MONITORING OF THE SCALE INSECT *ICERYA SEYCHELLARUM* (WESTWOOD) INFESTING GUAVA

**Moustafa M S Bakry** and **A Arbab**

***Scale Insects and Mealybugs Research Department, Plant Protection Research Institute, A.R.C, Dokki, Giza, Egypt***

*Department of Entomology, Faculty of Agriculture, Islamic Azad University, Takestan Branch, Takestan, Iran*

*Email: abbasarbab@hotmail.com (corresponding author)*

**ABSTRACT**

The present study is on the spatial distribution and for estimating the optimum sample size for monitoring the populations of the scale insect *Icerya seychellarum* (Coccomorpha: Monophlebidae) on guava. The study was done in 2017–2018 and 2018–2019 in Luxor, Egypt. It was observed that the scale occurred year round and there were three to four peaks of seasonal activity/year: beginning of June, mid-September and mid-November in 2017 and the beginning of April, mid-June, mid-August and mid-October in 2018. Data on the indices of distribution and Taylor’s and Iwao’s regression analyses indicated that the distribution reveal significant aggregation behaviour. The regression models of Taylor’s power law (b) and Iwao’s patchiness (β) were both significantly >1, indicating that *I. seychellarum* had an aggregation distribution with a negative binomial distribution. The Iwao regression coefficients were used to determine the optimum sample size required to estimate populations at three fixed precision levels. The optimum size decreased with increased mean population density in all levels of precision (5, 10 and 15%). These can be deployed to develop a sampling plan to estimate the population density of *I. seychellarum* accurately. Furthermore, the sampling protocol presented herein will be a tool for IPM decisions.

**Key words:** *Icerya seychellarum, Psidium guajava*, spatiotemporal distribution, population density, aggregation, optimum sample size, IPM

Guava *Psidium guajava* (Myrtaceae) are liable to be infested by several pests, among which *Icerya seychellarum* (Westwood) (Coccomorpha: Monophlebidae) is the main destructive one in Egypt (Sayed, 2008). Due to its sucking the sap and nutrient deprivation of the trees, there occur negative effects on the quality and quantity of the fruit as well as on general tree vigour (El-Said 2006; Mangoud 2000; Reda et al., 2010). This feeding results in the excretion of large amounts of honeydew, which causes sooty mould inhibiting photosynthesis. In addition, toxic saliva secreted by the insects may result in malformed leaves and poor shoot growth (Osman 2005).

Spatial distribution is one of the most characteristic properties of insect populations; in most cases it allows us to define them, and is a typical trait in insect populations and is an important characteristic of ecological communities (Debouzie and Thioulouse 1986). No field sampling can be efficient without understanding the underlying spatial distribution (Taylor, 1984). An understanding of the spatial distribution (i.e. regular, random or aggregated) of populations provides useful information, not only for theoretical population biology but also for field monitoring programmes, especially sequential sampling (Feng et al., 1993; Binns et al., 2000). A reliable sampling programme to estimate population density should include proper sampling time (date of sampling), sampling unit and number of sampling in which the determination of spatial distribution is crucial (Pedigo 1994; Southwood and Henderson 2000).

The regression models of Taylor (1961) and Iwao and Kuno (1968) depend on the relationship between the sample mean and the variance of insect numbers per sampling unit through time, and can provide a stable relationship from one year to another, based only on the observed sampling mean (Bisseleua et al., 2011). A knowledge of the spatial distribution of an insect is central to the design of a management programme, and is important in understanding the bioecology of species and forms the basis for developing a sampling protocol (Wearing 1988; Binns et al., 2000; Cho et al., 2001). No information is available in the literature concerning the spatial distribution of *I. seychellarum*. Therefore, the
present work was carried out to estimate the optimum sample size for this pest on guava. The results of this research can be used to draft monitoring methods and ultimately for establishing IPM strategies.

MATERIALS AND METHODS

A guava orchard, *Psidium guajava* (Myrtaceae) of about 4200 m² (one feddan) was selected in Esna district, Luxor Governorate for sampling. The orchard was at altitude 99 masl and latitude and longitude 25.67ºN 32.71ºE, and was sampled twice monthly from the beginning of March 2017 until mid-February 2019. The orchard received the normal agricultural practices (irrigation, fertilization, pruning etc.), except that no chemical control measures were applied before or during the study. This insect was identified by Dr. Fatma A. Moharum, Department of Scale Insect and Mealybugs, Plant Protection Research Institute, Agriculture Research Center, Egypt. Four guava trees, Balady variety, of approximately the same age (about 10 years old), size, height and vegetative growth were selected at random. Samples of 10 leaves from the terminal shoots were picked from the four cardinal directions (East-West-North-South) of each selected tree at fortnightly intervals (total 40 leaves per tree).

Regular fortnightly samples were picked at random from the different directions and strata of the tree. The samples were immediately transferred to the laboratory in polyethylene bags for inspection and were examined using a stereo-microscope. The total numbers of live insects on upper and lower surfaces of guava tree leaves were counted and recorded, linked to the inspection date and presented as a mean number of individuals per sample (10 leaves) ± SE.

A total of 48 samples over 48 dates were collected over a two-year period. All sampling was conducted from 7680 leaves, i.e. 4 trees x 4 directions x 10 leaves x 48 dates. Samples were frozen to preserve them for later processing. The spatial distribution among the sample units was determined using 21 indices and two regression methodologies, namely: Taylor’s (1961) and (Iwao and Kuno 1968). Soemargono et al. (2011) supported this assertion and recommended that in evaluating distribution of an arthropod, one should use several different techniques before drawing conclusions about population distribution.

Distribution indices used are based on sample means and variances (such as index of dispersion, clumping, crowding and Green’s index (Green 1966).

\[
C.V. = \frac{S}{\bar{X}} \times 100
\]

- Mean ($\bar{X}$): the mean number of individuals as a general average per sample (10 leaves) during the whole year; - Range of means of a population: The difference between the maximum mean number of a population and the minimum for the whole year was calculated by applying the following equation: - Range of Density (R) = Population density maximum − Population density minimum during the whole year; - Variance ($S^2$), standard deviation (S), standard error (SE) and median (Me) for samples were determined; - Coefficient of variance (C.V): To assess the fidelity of sampling, the coefficient of variation values for the studied years were compared. Where, S is the standard deviation of the mean and $\bar{X}$ is the mean of population; and - Relative Variation (R.V) is employed to compare the efficiency of various sampling methods (Hillhouse and Pitre, 1974). The relative variation for the studied years was calculated as follows:

\[
R.V = \left( \frac{SE}{X} \right) \times 100
\]

\[
(I.D.) = \frac{S^2}{\bar{X}} - 1
\]

Where, SE is the standard error of the mean and $\bar{X}$ is the mean of population.

- Index of dispersion ($I_{D}$): The index of dispersion is also known as the variance to- mean ratio. Dispersion of a population can be classified through a calculation of the variance-to-mean ratio; namely: Diffusion coefficient:

\[
S^2/\bar{X} = 1 \text{ random distribution, } < 1 \text{ regular distribution, and } > 1 \text{ aggregated distribution (where, } S^2 = \text{ sample variance; } \bar{X} = \text{ mean of population).}
\]

- Index of Lewis ($I_{L}$): Lewis index was also calculated as per the formula given hereunder to determine the dispersion:

\[
I_L = \sqrt{\frac{S^2}{\bar{X}}}
\]

The value of this index revealed >1 contagious; <1: regular and =1 random distribution.

- Cassie index ($Ca$): $Ca = (S^2 - \bar{X})/\bar{X}^2$

The spatial distribution pattern is aggregative, random and uniform when $Ca > 0$, $Ca = 0$ and $Ca < 0$, respectively (Cassie 1962). - The $K$ value of negative binomial distribution: The parameter $k$ of the negative binomial distribution is one measure of aggregation that can be used for insect species having clumped
or aggregated spatial pattern. When $k$ values are low and positive ($k < 2$), they indicate a highly aggregated population; $k$ values ranging from 2 to 8 indicate moderate aggregation; and values higher than 8 ($k > 8$) indicate a random population (Southwood 1995). The $k$ values were calculated by the moments method (Costa et al., 2010), and given by:

$$\kappa = \frac{\mu^2}{\sigma^2 - \mu}$$

- Departure from a random distribution can be tested by calculating the index of dispersion ($I_d$), where, $n$: denotes the number of samples:

$$I_d = \frac{(n-1)\sigma^2}{\mu}$$

$I_d$ is approximately distributed as $x^2$ with $n-1$ degrees of freedom. Values of $I_d$ which fall outside a confidence interval bounded with $n-1$ degrees of freedom and selected probability levels of 0.95 and 0.05, for instance, would indicate a significant departure from a random distribution.

This index can be tested by $Z$ value as follows:

$$Z = \sqrt{2I_d - (2n-1)}$$

If $1.96 \geq Z \geq -1.96$, the spatial distribution would be random, but if $Z < -1.96$ or $Z > 1.96$, it would be uniform and aggregated, respectively (Patil and Stiteler 1974).

- Index of mean clumping ($I_{DM}$) (David and Moore 1954):

$$I_{DM} = \frac{S}{\mu} - 1$$

The David and Moore index of clumping values increase with increasing aggregation. If the index value = 0, the distribution is random, positive value for negative binomial (aggregated) and negative value for positive binomial (regular).

- Lloyd’s mean crowding ($\bar{X}^*$): Mean crowding ($\bar{X}^*$) was proposed by Lloyd to indicate the possible effect of mutual interference or competition among individuals. Theoretically mean crowding is the mean number of other individuals per individual in the same quadrate:

$$\bar{X}^* = \bar{X} + [(S^2 / \bar{X}) - 1]$$

As an index, mean crowding is highly dependent upon both the degree of clumping and population density. To remove the effect of changes in density, Lloyd introduced the index of patchiness, expressed as the ratio of mean crowding to the mean. As with the variance-to-mean ratio, the index of patchiness is dependent upon quadrate size (Lloyd, 1967).

- Index of patchiness ($I_p$): is dependent upon quadrate size. $I_p = (\bar{X} / \bar{X}^*)$

If $I_p = 1$ random, < 1 regular and > 1 aggregated

- Green’s index (GI): $GI = [(S^2 / \bar{X}) - 1] / (n-1)$

This index is a modification of the index of cluster size that is independent of $n$ (Green, 1966). If GI > 0 or positive values are indicative of aggregation dispersion, GI < 0 or negative values indicative of uniformity or regular dispersion, and GI = 0 or negative values closer to 0 indicate randomness.

- To evaluate temporal changes in spatial pattern of the mealybug population during the studied years, an aggregation index ($1/k$) (Southwood and Henderson 2000) was used. It was calculated by the formula of

$$\frac{1}{k} = \frac{\bar{X}}{\bar{X}^*} - 1$$

where: $1/k$ is aggregation index or Cassie’s index $C$ and $(\bar{X} / \bar{X}^*)$ is Lloyd’s patchiness index. The values of $1/k < 0$, = 0, and > 0 represent regularity, randomness, and aggregation of the population in spatial pattern, respectively (Feng and Nowierski 1992).

Regression methods used include:

Taylor’s power law: The sampling distributions for total alive stages by I. seychellarum were modelled using both Taylor’s power law (1961). A power law function can be used to model the relationship between mean and variance as:

$$S^2 = a\bar{X}^b$$

where, $S^2$ is the variance; $\bar{X}$ is the sample mean; and $a$ is the scaling factor related to sample size and $b$ measuring the species aggregation. when, $b = 1$, $b < 1$ and $b > 1$, the distribution is random, regular and aggregated, respectively. Through the use of a log transformation, one can estimate the coefficients with linear regression as: $log(S^2) = log(a) + b log(\bar{X})$

where, $a$ and $b$ are the parameters of the model, estimated by linearizing the equation after a log–log transformation (Taylor 1984).

Iwao’s patchiness regression: This was used to quantify the relationship between mean crowding index ($\bar{X}^*$) and mean population density ($\bar{X}$)
Lloyd’s (1967) and using the following equation:

\[
X' = a + \beta X
\]

where \(a\) is the index of basic contagion and indicates the tendency to crowding (positive) or repulsion (negative), if \(a = 0\) indicates whether single individuals, a colony \((a > 0)\) or a negative association of individuals and \(0 > a > -1\) is the basic component of the distribution. The slope \((\beta)\) reflects the distribution of the population in space and is interpreted in the same manner as \(b\) of Taylor’s power law (Iwao & Kuno 1968). Goodness of fit for each model was evaluated by coefficients of determination \((R^2)\) and multiple correlation \((MR)\).

A Student t-test can be used to determine whether the colony is composed of single individuals and if colonies are dispersed randomly (Sedaratian et al., 2010 & Moradi-Vajargah et al., 2011).

Test \(b = 1\), \(t = (b - 1) / SE_b\) and Test \(\beta = 1\), \(t = (\beta - 1) / SE_\beta\)

where, \(SE_b\) and \(SE_\beta\) are the standard errors of the slope for the Taylor’s power law and Iwao’s model, respectively. Calculated values are compared with tabulated \((t)\) values with \(n-1\) degrees of freedom (Feng & Nowierski 1992). If the calculated \(t\) \((t_c)\) < \(t\)-table \((t_t)\), the null hypothesis \((b = 1)\) would be accepted and spatial distribution would be random. If \(t > t_t\), the null hypothesis would be rejected and if \(b > 1\) and \(b < 1\), the spatial distribution would be aggregated and uniform, respectively (Nacimamini et al., 2014). The annual data was pooled between two years and overall distribution coefficients were used. Presence or absence of differences between years was calculated based on formulas as follows:

\[
I_{slope} = - \frac{b_1 - b_2}{\sqrt{(SE_{b1}^2 + SE_{b2})}}
\]

\[
I_{slope} = - \frac{\beta_1 - \beta_2}{\sqrt{(SE_{\beta1}^2 + SE_{\beta2})}}
\]

where \(b_1\) and \(b_2\) were Taylor’s coefficient, \(\beta_1\) and \(\beta_2\) were Iwao’s coefficient of two years and \(SE_1\) and \(SE_2\) were their standard errors with \((n_1 + n_2)-2\) degrees of freedom (Feng & Nowierski 1992). The data of two years were integrated and a total distribution coefficient was estimated only when the difference between coefficients of two years was not significant.

For precision estimating optimum sample size, the coefficient from Iwao’s patchiness regression model was used. Precision \((D)\) was defined as follows:

\[
D = \frac{S}{X}
\]

Where, \(S\) is the standard error of the mean and \(D\) is a fixed proportion of the absolute mean of the population involved. It is also known as the allowable error, or fixed precision level, with which the mean is measured (Lindblade et al., 2000). Estimators with standard errors of 5, 10 and 15% at 0.05 probabilities were chosen for this study. The number of samples necessary to estimate the mean with fixed precision was determined by solving for the following:

\[
n = \left[\frac{(a + 1)}{X + (\beta - 1)}\right] / C^2
\]

Where, \(a\) and \(b\) are coefficients obtained from Iwao’s patchiness regression. Because Iwao’s regression coefficients provided the best explanation for the data, we developed sampling recommendations were developed based on Kuno’s formula (Kuno 1969).

All obtained data were subjected to analyses and calculations and were depicted graphically by Microsoft Excel 2010.

**RESULTS AND DISCUSSION**

**Seasonal activity of I. seychellarum**

As given in Table 1, showing that I. seychellarum had three population peaks during the first year (2017/2018). This occurred during the beginning of June, mid-September and mid-November with the mean population numbers of 63.75± 1.65, 93.75± 3.45 and 117.50± 3.52 individuals per sample, respectively. During the second year (2018/2019), indicated the occurrence of four peaks of seasonal activity for I. seychellarum per year, which was recorded in beginning of April, mid-June, mid-August and mid-October with means population numbers of 48.00± 1.78, 87.25± 2.87, 170.50± 5.72 and 137.50± 4.65 individuals/ sample (10 leaves).

The maximum population density of I. seychellarum was observed during the autumn, with mean values of I. seychellarum individuals considerably varying, and it was more in 2018-19 (69.86± 3.92 vs. 62.51± 2.5/10 leaves). The maximum values of log (mean of population) and of crowding of the total population were observed during autumn months, with maximum log (variance) observed during winter in 2017-18, and through the summer in 2018-19 (Table 1).
Table 1. Population of *I. seychellarum* on guava at Esna district, Luxor Governorate (March 2017 and February 2019)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean number of individuals per sample ± S.E.</td>
<td>Mean number of individuals per sample ± S.E.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variance</td>
<td>Log mean</td>
</tr>
<tr>
<td>March</td>
<td>1</td>
<td>29.50 ± 1.04</td>
<td>4.33</td>
</tr>
<tr>
<td>15</td>
<td>38.25 ± 0.85</td>
<td>2.92</td>
<td>1.58</td>
</tr>
<tr>
<td>15</td>
<td>46.75 ± 1.31</td>
<td>6.92</td>
<td>1.67</td>
</tr>
<tr>
<td>15</td>
<td>48.25 ± 1.70</td>
<td>11.58</td>
<td>1.68</td>
</tr>
<tr>
<td>May</td>
<td>1</td>
<td>51.25 ± 1.25</td>
<td>6.25</td>
</tr>
<tr>
<td>15</td>
<td>57.50 ± 1.19</td>
<td>5.67</td>
<td>1.76</td>
</tr>
<tr>
<td>15</td>
<td>45.25 ± 1.95</td>
<td>90.89</td>
<td>1.66</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>45.25 ± 1.95</td>
<td>90.89</td>
</tr>
<tr>
<td>June</td>
<td>1</td>
<td>63.75 ± 1.65</td>
<td>10.92</td>
</tr>
<tr>
<td>15</td>
<td>58.00 ± 1.58</td>
<td>10.00</td>
<td>1.76</td>
</tr>
<tr>
<td>15</td>
<td>62.50 ± 1.76</td>
<td>12.33</td>
<td>1.80</td>
</tr>
<tr>
<td>July</td>
<td>1</td>
<td>56.00 ± 1.87</td>
<td>14.00</td>
</tr>
<tr>
<td>15</td>
<td>66.50 ± 2.06</td>
<td>17.00</td>
<td>1.82</td>
</tr>
<tr>
<td>August</td>
<td>1</td>
<td>80.75 ± 2.50</td>
<td>24.92</td>
</tr>
<tr>
<td>15</td>
<td>64.58 ± 1.81</td>
<td>78.95</td>
<td>1.81</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>64.58 ± 1.81</td>
<td>78.95</td>
</tr>
<tr>
<td>September</td>
<td>1</td>
<td>86.75 ± 3.20</td>
<td>40.92</td>
</tr>
<tr>
<td>15</td>
<td>93.75 ± 3.45</td>
<td>47.58</td>
<td>1.97</td>
</tr>
<tr>
<td>October</td>
<td>1</td>
<td>72.75 ± 2.87</td>
<td>32.92</td>
</tr>
<tr>
<td>15</td>
<td>83.00 ± 2.65</td>
<td>28.00</td>
<td>1.92</td>
</tr>
<tr>
<td>November</td>
<td>1</td>
<td>105.50 ± 3.38</td>
<td>45.67</td>
</tr>
<tr>
<td>15</td>
<td>117.50 ± 3.52</td>
<td>49.67</td>
<td>2.07</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>93.21 ± 3.29</td>
<td>259.04</td>
</tr>
<tr>
<td>December</td>
<td>1</td>
<td>96.25 ± 3.35</td>
<td>44.92</td>
</tr>
<tr>
<td>15</td>
<td>54.00 ± 1.83</td>
<td>13.33</td>
<td>1.73</td>
</tr>
<tr>
<td>January</td>
<td>1</td>
<td>38.25 ± 2.06</td>
<td>16.92</td>
</tr>
<tr>
<td>15</td>
<td>32.00 ± 0.91</td>
<td>3.33</td>
<td>1.51</td>
</tr>
<tr>
<td>February</td>
<td>1</td>
<td>30.50 ± 1.50</td>
<td>9.00</td>
</tr>
<tr>
<td>15</td>
<td>31.00 ± 0.82</td>
<td>2.67</td>
<td>1.49</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>47.00 ± 4.94</td>
<td>586.43</td>
</tr>
<tr>
<td>General average</td>
<td></td>
<td>62.51 ± 2.54</td>
<td>621.01</td>
</tr>
</tbody>
</table>
Sampling

As given in Table 2, the relative variation (R.V.%) for the primary sampling data of *I. seychellarum* indicated that total population density was 4.07 (2017-18), 5.62 (2018-19) and 3.55% (pooled). With different insect species and different hosts, Naeimamini et al. (2014) stated that the relative variation for the primary sampling data of different stages of *Pulvinaria floccifera* (Westwood) (Coccomorpha: Coccidae) was less than 25% and that this was acceptable. Bakry (2018) reported that the relative variation for the primary sampling data of total populations of *Waxiella mimosae* (Signoret) (Coccomorpha: Coccidae) on sunt trees ranged from 8.52 to 19.79% in all seasons of the year, as well as over the entire year.

Spatial distribution

Distribution indices:

Table 2 reveals that the spatial distribution among the sample units was determined by 21 indices. The results of distribution by using the variance of the mealybug, *I. seychellarum* population on guava trees more than general average of total population density by pest and thus, the variance to mean ratio $S^2/m$ more than one indicating that the spatial distribution of total population of *I. seychellarum* is aggregation distribution over the entire year and during the two cumulative years. The index of Lewis of total live stages of the pest was significantly greater than one indicating contagious dispersion. Similarly, conclusions can be made from the results of Cassie index ($Ca$). Total population of the pest distribution was greater than zero, which indicated that *I. seychellarum* on guava trees has an aggregated distribution. The K values of the negative binomial distribution of the total *I. seychellarum* population ranged from 2 to 8 for both years individually and during the cumulative analysis indicating moderate aggregation.

The index values of mean clumping (IDM) were positive for the negative binomial. Z-test values and were greater than 1.96. The index of patchiness was greater than one and Green’s index (GI) was greater than zero and its values were positive. All these indices showed an aggregation distribution for the total population of *I. seychellarum*. The temporal changes in the spatial distribution pattern of *I. seychellarum* population were evaluated using $1/k$ (aggregation index). The value was >1 indicating an aggregated distribution.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max.</td>
<td>117.50</td>
<td>170.50</td>
<td>170.50</td>
</tr>
<tr>
<td>Min.</td>
<td>29.50</td>
<td>28.25</td>
<td>28.25</td>
</tr>
<tr>
<td>Mean</td>
<td>62.51</td>
<td>69.86</td>
<td>66.19</td>
</tr>
<tr>
<td>Range of mean</td>
<td>88.00</td>
<td>142.25</td>
<td>142.25</td>
</tr>
<tr>
<td>Median</td>
<td>57.75</td>
<td>59.38</td>
<td>57.75</td>
</tr>
<tr>
<td>$S^2$</td>
<td>621.01</td>
<td>1477.70</td>
<td>1057.45</td>
</tr>
<tr>
<td>$S$</td>
<td>24.92</td>
<td>38.44</td>
<td>32.52</td>
</tr>
<tr>
<td>SE</td>
<td>2.54</td>
<td>3.92</td>
<td>2.35</td>
</tr>
<tr>
<td>CV</td>
<td>39.87</td>
<td>55.02</td>
<td>49.13</td>
</tr>
<tr>
<td>RV</td>
<td>4.07</td>
<td>5.62</td>
<td>3.55</td>
</tr>
<tr>
<td>$S^2/m$</td>
<td>9.93</td>
<td>21.15</td>
<td>15.98</td>
</tr>
<tr>
<td>Lewis Index</td>
<td>3.15</td>
<td>4.60</td>
<td>4.00</td>
</tr>
<tr>
<td>Cassie index</td>
<td>0.14</td>
<td>0.29</td>
<td>0.23</td>
</tr>
<tr>
<td>K</td>
<td>7.00</td>
<td>3.47</td>
<td>4.42</td>
</tr>
<tr>
<td>$I_p$</td>
<td>943.78</td>
<td>2009.33</td>
<td>3051.53</td>
</tr>
<tr>
<td>Z value</td>
<td>29.70</td>
<td>49.65</td>
<td>58.60</td>
</tr>
<tr>
<td>$I_{on}$</td>
<td>8.93</td>
<td>20.15</td>
<td>14.98</td>
</tr>
<tr>
<td>$X^*$</td>
<td>71.44</td>
<td>90.02</td>
<td>81.16</td>
</tr>
<tr>
<td>$X^*/m$</td>
<td>1.14</td>
<td>1.29</td>
<td>1.23</td>
</tr>
<tr>
<td>GI</td>
<td>0.09</td>
<td>0.21</td>
<td>0.08</td>
</tr>
<tr>
<td>I/k</td>
<td>0.14</td>
<td>0.29</td>
<td>0.23</td>
</tr>
</tbody>
</table>
pattern which became more dispersed with time.

It was concluded that based on the 21 indices, *I. seychellarum* has an aggregation distribution. However, there is no report in literature regarding the distribution pattern of *I. seychellarum*. However, with other insects on different hosts, Chellappan et al. (2013) reported that the value of mean crowding increased with an increase in mean population density of *Paracoccus marginatus* (Hemiptera: Pseudococcidae). Li et al. (2017) observed a *K* value of the negative binomial distribution, and aggregation index (I), and Cassie index (Ca) are all higher than zero during May. This would indicate that *Parapoynx crisonalis* (Lepidoptera: Crambidae) larvae on were in an aggregation distribution. Bala and Kumar (2018) with Lewis index for all the sampling dates of the bug *Chauliops fallax* (Hemiptera: Malcidae) on soybean observed it as >1 with aggregated distribution Bakry (2018) studied that the spatial distribution of *W. mimosae* on sun trees using fourteen indices of dispersion, he recorded that the all models of dispersion indices, exhibited an aggregated distribution and follows a negative binomial distribution pattern for all alive different stages and total population of *W. mimosae*.

**Regression methods**

Taylor’s power law regression showed highly significant positive relationships between the log (mean of population) and log (variance) for the total population of *I. seychellarum* during the first, second years and on the two cumulative years (Table 3) and (Fig. 1). The calculated regression coefficient for Taylor’s method indicated that the slope of Taylor’s power law regression showed highly significant positive relationships between the log (mean of population), would increase the log of variance of population about 1.97 to 2.12 for the total alive population of *I. seychellarum* during the first, second years and with pooled data (Table 3).

The values of regression coefficient (b) from Taylor’s power law were significant being >1. The values were 1.97, 2.12 and 2.07, and the values of t-calculated of the slope (t) > t-table (t) indicating an aggregation. The relationship between these factors has given a good fit for Taylor’s model and the coefficients of determination ($R^2$) were 77.20, 93.47 and 87.10% for the total population during the first, second years and with pooled data. The $R^2$ value showed that the increase in values of variance of the population occurred due to the increase in mean of population density. In this model, the heterogeneity of the regression model indicated that the slope of Taylor’s power law (TPL) did not differ significantly between the two years: (TPL: slope = 1.97, SE_b = 0.23 and n_1 = 24 (2017-18), and 2.12, SE_b = 0.12 and n_2 = 24 (2018-19). The values of t-calculated ($t_1$) = -0.58< t-table ($t_1$) = 2.02 when the df = [(n_1+n_2)-2] = 44. Taylor (1984) contends that the slope (b) is an index of the spatial distribution characteristic of the species, but some studies have shown that b is not species specific and varies among environments and development stages (Downing, 1986).

The regression method of Iwao described the relationship between mean of population ($\bar{X}$) and mean crowding index. The $\bar{X}$ values of regression coefficient (β) were significantly >1, were 1.00, the values of t-calculated of slope ($t_1$) > t-table ($t_1$) indicated an aggregation distribution (Table 3). The calculated regression coefficient of Iwao’s method indicated that an increase of one degree in the mean of population, would increase the mean crowding index about one degree for the total population. Also, the intercept values (α) or the index of basic contagion were negatively and < zero and > -1. The values of (α) ranged from -0.98 to -1.01 (Table 3). The negative values indicated that an aggregation was from individuals rather than colonies and smaller than zero indicated that the total population of pest the basic component of the population tends to be a single individual.

The relationship between mean of population and mean crowding index had a better fit. The coefficients of determination ($R^2$) were 99.9% for the total population of the pest in all tested years as well as the pooled data. $R^2$ showed that the increase in the mean crowding index occurred due to the increase in mean of population (Table 3; Fig. 1). In this model, the heterogeneity of the regression model indicated that the slope of Iwao’s patchiness regression (IPR) did not differed significantly between the two years: (IPR: slope = 1.00, SE_b = 0.001 and n_1 = 24 (2017-18) and 1.00, SE_b = 0.001 and n_2 = 24 (2018-19). The values of t-calculated ($t_1$) = -0.97< t-table ($t_1$) = 2.02 when the df = [(n_1+n_2)-2] = 44 between the two studied years. These findings are in a great agreement with those of Tonhasca et al. (1996).

These results reveal that the regression coefficient (b) values of Taylor’s and (β) values of Iwao’s were both significantly >1 and the values of t-calculated of the slope ($t_1$) > t-table ($t_1$). This indicated that the total population of *I. seychellarum* tends to have an aggregation distribution. Generally, the regression models of Taylor’s power law and Iwao’s to estimate the spatial distribution of a pest. In this case it exhibited that an aggregated pattern and followed a negative
Table 3. Spatial distribution of *I. seychellarum* on guava trees (2017-18, 2018-19)

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Taylor’s power law</th>
<th>Iwao’s patchiness regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>SE_a</td>
</tr>
<tr>
<td>First year</td>
<td>-2.35</td>
<td>0.40</td>
</tr>
<tr>
<td>Second year</td>
<td>-2.56</td>
<td>0.21</td>
</tr>
<tr>
<td>Combined two years</td>
<td>-2.50</td>
<td>0.21</td>
</tr>
<tr>
<td>Difference between two years</td>
<td>-0.58</td>
<td>2.02</td>
</tr>
</tbody>
</table>

Table 4. Population density of *I. seychellarum* and optimum sample size (D = 0.05, 0.10 and 0.15) using enumerative sampling (2017-18, 2018-19)

<table>
<thead>
<tr>
<th>Years</th>
<th>Population density</th>
<th>Optimum number of sample size (n) for achieving a fixed precision levels (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First year</td>
<td>117.50</td>
<td>29.50</td>
</tr>
<tr>
<td>Second</td>
<td>170.50</td>
<td>28.25</td>
</tr>
<tr>
<td>Combined two years</td>
<td>170.50</td>
<td>28.25</td>
</tr>
</tbody>
</table>
binomial distribution pattern for the total population of *I. seychellarum*.

The present results are generally in agreement with those of Esfandiari and Mossadegh (2007). However, with the different insect species and different hosts, all b values from Taylor’s Power law regressions were significantly >1 indicating an aggregation distribution pattern for *Icerya purchasii* (Hemiptera: Margarodidae) on citrus trees. Furthermore, aggregated distribution patterns of other pests using these aggregation indices had been reported (Nematollahi et al., 2014; Arbab, 2014; Arbab and McNeill, 2014; Arbab and Mirphakhar 2016).

**Optimum sample size**

The optimal sample size was calculated using Iwao’s regression coefficient and the relationship between
optimum numbers of sample size and mean numbers of *I. seychellarum* total population. The levels of precision of 5, 10 and 15% were calculated during the first, second years, and with pooled data. The results revealed that the minimum numbers of sample required decreased rapidly with increased mean total population density (at 5, 10 and 15%) as given in Fig. 2. These results agree with those of Esfandiari and Mossadegh (2007). However, with other insects and different host also, similar inverse relationships had been observed between the minimum numbers of sample required and the precision level for sampling of the *I. purchasi* on citrus trees. Also, Arbab and McNeill (2014) reported that the optimum numbers of sample size decreased rapidly as *Sitona humeralis* weevil density increased in levels of precision (10 and 15%).

The optimum sample size fluctuated and depended upon the total population of *I. seychellarum* as well as the desired level of precision. With the precision level of 15%, the mean numbers of sample required for estimating the total population density of *I. seychellarum* are about two samples/monitoring date, a sample includes 10 leaves in 24 dates; and it was

![Fig. 2. Population density of *I. seychellarum* - optimum sample size (n) (D = 0.05, 0.10 and 0.15) using enumerative sampling (2017-18, 2018-19)](image-url)
suitable for IPM purposes. However, the values used for the population ecology studies need a precision of 10%, therefore, the sample size was increased to five samples/monitoring interval (Fig. 2). But for a more accurate estimate (D= %5), the required sample size of guava leaves increased to approximately 60 to 70 samples/monitoring interval (Fig. 2). The results further indicated that, the numbers of sample size required to achieve a desired level of precision were similar between the two years. This similarity in the number of samples of guava leaves could be explained by the similarity of the population density of the pest from year to another may have been influenced by the similarity of the environmental conditions during the study period.

These different precision levels (three lines) developed herein could be chosen for future ecological or insect behavioural studies. Precision levels of 5 and 10% were regarded where a higher level of accuracy is required. For IPM a 15% level would be acceptable. Although such large numbers of sample could be acceptable for research purposes, they may not be practicable for IPM decision support. These results agree with the findings of by Arbab (2014). One attribute of optimum sample size is that at a given density, the required numbers of sample size increases as the dispersion pattern becomes more aggregated (Wipfli et al., 1992).

Mealybugs differ from other insect taxa because their distribution pattern in subsequent stages is shaped by mobile first instars (the crawler stage). The adult females are sessile or move very short distances. The typical thigmotactic behavior of the crawler (Bodendeimer 1951), as the major factor, as well as other intrinsic behavior of the scales (e.g. tendency to settle closely to the parent female, phototaxis during crawlers’ dispersal) determine the distribution of a scale population (Nestel et al., 1995). Successful management of I. seychellarum strongly depends on the development of an appropriate sampling plan (i.e. easy to implement, suitable for rapid decision-making processes). In sampling programs, precision and cost-effectiveness are two of the most important factors that need to be considered (Pedigo 1994). The development of a sequential sampling scheme with a fixed statistical precision, may therefore, be useful for estimating of I. seychellarum density in guava orchards. Such an estimation, in turn, would also be valuable for ecological and pest management studies. Such a sampling program can be used in ecological investigations (Faleiro et al., 2002) as well as for detecting pest levels that lead to a justification of control measures (Arnaldo and Torres 2005).

The distribution pattern of the insect is essential in the management of I. seychellarum. The next steps are to develop an efficient scouting program and establish threshold densities for action that will inform growers on when the pest is active and when interventions (e.g. insecticides) can be applied. The results from this study show that it is reliable predictor of scale populations present in the field and will provide information on relative changes over time. The spatial distribution parameters of this species can therefore be employed to estimate the population density of I. seychellarum. It can be concluded that for the monitoring, sampling and population density estimation of I. seychellarum, the spatial distribution pattern should be considered, because minimal numbers of sample size are dependent on the spatial pattern of the sampled population.

ACKNOWLEDGEMENTS

The authors thank Dr. Walaa Abdelhady Hussien, Plant Protection Department, Faculty of Agriculture and Natural Resources, Aswan University, Aswan, Egypt, for suggestions for this study and in preparation of manuscript.

REFERENCES


Bodenheimer F S. 1951. Citrus Entomology in the Middle East with Special Reference to Egypt, Iran, Iraq, Palestine, Syria, Turkey. Dr W Junk, 'S-Gravenhage, Netherlands.


Monitoring of the scale insect icerya seychellarum (Westwood) infesting guava
Moustafa M S Bakry and A Arbab

Science 33: 207-213.
Southwood T R E. 1995. Ecological methods, with particular reference
Blackwell Sciences, Oxford, U.K.
Taylor L. R. 1984. Assessing and interpreting the spatial distributions of
law and patchiness regressions with regression diagnostics. Journal
of Economic Entomology 89: 1477-1484.
patterns and optimum sample size analyses for three plant bug
(Heteroptera: Miridae) species associated with Birds foot trefoil in

(Manuscript Received: __________; Revised: __________;
Accepted: November, __________; Online Published: __________)