Development of geospatial model for predicting *Metisa plana*’s prevalence in Malaysian oil palm plantation

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Abstract. *Metisa plana* (Walker) is leaves defoliating insect that is able to cause a staggering loss of USD 2.32 billion within two years to Malaysian oil palm industry. Therefore, an early warning system to predict the outbreak of *Metisa plana* that is sustainable in terms of cost, time, and energy is crucial. Nonetheless, the current approaches of conventional practices are highly dependent on ineffective and time-consuming in-situ data collection. Geospatial technologies can be used to obtain data in rapid, harmless, and cost-effective manners. Hence, this study utilized the technologies such as land surface temperature (LST), rainfall (RF), relative humidity (RH), and Normalized Difference Vegetation Index (NDVI) to i) examine climatic stresses that cause the outbreak of *Metisa plana*, ii) to construct the relationship between geospatial data and *Metisa plana* outbreak, and iii) to predict the outbreak of *Metisa plana* in oil palm plantation. LST between 24°C and 28°C showed a strong relationship with the presence of *Metisa plana*. Consistent day pattern was absent in the correlation between LST, RF, RH with *Metisa plana*. Presence of *Metisa plana* was not correlated with NDVI. ANN prediction models with the highest accuracy of 95.42% was achieved by using RH data. Model generated by combined variables were Able to predict the presence of *Metisa plana* with the accuracy of 72.64%. In summary, the elucidation of *Metisa plana*’s landscape ecology is possible with the utilization of geospatial technology, and temperature has been found to be the most important factor that influence the presence of *Metisa plana*.

1. Introduction

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 [1]. 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 [2]. Untreated infestation of *Metisa plana* or bagworm can lead to a devastating loss in oil palm industry mainly due to the potential of causing a complete skeletonization and an eventual death of oil
palm fronds. 50% of damage caused of *Metisa plana’s* infestation will bring about 43% or approximately 10 t/ha of fresh fruit bunch (FFB) for the next two consecutive years [3]. This was later supported by Basri [4] 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 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.

Currently, the effort of understanding ecological aspects affecting the insect pest outbreaks, along with their control approaches are highly dependent on *in-situ* data collection which can be ineffective. The exploitation of modern technology’s advancement such as geospatial technology has essentially benefited agricultural industry where the information on the triggering factors of insect pest outbreaks such as temperature, rainfall, and vegetation’s condition can be obtained in rapid, harmless, and cost-effective manners. Furthermore, the ability to forecast the infestation of this pest will be able to reduce the potential of a devastating impact of *Metisa plana* by controlling them before they spread.

Hence, this study is conducted to investigate the remotely-sensed derived ecological factors that influence the outbreak of *Metisa plana* by using geospatial technology and to develop model that incorporates the combination of these factors in order to predict *Metisa plana* outbreak.

### 2. Research Methods

#### 2.1. Study location

The conduction of this study took place in oil palm Tabung Haji Plantation located at 2° 57’ 30” N, 102° 53’ 0” E to 3° 1’ 0” N, 102° 53’ 0” E in the state of Pahang, Malaysia. The study site is spread over an area of 2000 ha comprises of 26 blocks. The main cultivation of this area is oil palm crops ranging from 10 to 20 years old with bagworm’s infestation level ranging from zero to mild.

#### 2.2. Data collection and data processing

##### 2.2.1. Bagworm census

The census data were collected biweekly over the period of 2014 and 2015. For each cycle, 25 palms were chosen randomly. The census was done in a destructive manner through the cutting of the 17th frond. Bagworm larvae of instar 1, 2, 3, and 4 were collected, pooled and then averaged for each block.

##### 2.2.2. Geospatial data

Geospatial data used for this study comprised i) land surface temperature (°C) (LST), ii) rainfall (mm) (RF), iii) relative humidity (%) (RH), and iv) Normalized difference vegetation index (NDVI) for the period of 2014 and 2015. LST, RH and NDVI data were provided by Moderate Resolution Imaging Spectroradiometer (MODIS) sensor of TERRA satellite while RF was obtained from The Tropical Rainfall Measuring Mission (TRMM) satellite and all of the data were subjected to spatial projection of WGS 1984 UTM Zone 47 N.

For LST, the data used for this parameter were 8 days composite LST, MOD11A2 version 6. The digital numbers (DN) of the images were converted to reflectance values in K and subsequently to LST values in degree Celsius (°C) using equation (1). Next, all of the images were subset according to the study area.

\[
LST = [DN \times 0.02] - 273.15
\]  

Where LST is the land surface temperature, DN is digital numbers of the pixels of the image and 0.02 is the scaling factor of MODIS LST.

As for RF, the data used were TRMM_3B42Daily version 7. The images format was first converted from network common data form (NetCDF4) to raster before the. Later, 8 days composite
RF images were computed according to LST date by using mosaic tool in ArcGIS software before the images were subset according to the study area.

MODIS sensor data MOD13Q1 were obtained from earthexplorer website for NDVI of both 2014 and 2015. Data used were provided at every 16 days with 250 m of spatial resolution. All of the images were subjected to pre-processing methods in ArcGIS software version 10.3.1 (Esri Inc., USA). The spatial projections were set to WGS 1984 UTM Zone 47 N. Afterward, digital numbers of the images downloaded were converted to NDVI values by multiplying the images with the scale factor of 0.0001. Then, all of the images were subset according to the study area. NDVI formula is describes in equation (2).

\[
NDVI = \frac{(NIR - R)}{(NIR + R)}
\]  

(2)

Where NDVI is the Normalized difference vegetation index, NIR is the near infrared and R is the red wavelength.

Since there was no direct retrieval method of RH from satellite measurements, the computation of RH was done according to algorithm described and modified for Malaysia’s utilization by Peng [3]. Hence, in doing this, two sets of MODIS products, MOD07 and MOD021KM were used. Firstly, the required band layers were extracted from each image by using MODIS conversion toolkit, an extension in ENVI software version 5.2 (Exelis Visual Information Solutions Inc., USA). Surface air temperature layers were extracted from MOD07 product images, while layers of NIR bands were extracted from MOD021KM product images. The algorithm was applied to the layers to compute RH images. Then, all of the images were subset according to the study area.

2.3 Data extraction

Prior to data extraction, the uniformity of all parameters pixel layer sizes were set to 250 m through resampling tool in ArcGIS software. Area-weighted mean (AWM) for all of the images were then calculated for each block of the study area according to equation (3). Later, the extracted data were apportioned to datasets according to census cycle. Each dataset consist of a pairing of the average number of bagworm of each block for each census cycle with the area-weighted mean of LST, RF, and RH at 1 to 6 weeks prior to the census cycle dates (time lag T1, T2, T3, T4, T5, and T6).

\[
AWM = \frac{\sum \text{(pixel area within a block} \times \text{pixel values within a block)}}{\text{total area of each block}}
\]

(3)

2.4 Statistical analysis

Statistical analysis was conducted by using statistical analysis software SAS version 9.2 (SAS Institute Inc., USA). The correlation between average bagworm per block with area-weighted mean of LST, RF, RH, and NDVI of each block of time lag T1, T2, T3, T4, T5, and T6 was determined by Pearson’s correlation coefficient (r) analysis using PROC CORR.

2.5 Artificial neural network

Data were apportioned into datasets of week 1 to 3 prior to the census date and these datasets was used to predict the number of bagworm occurrence. Datasets containing missing values was excluded before these data were exported to Alyuda software.

Network trainings were performed by using 7 different training algorithms; i) Quick propagation, ii) conjugate gradient descent, iii) quasi- newton, iv) limited memory quasi-newton, v) levenberg-marquardt, vi) online back propagation, and vii) batch back propagation. However, only training algorithm that produced the best results was presented in this study.
3. Results and Discussion

3.1. Correlation analysis

Correlation analysis between abiotic factors and Metisa plana’s infestations’ illustrated that the time lag effect is not prominent (Figure 1 to 3). However, correlation analysis between number of bagworm and LST was able to determine the optimum temperature for the survivability of Metisa plana’s population in this study field that is between 24°C to 28°C. It can be concluded that the presence of Metisa plana was consistently negatively correlated with LST above 28°C, suggesting that the LST above this value would contribute to the decline of bagworm’s population in the field. This finding also reflects a linear relationship between Metisa plana’s development and survivability with temperature. This is parallel to the fact that temperature is the main factor influencing their growth, survival, productivity, and dispersal [5-9].

This study has also found that the relationships between RF and RH with the presence of Metisa plana were inconsistent; correlations analysis was not able to determine the optimum values of cumulative rainfall that favour Metisa plana’s population. This suggests that RF and RH possess a non-linear relationship with Metisa plana. This finding is in agreement with a study performed by Ho [10] where RF was found to be the additional mortality factor for all larval stages of bagworms. RH, on the other hand, has been associated with the increase of pathogens and fungi attack [11].

Among all of the abiotic parameters analysed, NDVI was the only parameter that was insignificantly related to the infestations of Metisa plana. The lowest NDVI value recorded was 0.46 while the highest was 0.86 with a consistent trend ranging from 0.70 to 0.80. Hence, it can be hypothesised that due to the constant trend of NDVI, there was no obvious relationship between NDVI and the presence of Metisa plana can be synthesised.

![Figure 1. Correlation analysis between LST (°C) and number of Metisa plana.](image-url)
Table 1 represents the prediction accuracies of models generated by abiotic factors using ANN. RH was found to be the best single variable predictor for Metisa plana’s outbreak since its models’ performances were better than the LST and RF. Subsequently, this finding could be accredited to the ability of RH to represent the interaction of both temperature and rainfall at the same time would justify its better performance as a single variable predictor for predicting Metisa plana’s outbreak compared to LST and RF on their own.
Apart from that, the highest accuracy of RH it could be due to the use of calibrated RH data specifically for Malaysian region. From the ANN model obtained, RH prediction model was utilized to predict the presence of bagworm of 1 to 3 weeks in the future. Since this study focused on the prediction of *Metisa plana*’s larvae of instar level one to four, one to three weeks prior to these stages marks the reproductive stages of *Metisa plana*. This is in alignment with the importance of RH in regulating the efficiency of insects’ reproduction. The optimum level of RH for eggs hatchability is crucial due to the need of lubrication and soft cuticle tissues for eggs to be successfully hatched [12].

LST was expected to be the best single variable predictor for *Metisa plana*’s outbreak. This however was not the case when models generated using this parameter was shown to produce fair accuracies, but not the best. Henceforth, this result would illustrate that LST, as a single variable predictor is not strong enough to predict bagworm’s infestation on its own. This would also indicate that the infestations of *Metisa plana* are influenced by a combination of different abiotic factors in nature. Moreover, the accuracies of models produced by ANN were hypothesized to be lower than expected due to the usage of non-calibrated LST data over Malaysian region apart from missing data problems encountered owing to the presence of clouds.

Similar to LST, RF on its own is lacking in capabilities to capture the fluctuation pattern of *Metisa plana* and eventually unable to effectively predict its infestation and outbreak. This is in alignment with a finding by Basri [13] which stated that rainfall is not the best predictor for bagworm’s infestations and outbreak due to its inconsistent associations with bagworm.

The combination of predictor parameters was expected to be able to capture the dynamic relationship between abiotic factors and the infestations of *Metisa plana* better than the single predictor parameters as in nature fluctuations of *Metisa plana*’s populations are influenced by a combination of different abiotic factors. However, the result showed otherwise when the models generated by the combined parameters produced models with satisfactory accuracy of 66.44% (LST+RF), 79.56% (LST+RH), 74.83% (RF+RH), and 72.64% (LST+RF+RH).

Even so, this result was expected due to the usage of non-calibrated data as well as the lack of continuity of data collected due to cloud cover. Therefore, in order to improve the prediction model, geospatial data calibration should be conducted. On the same note, temporal interpolation of geospatial data could also be applied in order to compensate data discontinuity.

**Table 1.** ANN analysis between abiotic parameters and *Metisa plana*.

| Parameter     | Network architecture | Training algorithm                  | Training absolute error | Validation absolute error | Training accuracy | Validation accuracy | Test accuracy |
|---------------|----------------------|-------------------------------------|-------------------------|---------------------------|-------------------|-------------------|--------------|
| LST           | [3-5-1]              | Conjugate gradient descent          | 0.13                    | 1.32                      | 93.73 %           | 69.31%            | 69.61%       |
| RF            | [3-8-1]              | Quick propagation                   | 0.97                    | 1.22                      | 81.31 %           | 77.42 %           | 66.92 %      |
| RH            | [3-8-1]              | Quick propagation                   | 0.56                    | 1.14                      | 99.56 %           | 93.63 %           | 95.29 %      |
| LST + RF      | [6-7-1]              | Quick propagation                   | 0.85                    | 1.47                      | 91.90 %           | 83.59 %           | 66.44 %      |
| LST + RH      | [6-7-1]              | Limited Memory Quasi-Newton         | 0.55                    | 0.73                      | 98.42 %           | 55.89 %           | 79.56 %      |
| RF + RH       | [6-7-1]              | Levenberg-Marquardt                | 0.52                    | 0.55                      | 81.02 %           | 69.16 %           | 74.83 %      |
| LST + RF + RH | [9-15-1]             | Levenberg-Marquardt                | 0.02                    | 1.13                      | 99.75 %           | 70.86 %           | 72.64 %      |
4. Conclusion
In comparing LST, RF, and RH as a single variable predictor for predicting the outbreak of Metisa plana, the latest was found to be the most reliable predictor, while the former two factors, on their own, were considered as co-factors that contribute to the outbreak of Metisa plana. A few limitations of the utilization of remote sensing data in this study were observed. Firstly, data availability was compromised by the presence of cloud cover. Secondly, the usage of non-calibrated remote sensing data might undermine the accuracy of Metisa plana’s prediction model developed. These limitations could be overcome with the improvement of data continuity through temporal interpolation and geospatial data calibration to improve the accuracy of models developed. On the whole, the application of remote sensing and geospatial technology with the integration of ANN prediction method was able to determine the factors influencing the outbreak of Metisa plana. Furthermore, these technologies were proven to be reliable in predicting this pest’s prevalence through the construction of prediction models with the accuracies that go up to 95%.

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