TEMPORAL GEOSPATIAL ASSESSMENT OF COCOA POLLINATOR, *Forcipomyia* IN COCOA PLANTATION AREA

Saripah, B. [1*]**, Nor Aizam, A.** [2*] **& Ummu Syaira Ain, R.** [2]
[1]Malaysian Cocoa Board, 5 – 7th Floor, Wisma SEDCO,
Lorong Plaza Wawasan, Off Coastal Highway, Locked Bag 211,
88999 Kota Kinabalu, Sabah, Malaysia.
[2]Applied Remote Sensing and Geospatial Research Group,
Centre of Studies Surveying Science & Geomatics,
Faculty of Architecture, Planning and Surveying,
Universiti Teknologi MARA Shah Alam, Selangor.
*Corresponding author: *nor aizam@uitm.edu.my*
sari@koko.gov.my

ABSTRACT

The objective of the study is to investigate the pollinator, *Forcipomyia* spp. (Diptera: Ceratopogonidae) population after augmentation of different breeding medium stuffed in the portable breeding container. The observation was carried out both in the laboratory and in the cocoa field, and temporal geospatial assessment was obtained through geospatial analysis. A spatial distribution map of the pollinator population was produced to determine the distribution according to substrates, distances, and duration. The population of the cocoa pollinator in the laboratory was observed for 60 days. Meanwhile, field observation was carried out for the period of 94 days (Days 1, 12, 24, 38, 52, 66, 80 and 94), at four distances (2, 5, 8 and 12 m). Three breeding mediums were selected, which were cocoa pod husk, banana stump, and combination of cocoa pod husk and insect-infested pods. The data were analyzed using statistical software, as well as using Geographical Information System (GIS), and geospatial statistic. Contradict results were obtained both for laboratory and in the field where banana stumps harbored the highest number of pollinators in the former observation. Meanwhile, in the latter observation, cocoa pod husk harbored a higher number of captured pollinators compared with the other breeding medium. The results denoted that cocoa pod husk and banana stumps should be considered as the most appropriate medium for pollinator increment in the cocoa plantation. Continue adding the breeding medium inside the container after Day-60 and increased the number of an individual breeding container are promoted for the sustainability of the population for more extended period. With the aid of geospatial interpolation technique, temporal geospatial assessment of cocoa pollinator can be determined more accurately. This information will be benefited cocoa operators to determine the best time to augment more breeding medium as well placement of breeding substrates to increased pollinator population in the cocoa field.

Keywords: Pollinator, *Forcipomyia,* cocoa, *Theobroma cacao,* Geographical Information System

ABSTRAK

Kajian ini dijalankan bagi menilai populasti pendebunga koko, *Forcipomyia* spp. (Diptera: Ceratopogonidae) selepas menambahkan beberapa media pembiakan berbeza di dalam bekas pembiakan yang boleh dipindahkan. Pemerhatian ini di jalankan di dalam makmal dan juga di kebun koko, dan penilaian ruangan berkaitan tempoh masa dinilai menggunakan analisis geospatial. Peta sebaran populasi pendebunga mengikut tempoh masa dijana bagi menentukan sebaran berdasarkan media pembiakan, jarak dan juga tempoh masa. Populasi pendebunga koko dikaji di dalam makmal selama 60 hari. Manakala populasi di kebun dijalankan selama 94 hari (Hari pertama, 12, 24, 38, 52, 66, 80 dan 94) pada empat jarak yang berbeza (2, 5, 8 and 12 m) daripada bekas pembiakan. Tiga media pembiakan dipilih iaitu kulit koko sihat, batang pisang, dan kombinasi kulit koko dan buah koko yang diserang serangga. Data dianalisis menggunakan perisian statistik dan juga menggunakan Sistem Maklumat Geografi (GIS), bagi statistik geospatial. Keputusan berlawanan diperoleh bagi pemantauan di makmal dan juga di kebun, di mana media batang pisang merekodkan bilangan pendebunga tertinggi di makmal. Manakala media kulit koko merekodkan bilangan pendebunga tertinggi ditangkap di kebun berbanding media pembiakan lain. Keputusan ini menunjukkan kulit koko dan batang pisang boleh dipertimbangkan sebagai media pembiakan terbaik bagi meningkatkan populasi pendebunga di ladang koko. Penambahan media pembiakan secara berkala di dalam bekas pembiakan perlu dilaksanakan selepas Hari-60 dan penambahan bilangan bekas pembiakan perlu dilakukan pagi memastikan kestabilan populasi pada tempoh yang lebih lama. Dengan bantuan teknik interpolasi geospatial, penilaian pendebunga koko secara pemetaan berkala dapat ditentukan dengan lebih tepat. Informasi ini amat berguna kepada individu yang berkait dengan tanaman koko bagi menentukan masa terbaik menambahkan media pembiakan, di samping menentukan lokasi terbaik meletakkan bekas pembiakan bagi meningkatkan populasi pendebunga koko di kebun koko.

Kata kunci: Pendebunga, *Forcipomyia,* koko, *Theobroma cacao,* Sistem Maklumat Geografi

INTRODUCTION

The production of essential crops in the world such as sugar cane, potato, beet, and cassava are highly depending on vegetative propagation, whereas wind pollination is critical for maize, rice, and wheat. The importance of insect pollination was proven where it is estimated that 75% of primary crops rely on the pollinator (Klein et al. 2007). Insect pollinators play an essential functional role by supporting ecological stability as well as food security worldwide (Crenna et al. 2017). Insect pollinators are crucial for global food supply, other fundamental goods and services, and responsibilities as an agent in pollinating more than 80% of wild plant species in the world (Klein et al. 2007).

Cocoa, *Theobroma cacao* L. (Malvales: Sterculiaceae) bearing fruits all year round, and the development stages are started after pollination of the cocoa flowers occurs. However, only 1-5% of the flowers can successfully produce as a cocoa bud (Lee et al. 2013). Cocoa and coffee are two major insect-pollinated tropical plantation crops. Both crops are formerly known as self-compatible, however, produces different breeding systems and become strictly self-incompatible crops. Cocoa was listed with another 12 foremost plant which their production would decline by over 90% due to the lack of pollinators (Klein et al. 2008). As an incompatible species, the role of pollinator in the process of depositing pollen on the flower’s style was very crucial for successful pollination. Cocoa flowers highly depend on pollinators to pollinate due to self-incompatibility occurred, where cocoa trees could not set fruit with their pollen, nor with one another. This phenomenon occurred even the pollen tubes would normally grow, but the male gamete does not fuse with the female gamete when the mating is incompatible (Wood & Lass 1985).

As an incompatible species, the role of pollinator in the process of depositing pollen on the flower's style was very crucial for successful pollination. The most important group of pollinating insects belonging to several genera of the family Ceratopogonidae (Nematocera: Diptera), especially the genus of *Forcipomyia*. These small size midges with the length of 2 to 3 mm demonstrated as an excellent pollinator due to their visitation rates and massive deposition of pollen grains on the stigma (Adjaloo & Oduro 2013). The population of *Forcipomyia* builds up during the rainy season and the estimated life cycle of *Forcipomyia* is approximately 28 days (Wood & Lass 1985). *Forcipomyia* spp. able to deposit a minimum of 35 pollen grains on the stigma of cocoa flowers for adequate pollination to occur (Brew 1984).

The availability of pollinator highly depends on multiple anthropogenic drivers (Novais et al. 2016), and agricultural intensification may contribute to the declining trend with the reduction of floral resources and nesting areas in remnant habitats (Kennedy et al. 2013). Lack of botanical diversity in monoculture compared to intercrop plantations will later on limit the availability of food source for pollinators. 'The pollinator crisis' occurred in most of the continents; including the USA and in central Europe (the first and second largest food producers in the world), regarding declining of the population in wild and domesticated pollinators (Levy, 2011). The effects of a possible pollinator crisis on the food crop production in Brazil (the fourth largest food producer and the third largest food exporter in the world) were discussed in details by Novais et al. (2016). Their study indicated that 68% of the 53 major food crops depend to some degree on animal pollination. It was stated that the loss of pollination services for 29 major food crops reduce the contribution to the Brazilian GDP by 6.46% to 19.36%, accounted for 4.86 to 14.56 billion dollars/year in term of monetary value.

Reduction of pollinator numbers would limit the availability of foods and other essential ecosystem services. Declining trends of the pollinator population may occur at different spatial and temporal scales (Novais et al. 2016), including reduction of flower resources. Lack of floral diversity, especially in monoculture ecosystem can limit the provisioning of resources required by these midges (Blaauw & Isaacs 2014). Pollinators highly dependent on decaying organic materials, and lack of the substrates in the cocoa field may limit their population build up, especially during the extended dry period (Saripah & Alias 2018). Therefore, to sustain their population, pollinator abundance may be synchronized through environmental manipulation, by providing suitable breeding sites in the cocoa field (Azhar & Wahi 1984). The development of temporarily-stable pollinator populations may be promoted by providing supplemental and additional breeding mediums in the cocoa field (Azhar 1990). Providing of breeding mediums inside portable breeding containers may help in population enhancement in the cocoa field. The selection of breeding mediums including cocoa pod husks (CPH), banana stumps; and combination of cocoa pod husks with insect infested pods is due to their availability in the cocoa field. Additional substrates that will be provided must be practical and easily found in the cocoa field, and will increase the population built-up of *Forcipomyia* sp. (Saripah & Alias 2018). However, the substrate must be replaced regularly, due to the moisture contents will be reduced over time.

Besides, placement of portable breeding containers near to the cocoa trees will harbour a higher number of pollinators, compared if the containers were placed a few distances from cocoa trees.

Distribution of cocoa's pollinator is easier to be interpreted by the aid of the Geographical Information System (GIS) technique. The spatial analysis is a useful tool due to the high percentage of information obtained from the spatial component (Chang 2016). Implementation of GIS able to produce a spatial distribution map of cocoa's pollinator and will help in the decision making later on. In recent years, GIS was successfully implemented in various fields of study and management decision (Abdul Hakim 2014). Unfortunately, measuring every point of the height, magnitude or concentration of a phenomenon in the field is difficult and time-consuming. Hence, the spatial interpolation method with the using of individual point with known value is vital to estimate the unknown value of selected points. This unknown value can be determined by a mathematical equation which focuses on the value of adjacent known points.

Furthermore, interpolation was carried out based on the theory of spatially distributed objects, spatially related and object that tend to have similar characteristics. Spatial interpolation includes two different techniques for generating raster surface, which is local interpolation and global interpolation. Both methods have a deterministic and stochastic model which respectively provides no assessment of errors using predicted values, and later on, providing an evaluation of error with estimated variances.

The spatial distribution of pollinators using GIS software provides more significant results and offers more in-depth analyses especially for the field data. Therefore, this study aims to investigate the effect of three different mediums on the pollinator population. The observation was carried out in both laboratory and the cocoa field, and geospatial analysis was carried for temporal geospatial assessment of pollinator populations. A spatial distribution map of pollinator population at different types of breeding medium (banana stumps, cocoa pod husks, and insect-infested pods) were evaluated at four different ranges from the portable breeding containers (2, 5, 8 and 12 meters). A spatial distribution map was also generated based on multi-temporal observation period.

MATERİALS AND METHODS

Study Site

The study of the pollinator population was carried out at the Cocoa Research and Development Center (CRDC), Malaysian Cocoa Board Bagan Datuk, Sungai Sumun, Perak, Malaysia (Longitude E.100 M, 52' 0', Latitude N3 53' 42). The population was monitored in the laboratory, and the temporal geospatially assessment was undertaken in the cocoa field. The study conducted at Block 4B with the planting system of 2 x 3meters, 1,012 stands of mature cocoa trees and 75 stands of *Gliricidia macculata* as a shade tree. This 1.5ha block was selected due to uniform, mature cocoa tree stands and having the sufficient number of shade trees.

Data Collection and Methods

Three different raw breeding mediums were selected; cocoa pod husk (CPH), banana stumps and combination of cocoa pod husk and insect-infested pods. Mediums were cut into small pieces to promote the rotting process later on. Substrates were constructed until at least 75% of the closed-lid black containers (50cm x 32cm) were filled with the mediums. Several small holes were created for air ventilation and allowed to discharge liquid waste during the rating process of the medium. This field experiment was set up in a randomized complete block design with four treatments and three replicates.

The containers were placed randomly and number of pollinators visited cocoa trees was monitored at four distances from the containers (2, 5, 8 and 12 m). Total 48 trees were sampled at the intervals of 12 to 14 days between the sampling occasions. Data were assessed for a period of 94 days at Days 1, 12, 24, 38, 52, 66, 80 and 94 for field observation. Each tree was sampled for five minutes from 7.30 to 10.00 am. Captured pollinators were identified for their sexes. The numbers of pollinators were observed using an aspirator by sucking the insects perching on cocoa flowers, trees, branches, and surrounding areas. The use of transparent bottles as part of an aspirator is crucial due to the small size of the midges, and challenging to observe directly in the field.

For laboratory observation, approximately 150 to 200 grams of each medium in the containers were brought back to the laboratory. Three breeding containers from each medium were selected as a replicate. Samples then were placed inside small individual transparent containers, and numbers of pollinators were examined after one or two days from the collection dates. Observation was carried out at Days 3, 6, 10, 14, 18, 22, 25, 27, 31, 36, 41, 45, 47, 50, 53, 56 and 60. The collected data were arranged and pooled together in Excel® program. The statistical analysis and significant differences were analyzed using SAS® software (a SAS® system for Windows® V8). The means were separated prior to ANOVA analysis and GLM procedures at an overall significance level of $\alpha = 0.05$.

The temporal geospatially assessment was carried out using Geographical Information System (GIS) spatial analysis utilizing the ArcGIS software version 10.4 developed by the Environmental System Research Institute (ESRI), California, United States. The ArcGIS software is widely known for geographic data acquisition, analyzing mapped information and map creation of point (i.e., a single feature such as a tree), polygon (i.e., cocoa plantation area or boundary) and polyline (i.e., road or any connected linear features) data format. The GIS tightly integrated with the Global Positioning System (GPS) which recorded any required features on the land surface with a specific coordinate reference system (CRS). In this study, the position of each breeding container and 48 of random sampling cocoa tree locations were recorded using handheld GPS of WGS84 47N CRS in latitude and longitude (i.e., degree, minute and second) data format. These data were then restored in the Microsoft Excel format (.xls), and subsequently, imported and converted into a shapefile format (.shp) prior to be processed in ArcGIS software. ArcMap is the main component of an ESRI's ArcGIS and generally used to create, manipulate and analyze the geospatial data.

A spatial buffer tool analysis was used to determine the distance of captured pollinators from the breeding container. The buffer was applied to measure the distance, and multiple ring buffers were utilized to create various buffer distances simultaneously at interval distance ranges of 2m, 5m, 8m and 12m from the containers. Furthermore, to produce a spatial distribution map of pollinator counted (in number) for each cocoa trees the local interpolation method was applied using a stochastic model of Kriging. Kriging is a geostatistical method for spatial interpolation, which able to access the quality of prediction of unknown data values according to known data values such as the number of pollinators counted on the field. The formula to estimate the prediction of the infested pod as in Equation 1 below:

$$\hat{Z}(S_0) = \sum_{i=l}^{N} w_i Z(S_i) \quad \text{(Eq. 1)}$$

Where Z (s_i) is the measured value at the *i*th location, w_i is an unknown weight for the measured value at the *i*th location, s_0 is the prediction location, and N is the number of measured values.

RESULT AND DISCUSSION

Laboratory Observation of Pollinator Population

The number of pollinators emerged from each sampled of the breeding medium was recorded for 60 days in the laboratory. Regardless of the different breeding medium, pollinators started to appear after 22 days (1.7 fg), even the population was below than three individuals per treatment (Figure 1). The number of pollinators started to increase from Day-36 (4.1 ef) onwards and reached its peak on Day-50 (15.4 a). Declining trends in the population were observed from Days-53 through Days-60.

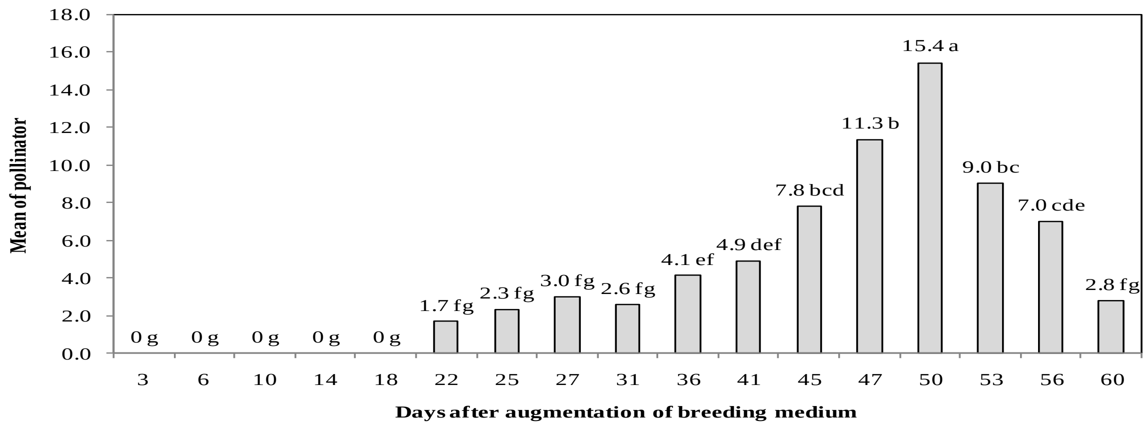

Figure 1. The mean of pollinators recorded throughout 60-days after augmentation of breeding medium.

Observation on individual breeding medium denoted that banana stumps harbored highest mean of pollinator emerged from the medium samples, and started to appear on Day-22 and reached the maximum at Day-50 (Figure 2). Lower population observed in the cocoa pod husk (CPH) and infested pod breeding medium. Similar trends were observed where all three substrates recorded the highest population on Day-5, and gradually decreased after that.

Based on sex, female pollinators exceed males' pollinators regardless of the different breeding medium (Figure 3). The highest female was recorded on the banana stumps medium (5.765 a) and significantly different ($p>0.05$) with cocoa pod husk (1.500 b) and infested pod husk (0.745 b). Similar trends denoted for male pollinators, where 3.098 an individual recorded emerged from banana stumps, 0.921 b from cocoa pod husk (CPH) and 0.647 b from the insect-infested pod husk. The overall population was the highest at banana stumps (8.862 a) throughout 60-days of laboratory observation and significantly different with other two breeding medium.

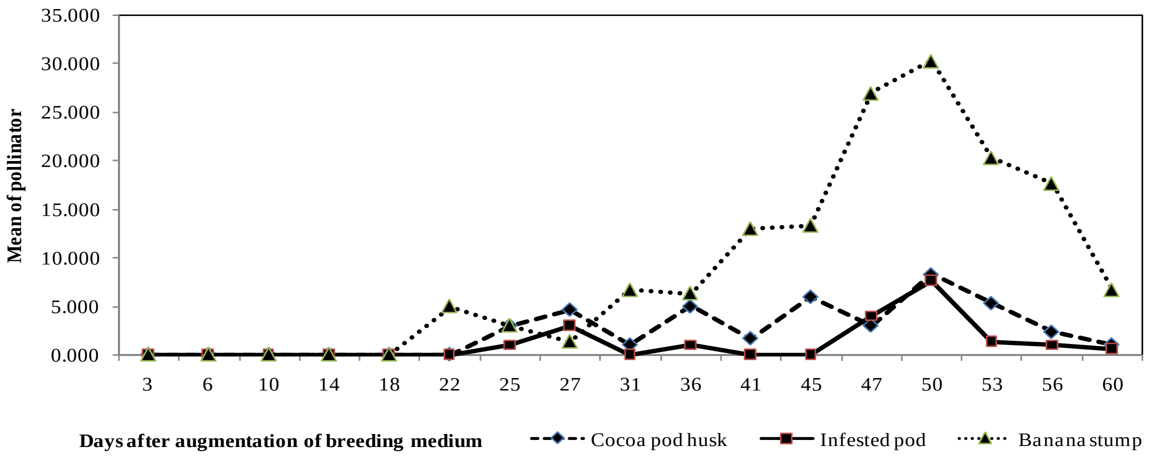

Figure 2. The mean of pollinators recorded throughout 60-days after augmentation at the cocoa pod husk, insect-infested pods and banana stump breeding medium.

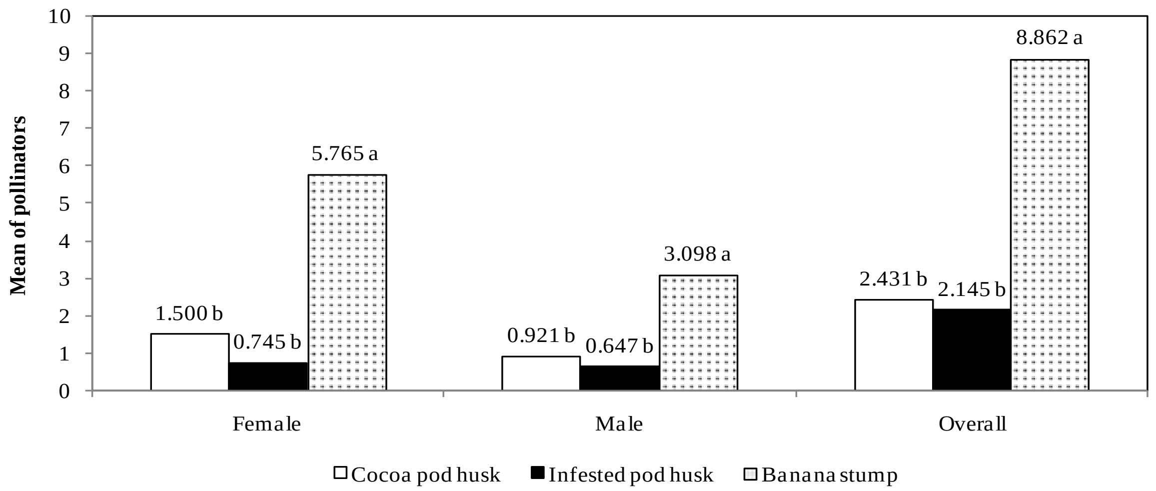

Figure 3. Mean of male, female and overall pollinators recorded throughout 60-days after augmentation of breeding medium.

Field Observation of the Pollinator Population

Regardless of the different breeding medium, Day-52 (2.875 a) recorded the highest population of pollinator captured in the field, and significantly different ($p>0.05$) with Days-1, 12, 66, 80 and 94 (Figure 4). An increasing number of pollinators were observed from Day-24, and declining trends recorded from Day-66 and onwards. Even pollinator was recorded at four different ranges from the breeding medium; however, there was no significant different ($p<0.05$) was observed in the range of 2, 5, 8 and 12 meters from the breeding container (Figure 5).

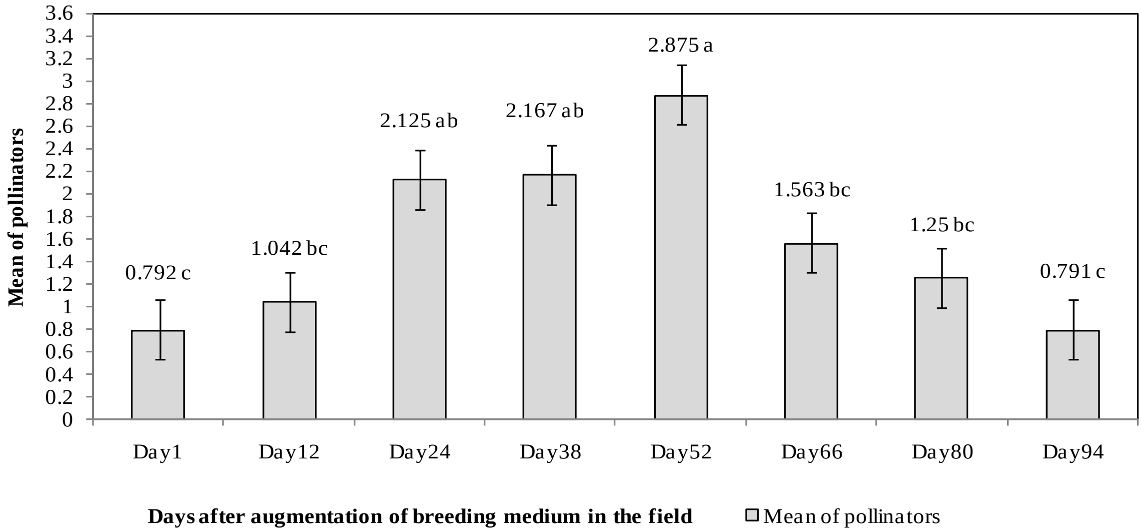

Figure 4. Mean of captured pollinator in 94 days of the field observation.

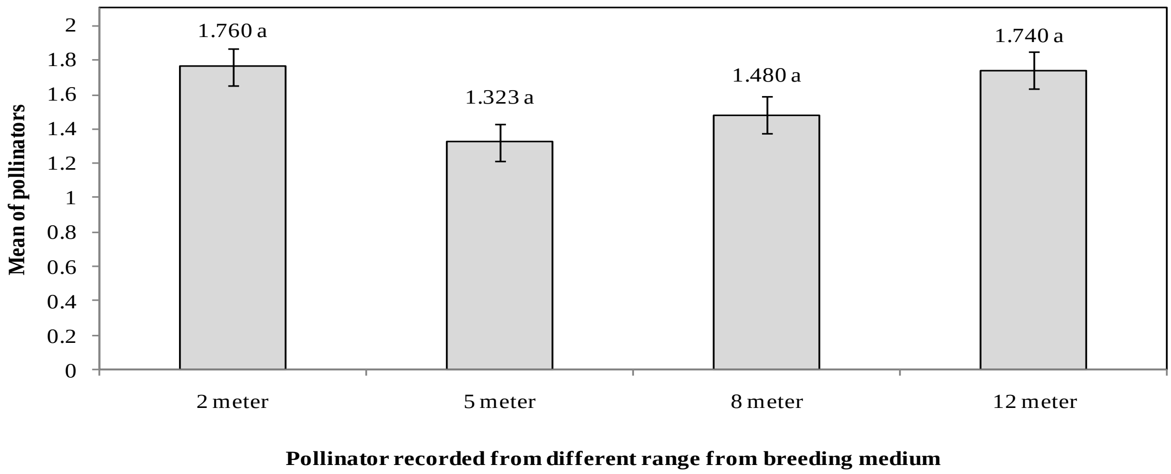

Figure 5. Pollinator recorded from different range from breeding medium.

Spatial Distribution Map of Pollinator Population

The number of pollinators at different substrates counted on the cocoa's plantation field was further analyzed spatially using GIS and represented as interpolated distribution maps apart from statistical analysis as described in the previous section. Six different classes of pollinator distribution map were derived for number of pollinators from 0 – 1 (blue color), 2 – 3 (dark green color), 4 – 5 (light green color), 6 – 7 (light orange color), 7 – 8 (dark orange color) and 10 – 11 (red color) (Figure 6 (a) to (d)). Besides, points of cocoa's sample tree in GIS format (.shpfile) were represented by colors of red for Control, white color for CPH, purple color for Banana stumps and brown color for insect infested pod (Figure 6 (a) to (d)). Spatial distribution map of the insect-infested pod indicated out of 12 samples of trees only four trees have the number of pollinators between 0 to 3, meanwhile, banana stumps, control and CPH have a number of pollinators of 9, 0, and 11, respectively (Figure 6 (a) to (d)). These observations may indicate that pollinator more prefer to breed in CPH, compared to other treatments. CPH may possess physiochemical and antimicrobial properties with higher moisture content that is suitable for the pollinator's breeding place. Banana stumps substrate harbored a second highest number of pollinators, and this might be due to more water retention, which served as a suitable breeding medium, even it becomes drier during prolonged dry seasons (Saripah 2013).

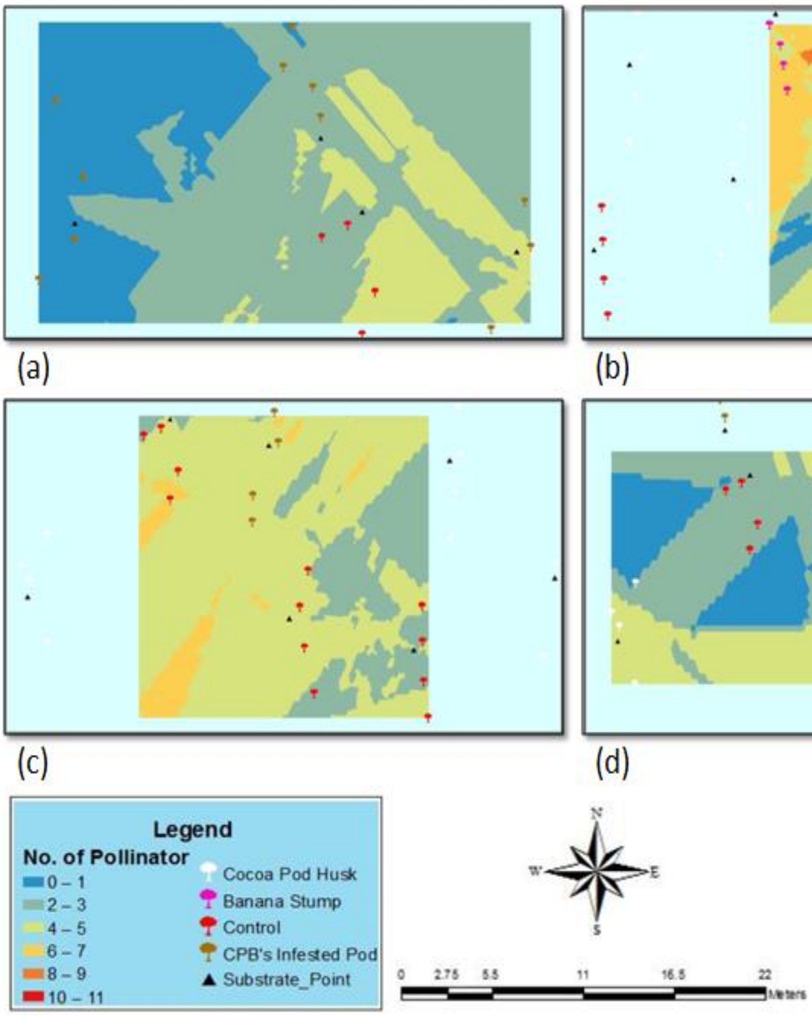

Figure 6. Spatial distribution map of cocoa's pollinator population, according to a) CPB's Infested pod b) Banana Stumps c) Control d) Cocoa Pod Husk.

The numbers of pollinators emerged from breeding container were also mapped spatially in a GIS environment (Figure 7). The distance of pollinators distribution was quantified from each buffer size represented in a different color as of 2m, 5m, 8m and 12 m with white, purple, red and orange ring colors respectively. The spatial buffer analysis indicated that the distance of 2m to 5m has the lowest number of pollinators, even though it is nearest to the breeding container. Interestingly, the highest number of pollinators were recorded within distance from 8m to 12m as opposed to 2m and 5m (Figure 7).

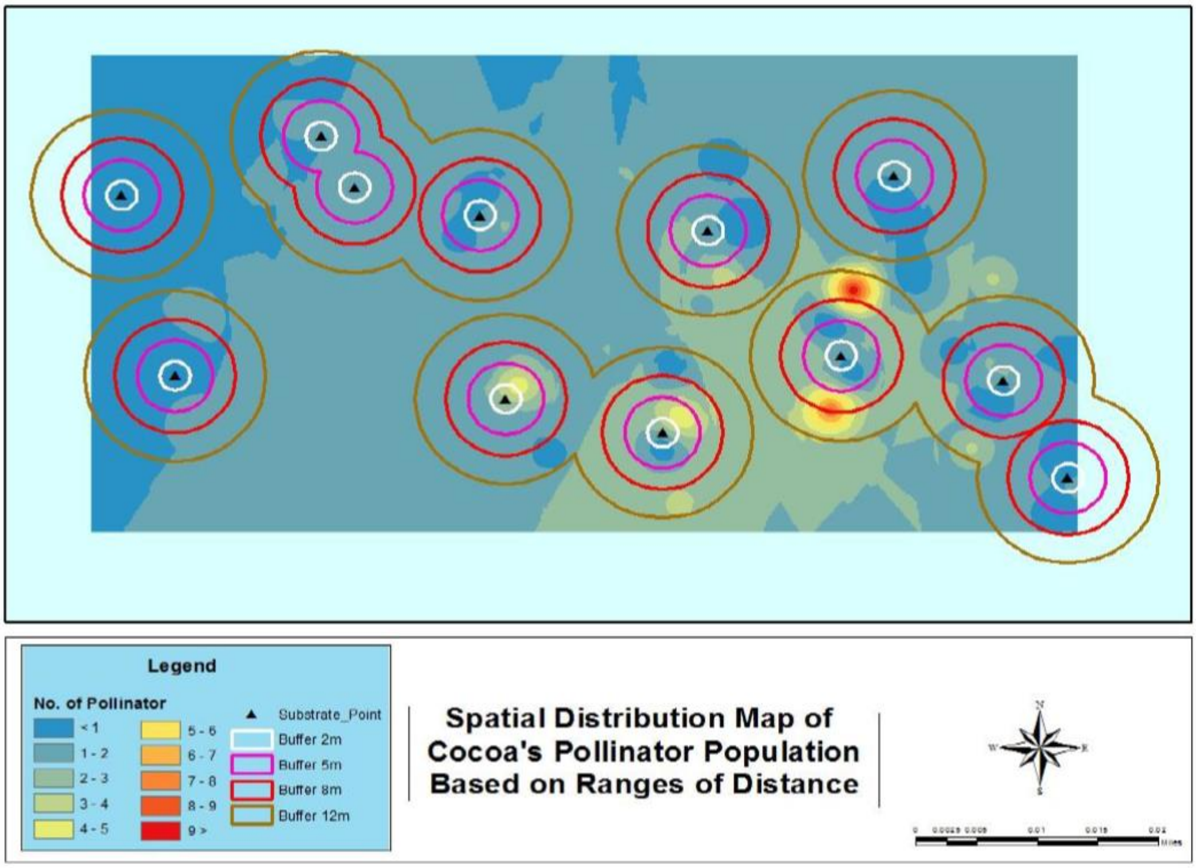

Figure 7. Spatial distribution map of cocoa's pollinator population, according to distance 2m, 5m, 8m, and 12m.

The number of pollinators emerged based on the number of days (i.e., Days 1, 12, 38, 52, 66, 80 and 94) were also spatially analyzed using Kriging interpolation method, and presented as pollinators distribution maps (Figure 8). Seven pollinators distribution categories were derived with Class 1 of 0-1 number of pollinators, Class 2 (2 – 3), Class 3 (4 - 5), Class 4 (6 - 7), Class 5 (8 – 9) and Class 6 (10 – 11) with different assigned colors (Figure 8). The results showed that the Day 1 to Day 12 indicated low numbers of pollinators recorded from 48 sample trees with only six trees have pollinators' distribution above Class 2, and the rest of the trees have a distribution of Classes 1 and 2. According to Saripah (2013) and Saripah & Alias (2018), the number of pollinators was low due to lower moisture contents inside the breeding container as the rotting process did not take place yet in the early stage.

Afterward, the number of pollinator emergence started to increase at Days 24, 38 and 52 of 48, 20 and 38 trees respectively, with pollinator distribution Classes 3 to 6 (i.e., between 4 to 11 pollinators). This might due to the decomposition process of the substrates was taken place and caused a higher number of pollinators that emerged. The number of pollinators gradually decreased at Days 66, 80 and 94 with only 11, 8 and 16 trees have pollinator from Class 1 to Class 3 only (i.e., 0 to 5 pollinators counted) (Figure 9). This is probably due to the substrates may start to dehydrate during this sampling period and cause a lower number of emerging pollinators. The previous study suggested that the pollinators highly breed in the moist habitats rather than dry or dehydrated condition; thus; long dry seasons can affect their natural population (Young 1982).

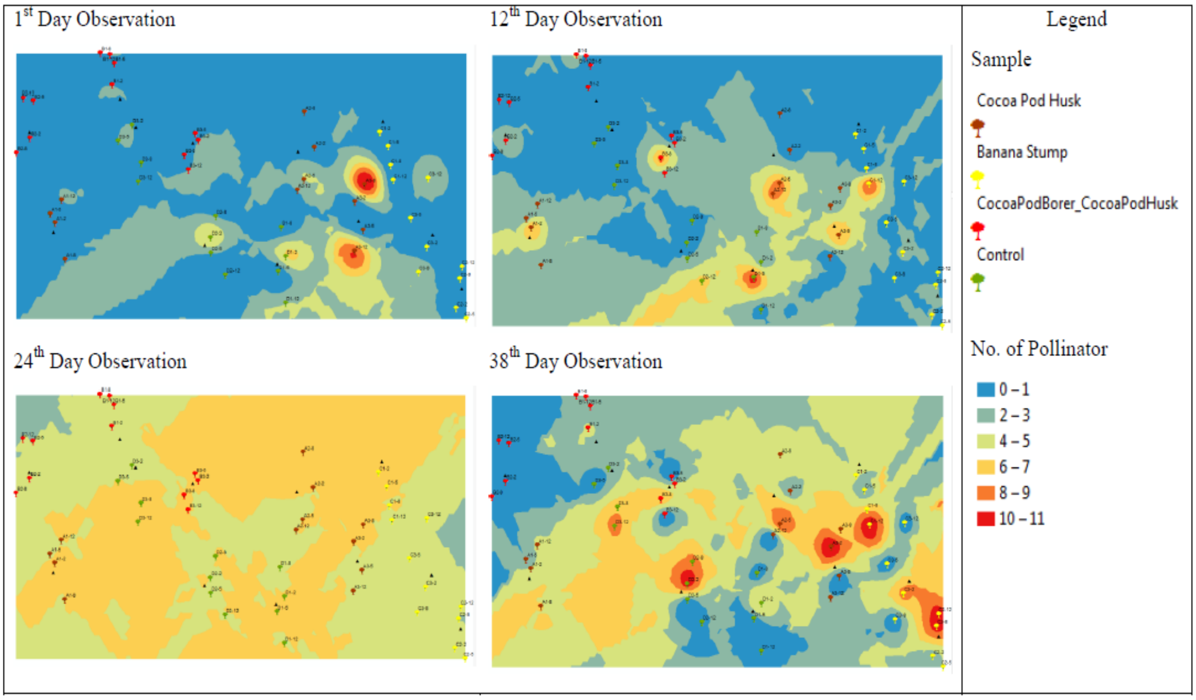

Figure 8. Spatial distribution map of cocoa's pollinator population based on temporal a) 1st days, b) 12th days, c) 24th days and d) 38th days.

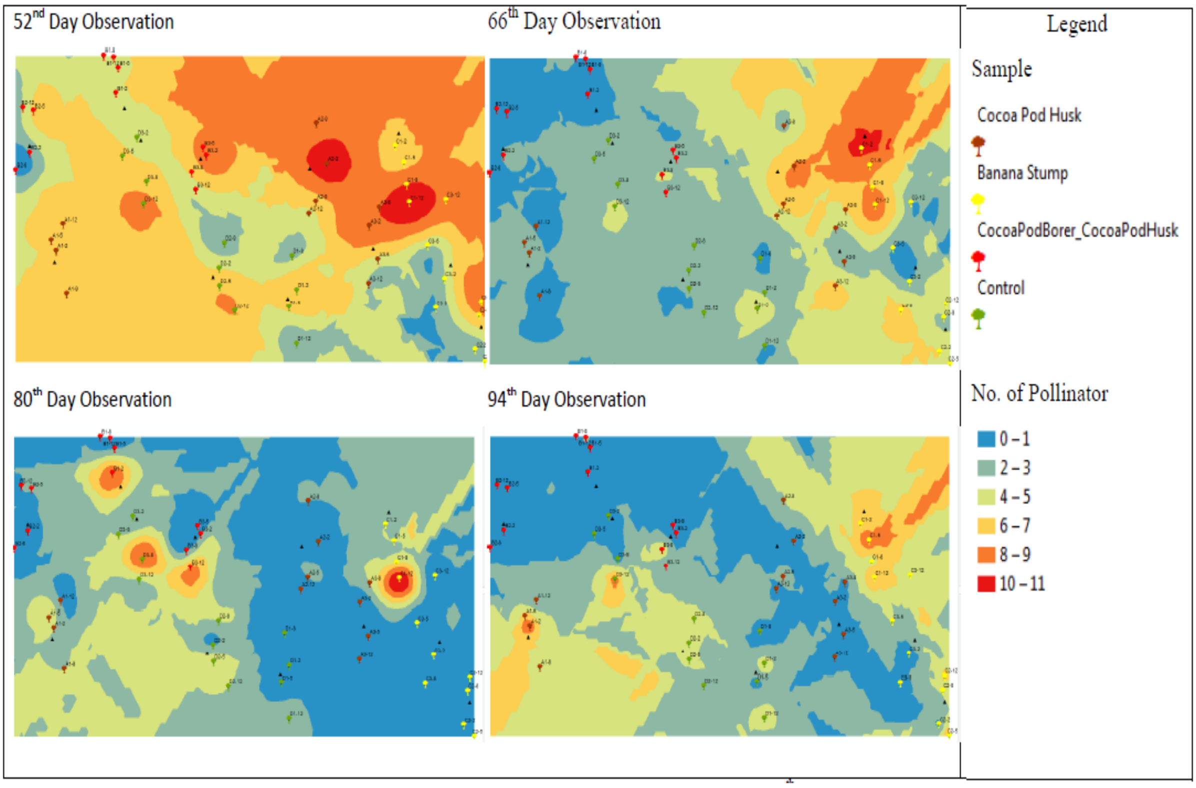

Figure 9. Spatial distribution map of cocoa's pollinator population based on temporal a) 52nd days, b) 66th days c) 58th days and d) 94th day.

The spatial analysis according to temporal condition revealed that the CPH medium was the preferable substrate to breed compared to others, since the Day-1 until the last day of observation (Figures 8-9). Nonetheless, the banana stump was able to breed more pollinator as in the laboratory observation. CPH and banana stump deemed suitable habitats for a pollinator to breed as opposed to the others substrate due to its appropriate moisture characteristic. The spatial temporal analysis indicated that the number of pollinators started to increase at the Day-24 and the highest population detected at the Day-52; meanwhile, it's begun to decrease from the Day-66 which shows a similar trend as detected using statistical analysis as described in the previous section. Therefore, it is highly recommended that the breeding medium needs to be replaced or added at Day-66 as their components begin to dehydrate. Augmentation of more breeding container needs to be positioned in a row of the cocoa field, and by applying these strategies, the possibility population increment occurs in the cocoa field.

CONCLUSION

GIS is a powerful tool for decision-making process as in this study it’s used to evaluate the effectiveness of cocoa’s pollinator population enhancement according to a different substrate using geospatial techniques. Cocoa Pod Husk (CPH) substrate harbored the highest number of pollinators as compared to other substrates as revealed using spatial temporal analysis (Day-1 until Day-94) even contradicted by the laboratory observation. The number of pollinators started to increase from Day-24 (in the field) and Day-22 in the laboratory. The population reached its peak at the Day-50 (laboratory) and Day-52 (in the field) and started to decline at Day-60 and onwards. Despite the low population of pollinator captured in the field, the higher number of individuals emerged in the laboratory may suggest that banana stumps and CPH can be considered as the preferable medium for population increment of pollinators in cocoa ecosystem. Providing an appropriate number of breeding container and suitable breeding medium may increase pollinator population, and the chances of cocoa flowers being pollinated are increased and subsequently improved the cocoa productivity.

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