PLANTATIONS IN MALAYSIA

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By

SITI AISYAH BINTI RUSLAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

To

The beloved people in my life

For the sacrifices, support, and strength

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

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November 2018

Chairman : Associate Professor Farrah Melissa Muharam, PhD
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Metisa plana (Walker) is a leaves defoliating insect that is able to cause complete skeletonization and death of the oil palm's fronds. This insect can cause a loss of USD 2.32 billion for two consecutive years given only 10% of the 5 million hectares of oil palms being infested. Hence, efficient, rigorous control methods should be properly planned. In order to do this, the role of environmental factors on the pests' population's fluctuations should be well understood. Nonetheless, the current practices are still leaning towards the conventional approaches that are highly dependent on ineffective, time-consuming in-situ data collection. On the other hand, the utilization of geospatial technologies can be used to obtain data in rapid, harmless, and cost-effective manners. This study utilized the geospatial technologies to i) examine spatial and temporal climatic stresses that cause the outbreak of *Metisa plana*, ii) to construct the relationship between the geospatial data and *Metisa plana* outbreak, and iii) to predict the outbreak of *Metisa plana* in oil palm plantation. *Metisa plana* census data of larvae instar 1, 2, 3, and 4 were collected approximately biweekly over the period of 2014 and 2015. Moderate Resolution Imaging Spectroradiometer (MODIS) and The Tropical Rainfall Measuring Mission (TRMM) satellite images providing values of land surface temperature (LST), rainfall (RF), relative humidity (RH), and Normalized Difference Vegetation Index (NDVI) were extracted and apportioned to 6 time lags; 1 week (T1), 2 weeks (T2), 3 week (T3), 4 weeks (T4), 5 week (T5) and 6 weeks (T6). Linear relationship between *Metisa plana* with LST, RF, RH, and NDVI were carried out using the Pearson's correlation, multiple linear regression (MLR) and multiple polynomial regression analysis (MPR). Artificial neural network (ANN) was then used to develop the best prediction model of *Metisa plana*'s outbreak. Presence of *Metisa plana* was influenced by LST, RF and RH, but not *NDVI*. The LST between 24^{o}C and 28^{o}C showed a strong relationship with *Metisa plana*, whereby its presence started to decline with LST from 28^{o}C and above. However, the effect of time lag on the presence of *Metisa plana* was not prominent. The best MLR model was obtained with LST, RF and RH at T4 to T6 with an adjusted R^2 = 0.29. The MPR model of LST at T4 to T6 depicted the best fit line with an adjusted R^2 = 0.50. The highest accuracy of 95.29% was achieved by models generated by ANN utilizing the relative humidity at T1 to T3. The model generated by combined variables, LST, RF and RH at T4 to T6 was able to predict the presence of *Metisa plana* with the accuracy by up to 89.95%. Based on the result of this study, the elucidation of *Metisa plana*'s landscape ecology was possible with the utilization of geospatial technology.

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

PEMBANGUNAN MODEL GEOSPASIAL BAGI LETUSAN *Metisa plana* (WALKER) DAN RAMALAN LETUSANNYA DI PERLADANGAN KELAPA SAWIT MALAYSIA

Oleh

SITI AISYAH BINTI RUSLAN

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Metisa plana (Walker) ialah serangga pemakan daun sawit yang berupaya menyumbang kepada kerosakan dan kematian pelepah sawit. Dengan hanya kerosakan minimum sebanyak 10% selama 2 tahun berturut-turut, hasil tanaman daripada 5 juta hektar kawasan lading sawit boleh berkurang sehingga 2.32 bilion USD. Oleh itu, kaedah pengawalan yang efisien bagi menghalang infestasi serangga perosak ini adalah amat penting untuk dirancang. Justeru, kefahaman dan pengetahuan yang mendalam terhadap kesan faktor persekitaran terhadap populasi *Metisa plana* adalah penting. Walau bagaimanapun, pada masa kini, teknik pengumpulan maklumat masih lagi bergantung kepada teknik konservatif yang kurang efisien di mana ianya dilakukan secara *in-situ.* Penggunaan teknologi geospasial mampu untuk membantu pengumpulan maklumat dengan lebih pantas, selamat kepada alam sekitar, dan lebih menjimatkan. Oleh yang demikian, kajian ini memfokuskan kepada penggunaan teknologi geospasial bagi i) mengkaji faktor iklim yang mempengaruhi penularan populasi dan infestasi *Metisa plana* dari segi masa dan spasial, ii) membina hubung kait di antara data geospasial dan infestasi *Metisa plana*, dan iii) meramal infestasi *Metisa plana* di ladang kelapa sawit. Bancian terhadap bilangan larva *Metisa plana* peringkat satu, dua, tiga, dan empat telah dilakukan pada setiap dua minggu dalam tempoh 2014 dan 2015. Data nilai suhu permukaan (LST), kadar hujan (RF), kelembapan relatif (RH), dan index perbezaan normaliti tumbuhan (NDVI) telah diekstrak daripada imej satelit Moderate Resolution Imaging Spectroradiometer (MODIS) dan The Tropical Rainfall Measuring Mission (TRMM). Data-data yang telah diekstrak daripada imej satelit yang dinyatakan telah dibahagikan kepada enam lag masa iaitu satu sehingga enam minggu sebelum tarikh bancian; satu minggu (T1), dua minggu (T2), tiga minggu (T3), empat minggu (T4), lima minggu (T5), dan enam minggu (T6) bagi tujuan analisa. Analisa korelasi Pearson, regrasi linear berganda (MLR), dan regrasi polynomial berganda (MPR) diantara setiap tarikh bancian dengan 6 lag masa telah digunakan untuk mencari hubungan di antara data geospasial dan

infestasi *Metisa plana*. Setelah itu, rangkaian neural buatan (ANN) telah digunakan untuk menghasikan model yang terbaik bagi meramal infestasi populasi *Metisa plana*. Hasil kajian telah menunjukkan bahawa terdapat hubungan yang signifikan di antara infestasi Metisa plana dengan LST, RF, dan RH, tetapi tidak dengan NDVI. LST di antara 24^{o}C hingga 28^{o}C mempunyai hubungan signifikan yang kuat dengan infestasi *Metisa plana* di mana infestasi *Metisa plana* menurun apabila LST melebihi 28^{o}C. Selain itu, corak lag masa yang tidak konsisten dapat dilihat pada korelasi di antara LST, RF, dan RH dengan *Metisa plana*. Model terbaik telah dihasilkan daripada gabungan LST, RF, dan RH melalui analisa MLR pada T4 hingga T6 dengan R^2 terubah suai = 0.29. Model terbaik daripada MPR menunjukkan LST bagi T4 hingga T6 memberikan garisan fit yang terbaik iaitu pada R^2 terubah suai = 0.5. Model yang dijana oleh ANN menggunakan data kelembapan relatif memberikan ketepatan yang tertinggi iaitu sebanyak 95.29% pada T1 hingga T3. Manakala model yang dijana melalui kombinasi LST, RF, dan RH pada T4 hingga T6 telah memberikan ketepatan sebanyak 89.95%. Hasil kajian ini juga berjaya membuktikan bahawa penggunaan teknologi geospasial mampu meramal infestasi *Metisa plana*.

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I certify that a Thesis Examination Committee has met on 5 November 2018 to conduct the final examination of Siti Aisyah binti Ruslan on her thesis entitled "Development of Geospatial Model for *Metisa plana* (Walker) Outbreak and Outbreak Prediction in Oil Palm Plantations in Malaysia " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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ANN	Artificial neural network
AWM	Area weighted mean
BBP	Batch back propagation
BP	Back propagation
BSLRC	Broad-spectrum long-residual contact
CGD	Conjugate gradient descent
CMORPH	Climate Prediction Centre morphing method
DAAC	Distributed Active Archive Centre
DBI	David-Bouldin Index
DBM	Diamond backmoth
DD	Degree days
DEM	Digital elevation model
DN	Digital number
ETa	Actual evapotranspiration
ETM+	Enhanced thematic mapper
EVI	Enhanced vegetation index
FFB	Fresh fruit bunch
GES DISC	Goddard Earth Sciences Data and Information Services Center
GIS	Geographic information system
GNI	Gross national income
GPCP-1DD	Global Precipitation Climatology Project 1 Degree Daily
GPS	Global positioning system
ha	Hectare

IPM	Integrated pest management
K	Kelvin
km	Kilometer
LAADS	Level-1 Atmospheric Archive & Distribution System
Landsat TM	Landsat thematic mapper
LM	Levenberg-marquardt
LMQN	Limited memory quasi-newton
LST	Land surface temperature
m	Meter
MAE	Mean Absolute Error
MCI	Moisture condition index
MD	Mean Difference
MLP	Multi-layer perceptron
MLR	Multiple linear regression
mm	Millimetre
MODIS	Moderate Resolution Imaging Spectroradiometer
MPB	Mountain pine beetle
MPR	Multiple polynomial regression
MSE	Mean squared error
MSG	Meteosat second generation
NDIIb6	Normalized difference infrared index band 6
NDIIb7	Normalized difference infrared index band 7
NDMI	Normalized difference moisture index
NDVI	Normalized vegetation index
NDWI	Normalized difference water index

NetCDF4	Network common data form
NIR	Near infrared
NOAA	National Oceanic and Atmospheric Administration
OBP	Online back propagation
^{o}C	Celsius
p	Calculated probability
PERSIANN-CDR	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks Climate Data Record
QN	Quasi- newton
QP	Quick propagation
R	Red
r	Correlation coefficient
R^2	Coefficient of determination
RF	Rainfall
RH	Relative humidity
RMSE	Root Mean Square Error
SARIMA	Seasonal autoregressive integrated moving average
SD	Standart Deviation
SPOT	Satellites Pour l'Observation de la Terre or Earth-observing Satellites
SRTM	Shuttle radar topography mission
SWIR	Short-wavelength infrared
TCI	Temperature condition index
TRMM	The Tropical Rainfall Measuring Mission
USGS	United States Geological Survey

CHAPTER 1

INTRODUCTION

1.1 Study background

The worldwide consumption of palm oil soared from 14.6 million tonnes in 1995 to 61.1 million tonnes in 2015, making it the most consumed oil in the world (European Palm Oil Alliance, 2016). Malaysia ranks second among the largest palm oil global exporter after the neighbouring country Indonesia, supplying by up to 32.6 % of the world's total palm oil exports, which can be translated to approximately USD 9 billion in 2016 (Workman, 2017). Palm oil is also the fourth largest contributor to the national economy, accounting RM 52.7 billion of the Gross National Income (GNI) and is projected to raise to up to RM 178 billion worth of GNI in 2020 (Pemandu.gov.my, 2014). The global dependence of palm oil will continue to rise and its demand is expected to increase to an additional 25 million tonnes per year in the forthcoming 10 years. Consequently, in order to satiate the demand, the production of palm oil will have to be amplified to 85 million tonnes a year (Mielke, 2017). On that account, it is important for diligent efforts and good agriculture practices to take place in order to increase the productivity of oil palm and consequently to achieve the desired yield production. These however, can be compromised by the presence of insect pests such as bagworm.

Bagworm (*Lepidoptera: Psychidae*) is an important defoliating caterpillar that relies on crop leaves as their source of nutrients and shelter. In order to survive, bagworm larvae use 68% of the leaf tissues removed from oil palm for growth and development while the other 32% to construct portable outer cases which act as shelter that they carry around with them as they feed (Basri *et al.*, 1995; Kok *et al.*, 2011). In Malaysia, the most economically devastating species of bagworms for oil palm plantations are *Metisa plana* (Walker), *Pteroma pendula* (Joannis), and *Mahasena corbetti* (Tams). Among these species, *Metisa plana* have caused the most detrimental effect in Peninsular Malaysia, judging by the magnitude of its infestations and damages (Basri *et al.*, 1988) that is resulting from efficient dispersion mechanisms that lead to high reproductive success (Tuck *et al.*, 2011).

1.2 Problem statement

Untreated infestation of *Metisa plana* can lead to a devastating losses in oil palm industry mainly due to the potential of causing a complete skeletonization and an eventual death of oil palm fronds. This will jeopardize the ability of palms to carry out photosynthetic activities that will suppress the growth of the palms and reduce the efficiency of palms to produce optimum yield. Wood *et al.* (1973) earlier captured the threatening nature of this pest by demonstrating that 50% of damage caused by its infestation will bring about 43% or approximately 10 t ha^{-1} of fresh fruit bunch (FFB) for the next two consecutive years. This was later supported by Basri (1993) which stated that even at a lower level of damage of 10% to 13%, the loss of yield of oil palm can go up to 40%. These figures can be translated into a loss of approximately USD 2,032 per hectare, which will eventually cause a loss of USD 2.32 billion for two consecutive years, given only 10% of the 5 million hectares of oil palms being infested.

Taking into account the high potential of severe economic losses that could be initiated by *Metisa plana*, rigorous control methods and mitigation systems should be properly planned and executed. Furthermore, the control methods must be efficient in terms of cost, time, and man power, as well as not harmful to oil palms and the environment. The success in doing so is to ensure that necessary steps are to be carried out at the precise times and locations. In order to achieve this, the ecological knowledge of *Metisa plana* especially spatial and temporal domain, should be well understood. Ecological aspects such as weather plays an important role in the lavishness of bagworm's outbreak owing to its adverse influence on insect's behaviour.

1.3 Justification

Currently, the effort of understanding weather aspects affecting the insect pest outbreaks, along with their control practices are still leaning towards the conventional approaches that are highly dependent on in-situ data collection which can be ineffective. The exploitation of modern technology such as geospatial technology have essentially benefited agricultural industry. This technology, which encompasses of remote sensing, global positioning system (GPS), and geographic information system (GIS) have been used in the assessment and monitoring of crop pests and diseases. Unlike the conventional approaches, information on the triggering factors of insect pest outbreaks such as temperature, rainfall, and vegetation's condition can be obtained through this technology in rapid, harmless, and cost-effective manners. Hence, early detection of insect pest outbreaks via geospatial technology can potentially (i) reduce labour time and cost, (ii) limit environmental pollution, and (iii) reduce the potential of a devastating impact of insect pest outbreaks by controlling them before they spread. Furthermore, the monitoring of crops condition within a large area of plantation could be done synchronously with the help of geospatial technology.

1.4 Objective

The overall objective of this study is to develop a model to predict the outbreak of *Metisa plana* in oil palm plantation.

1.4.1 Specific Objectives

The specific objectives of this study are:

i. To compare the spatio-temporal distribution of *Metisa plana*'s infestation and weather parameters in 2014 and 2015.

ii. To investigate the remotely-sensed derived factors that influence the outbreak of *Metisa plana* in oil palm plantation.

iii. To develop model that incorporates the combination of remotely-sensed derived factors influencing the outbreak of *Metisa plana*.

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