ON ASPECTS OF SAMPLING ELDANA SACCHARINA WALKER (LEPIDOPTERA: PYRALIDAE) POPULATIONS AND DAMAGE IN SUGARCANE

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Abstract

During 2000-2004 a series of field-based insecticide trials were conducted against the sugarcane borer Eldana saccharina Walker (Lepidoptera: Pyralidae) (Eldana) in carry-over cane. Opportunity was taken to re-analyse data assessing Eldana damage and larval numbers in the untreated plots of these trials. The aim was to examine trends in damage and populations over time and their sampling errors. In addition, the relationship between measures of damage was examined as well as position of damage over time. A sequential sampling plan was also developed.

Results showed that over the period August to April, damage and larval numbers increased four and nine-fold, respectively. Also shown was that estimates of damage were more reliable than estimates of larval numbers (average $r^2$ 0.71 and 0.64, respectively). The analysis revealed that there was a reasonable association between the measures ‘% internodes bored’ and ‘% stalks bored’ ($r^2$ 0.39-0.83). Because the latter measure is the simpler of the two to assess, this association may allow a more rapid estimate to be made of the former, the critical measure associated with Eldana losses. Sampling error was highest in the initial surveys, (August) and lowest in the final surveys (April). Trends in the position of damage confirmed that most damage is restricted to the lower section of the stalk but that, over time, damage can occur higher up the stalk.

A sequential sampling plan was developed based on the percentage of internodes bored and using the negative binomial distribution. This demonstrated the possible value of this technique in field sampling for Eldana.

Keywords: sugarcane, Eldana, field sampling errors, damage trends

Introduction

The sampling of insect populations over time in crops can provide critical information on sampling efficiency, crop damage and population trends useful in helping to assess the economics of control options (Binns et al., 2000). Reported here is the use of field data to assess various parameters of sampling for the sugarcane borer Eldana saccharina Walker (Lepidoptera: Pyralidae) (Eldana) and their reliability. This borer remains a major constraint to maximising the economic potential of sugarcane in large parts of the sugar industry.

During 2000-2004, trials were conducted to assess the efficacy of the synthetic pyrethroid alpha-cypermethrin (Fastac®) against Eldana (Leslie et al., 2006). Data from the untreated plots of these trials was re-examined and used to assess sampling efficiency, as well as trends
in damage and populations of untreated populations of this pest. Assessment of such population parameters from field sampling can provide a useful guide to commercial decision making as well as supporting decisions made by the Local Pest, Disease and Variety Control Committees (LPD&VCCs) concerning hazards posed by pest populations. The data were also used to develop a sequential sampling plan for this pest based on the measure percent internodes bored (%IB).

**Material and Methods**

Field trials used in this study comprised sugarcane plots of 0.1-0.4 ha in area (in one trial plots were 0.5-0.8 ha). Crops were typically eight months old in August and 16 months old at harvest. This was to match the typical carry-over cane scenario where Eldana can become a serious economic threat in crops of this age at harvest. Sampling was conducted once every two months over this period. Only data from untreated (control) plots were used, so as to assess trends in untreated populations of Eldana.

**Sampling**

Sampling comprised the following basic strategy. The number of rows per plot was divided by the number of inspectors available (usually five). In small plots (20 rows by 15 m), every fourth row was sampled along its length. Where a 50 stalk sample was taken, each inspector collected ten stalks along the row length, equally spaced, so as to sample equally along the entire row. In subsequent surveys the row adjacent to the previously sampled row was sampled, and so on. In the trial with larger plots a similar pattern was followed so as to sample across the entire plot.

**Data and analysis**

For each sample the following measures were made: Number of stalks bored, number of internodes/stalk, number of internodes bored/stalk, number of larvae/stalk and position of any damage (simply classified at ‘top’, ‘middle’, or ‘bottom’ of stalks). Damage assessment was calculated as % internodes bored (%IB) and % stalks bored (%SB). Larval numbers were assessed as larvae/stalk.

Data from six trials were used in this study, one for each year from 2000 to 2004 (two trials in 2001). In each trial four surveys were conducted over the August to April period. For each sample of 50 stalks, the mean/variance relationship was calculated for variables used (%IB, %SB and larvae/stalk) so as to assess the type of dispersion which in turn dictates the approach for subsequent analysis (Southwood, 1978).

**Sampling efficiency**

Central to the use of survey data in decision making is the precision of the estimates taken. De Villiers and Pringle (2008) give the following equation to estimate the level of precision-D, from given values of sample mean $\bar{x}$, variance $S^2$ and number of samples N.

$$D = \left(\frac{1}{\bar{x}}\right) \sqrt{\frac{S^2}{N}}$$

Eq 1

Because the variance does not always remain constant, particularly in the case of insect populations, equation 1 has to be modified using Taylor’s power law (Taylor 1961):

$$S^2 = a(\bar{x})^b$$

Eq 2

where $a$ and $b$ are linear regression parameters from the regression of means against variances.
Thus, equation 1 now becomes:

\[ D = \left( \frac{1}{N} \right) \sqrt{\left( a \bar{x}^b \right) / N} \]  

Eq 3

Equation 3 can be used to estimate the precision of samples for different means and varying numbers of sampling units. The parameter \( D \) can be multiplied by 100 to provide a percentage sampling error (de Villers and Pringle, 2008). Linear regression plots of log mean against log variance were obtained for each year’s data using %IB and larvae/stalk (the two trials conducted in 2001 were combined for this analysis). From these plots, the parameters \( a \) and \( b \) were obtained. These were then used in equation 3 to calculate values of \( D \) over a range of values for sample size (\( N \)) with the given sample mean.

**Sequential sampling**

Sequential sampling is a procedure that assesses the cumulative value of a measure (%IB for example) after taking a defined number of samples, so as to determine whether or not the value does or does not exceed a critical decision making value. A decision can then be made to take no action, continue sampling or take some specified action. The following example used data on Eldana damage (%IB) and followed the procedures described in Southwood, (1978).

Any sequential sampling plan requires an understanding of the distribution that best fits the data, as plans differ according to the type of dispersal a pest population demonstrates. To determine this, the Index of Dispersion (\( I_D \)) can be used.

\[ I_D = \frac{S^2}{\bar{x}} \]  

Eq 4

where \( S^2 = \) sample variance, \( n = \) sample size and \( \bar{x} = \) sample mean.

The \( I_D \) indicates the degree of departure from randomness and so whether or not the data fit the Poisson distribution. The \( I_D \) was calculated for %IB for each year’s data and values ranged between 309 and 568. If the data followed the Poisson distribution, these values will not lie outside the 0.95-0.05 limits of \( \chi^2 \) for \( n-1 \) (\( n=50 \)) values, which range between 67.5 and 27.9. Thus %IB did not follow the Poisson distribution and Eldana damage tended to be aggregated. Consequently the parameter \( k \) of the negative binomial was calculated and used to develop a sequential sampling plan. For each sampling date and for each year, \( k \) was calculated using the following equation.

\[ k = \frac{\bar{x}^2}{S^2 - \bar{x}} \]  

Eq 5

where \( S^2 \) and \( \bar{x} \) are the variance and mean of the samples taken.

**Results**

*Trends in damage and populations over time*

The levels of damage assessed over the period of the trials (from July/August to March/April) were regressed against time. Analysis showed that a first order polynomial regression equation provided the most reliable fit for all trials and a typical plot is shown in Figure 1. The regression equations for each trial and related calculations are shown in Table 1. Estimates of damage show that over the August to March period damage can increase from two to nine times the initial level, with an average of a four-fold increase. A similar analysis can be conducted using Eldana larval numbers, which shows that these can increase between
one and 24 times the initial estimate with an average eight-fold increase. However, as shown in Table 1, the variation is greater for larval numbers than for damage, showing that the latter measure is probably the more reliable estimator of the impact of this pest. Additionally, as damage is directly related to economic loss, this measure can be considered to be the more important in any economic assessment of the impact of Eldana.

**The relationship between %IB and %SB**

When sampling sugarcane, assessing the number of internodes bored is an accurate but time-consuming process compared to assessing only the numbers of stalks bored (the former requires vertically splitting stalks to clearly see which internodes have been damaged by the borer and counting these). Assessing the percentage of stalks bored (%SB) alone may allow a more rapid estimation of the important measure percent internodes bored (%IB) if there were an association between the two measures. (The importance of the measure ‘%IB’ lies in the fact that it is closely associated with losses caused by Eldana (Bond, 1988)). A typical plot relating these two measures is shown in Figure 2. It can be seen that, up to approximately 30% IB, the relationship appears to be linear, thereafter %SB does not increase as %IB increases. Linear regression plots were fitted to the data of each trial covering the 0-30% IB only range. Shown in Table 2 are the regression equations for %IB against %SB for all trials in this study. The average correlation coefficient over all trials was 0.56±0.166 (x±SD) showing a fair association between these two measures. Thus, by assessing %SB alone it may be possible to reliably predict values of %IB without the time consuming need to split stalks.

![Figure 1](image_url)  
*Figure 1. Trends in the levels of Eldana damage (%IB) (top plot) and numbers (larvae/stalk) (bottom plot) recorded from six trials during the period August to March.*
Table 1. Parameters of polynomial regression equations from the plots of *Eldana saccharina* damage (top) and larval numbers (bottom) over time in six field trials.

<table>
<thead>
<tr>
<th>Year of trial</th>
<th>Regression equation parameters</th>
<th>Estimated initial level of damage (%IB)</th>
<th>Estimated final level of damage (%IB)</th>
<th>Proportional damage increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>-3.1329 20.329 -7.8955 0.7988</td>
<td>9.3</td>
<td>23.3</td>
<td>2.5</td>
</tr>
<tr>
<td>2003</td>
<td>-0.7353 6.2432 8.4075 0.4359</td>
<td>13.9</td>
<td>21.6</td>
<td>1.6</td>
</tr>
<tr>
<td>2002</td>
<td>-0.0557 12.976 -7.9585 0.7266</td>
<td>5.0</td>
<td>43.1</td>
<td>8.7</td>
</tr>
<tr>
<td>2001</td>
<td>1.2239 0.8181 5.1459 0.925</td>
<td>7.2</td>
<td>28.0</td>
<td>3.9</td>
</tr>
<tr>
<td>2001</td>
<td>0.7824 1.6174 4.2208 0.5291</td>
<td>6.6</td>
<td>23.2</td>
<td>3.5</td>
</tr>
<tr>
<td>2000</td>
<td>4.0695 -9.208 19.084 0.8204</td>
<td>13.9</td>
<td>47.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>9.93</td>
<td>31.09</td>
<td>3.92</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>3.83</td>
<td>11.23</td>
<td>2.48</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year of trial</th>
<th>Regression equation parameters</th>
<th>Estimated initial population (larvae/stalk)</th>
<th>Estimated final population (larvae/stalk)</th>
<th>Proportional population increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>-0.1792 1.3555 -1.1175 0.7449</td>
<td>0.1</td>
<td>1.4</td>
<td>24.4</td>
</tr>
<tr>
<td>2003</td>
<td>0.05 -0.2247 0.4 0.2529</td>
<td>0.2</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td>2002</td>
<td>-0.0532 0.8994 -0.8726 0.6868</td>
<td>0.2</td>
<td>1.9</td>
<td>10.4</td>
</tr>
<tr>
<td>2001</td>
<td>-0.0028 0.2027 0.0984 0.9505</td>
<td>0.1</td>
<td>0.7</td>
<td>6.6</td>
</tr>
<tr>
<td>2001</td>
<td>-0.1103 0.6539 0.4543 0.5784</td>
<td>0.1</td>
<td>0.4</td>
<td>4.4</td>
</tr>
<tr>
<td>2000</td>
<td>0.1163 -0.1997 0.6912 0.6256</td>
<td>0.6</td>
<td>1.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.21</td>
<td>1.07</td>
<td>8.35</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>0.20</td>
<td>0.70</td>
<td>8.49</td>
</tr>
</tbody>
</table>

Equation is of the form: $y = ax^2 + bx + c$, where $x$ = time of sample

Figure 2. Relationship between % Internodes Bored (%IB) and % Stalks Bored (%SB) from assessments of untreated plots of the 2002 insecticide trial.
Table 2. Linear regression equation parameters for six data sets relating % Internodes Bored (%IB) and % Stalks Bored (%SB).

| Year of trial | Regression equation parameters |  
|---------------|--------------------------------|---|
| 2004          | 0.4726                          | -22.553 | 0.6088 |
| 2003          | 0.2596                          | -3.2638 | 0.4676 |
| 2002          | 0.3464                          | 2.657   | 0.4118 |
| 2001          | 0.2356                          | -2.8994 | 0.8316 |
| 2001          | 0.1858                          | -0.4978 | 0.6189 |
| 2000          | 1.0463                          | -78.612 | 0.3908 |

Equation is of the form: $y = ax + b$, where $y = \%IB$ and $x = \%SB$

**Sampling efficiency, $D$**

Sampling efficiency is important as it indicates how sample size and damage levels (or insect numbers) are associated. In this study only the initial and final survey data were analysed and the results are shown in Figures 3 and 4.

![Figure 3](image1.png)

**Figure 3.** Percentage sampling error (sampling efficiency $D_*100$) related to sample size based on Eldana larval numbers/stalk sampled from the initial and final surveys of control plots of six insecticide trials.

![Figure 4](image2.png)

**Figure 4.** Percentage sampling error (sampling efficiency $D_*100$) related to sample size based on percent Internodes Bored sampled from the initial and final surveys of control plots of six insecticide trials.
Figure 3 shows plots based on estimates of larval numbers (larvae/stalk). It can be seen that, as sample size increases, so the sampling error declines. Errors were larger in the initial survey compared to the final surveys for sample sizes less than 30. This can be attributed to the lower density of Eldana populations at the start of the trials (average initial and final population estimates were 0.2 and 1.1 larvae/stalk, respectively). In the initial surveys, sampling error varied between years. The lowest error at the sample size of 50 stalks/plot (the size used in the trials) was shown in the 2000 trial (having the highest Eldana population density of 0.63 larvae/stalk) while the highest error was shown in 2001 (lowest Eldana population density of 0.11 larvae/stalk). It was estimated that, for the sampling error in this trial to be reduced to an acceptable 5 or 10%, a sample size of 1246 or 4987 stalks, respectively, would be required. Sampling errors in the final surveys were lower over all years compared to the initial surveys and declined as sample size increased. At the actual sample size taken in these surveys, the average error was approximately 13.1% with an average Eldana population density of 1.1 larvae/stalk.

Sampling errors based on %IB are shown in Figure 4. The range in errors is much lower for this measure compared to that based on larval numbers. In the initial surveys the average estimated error over all years at the actual sampled stalk number of 50 was 10.2%. This was higher where damage levels were lowest, in 2001 (%IB was 7.2%) and lowest where damage was highest, in 2002 (%IB was 65.8%). Sampling error was low in all the final surveys. At the actual sample size, the average sampling error over all years was 6.6%.

**Sequential sampling**

The values of $k$ calculated for the measure %IB were lower in the earlier samples (September and November), indicating greater aggregation and larger in the later samples (January and March) indicating a more random distribution. The average values of $k$ over the five year’s data were 1.2±0.84 and 4.8±2.01 (mean±SD) for the earlier and later samples respectively. The value of $k$ of the earlier samples was used to calculate the equations for the lines shown in Figure 5. The plots show the acceptance and rejection lines based on 5% IB or more (top line) or 1% IB or less (bottom line) in a sample.
These values were selected based on the range of threshold values used in industrial surveys. In this example, if, after sampling 20 stalks, the cumulative %IB exceeds 60%, action is required. (Such actions may be to treat or harvest the crop.) If it is less than 45% no action is required.

The value of this technique is that it offers the possibility of making a decision without necessarily sampling a large number of stalks. Where the level of damage accumulated from initial samples is extremely high or low, such charts can enable decision making without the need to take further samples. It can be, however, that sampling results in values always lying in the ‘in between’ area of the chart (i.e. the decision is always to keep sampling). Under such circumstances, a cut-off sample size needs to be decided upon empirically and action taken.

**Position of damage**

While samples were being collected for damage and population assessment, opportunity was taken to record the position of damaged internodes along the stalk. For each stalk sampled, the number of internodes damaged and their position was recorded simply as being either at the ‘top’, ‘middle’ or ‘bottom’ of a stalk. For each survey, the cumulative number of internodes bored at each position was calculated and expressed as a percentage of the total number of bored internodes counted. Although such an analysis was conducted for all surveys over the period of the trials (no data for 2000), values from the initial and final surveys only are presented in Figure 6.

Results confirm that most damage occurred in the lower and middle sections of stalks. This was so when the infestations were light (at the beginning of the trial) and later on when infestations increased. Although variable, there was an indication that, over time, the percentage of damage occurring in the upper region of stalks increased. Overall it is clear that Eldana damage can occur along the entire length of stalks, and confirms the value of the current practice of inspecting the entire length of sampled stalks for Eldana damage.

![Figure 6. Trends in the position of Eldana damage in the untreated (control) plots of Eldana control trials at two sampling dates.](image-url)
Discussion

The trends in damage and larval numbers used in this study only follow the population over part of the year – from August to April. However, this is the most important period when Eldana damage can reach levels that effectively destroy the economic value of a crop. The polynomial regressions of the two measures of damage tended to provide a more reliable association than the linear regressions that Leslie (2009) used in their analysis, which included the data used in this study. Results showed that, in uncontrolled Eldana populations, damage can increase four-fold over this critical period and larval numbers eight-fold. The variability between seasons may well relate to factors such as the presence or absence of seasonal crop stress, which is known to influence Eldana populations (Atkinson and Nuss, 1989).

A feature of the trend in damage is the association between the percentage of internodes bored and the percentage of stalks bored. This study shows that this association is reasonably linear up to levels of 30% IB. Thereafter the relationship breaks down, when levels of stalk damage approach 90-100%. However, by using this relationship over the range 0-30% IB (the range over which damage is most frequently encountered in the field) it may be possible to increase the time efficiency of scouting operations, particularly industrial surveys which assess %IB in their scouting operations. (The value %Stalk Length Red is actually used in the field, but the two measures – %IB and %SLR – are closely associated and may be used interchangeably.) Were industrial surveys to focus on assessing %SB only, a simple correlation table may allow %IB to be estimated and the hazard level determined based on %SB alone – an easier (and more rapid) measure to take, possibly allowing a greater number of surveys to be conducted with minimal loss of value. A problem may be the widespread assessment of larval numbers in industrial surveys, which requires the slicing of stalks to locate any larvae. By not slicing stalks it would not be possible to assess larval numbers, or confirm that the damage was caused by Eldana. The latter problem could be addressed by periodically slicing a stalk to confirm the borer present. But the inability to assess larval numbers in a survey would require a reassessment of the value of this measure.

Sampling efficiency is important in being able to estimate the reliability of the samples collected. The analysis conducted here shows that estimations of Eldana damage from surveys tended to be more reliable than estimating larval numbers and that, as the incidence of damage increases over time, so does the reliability of estimates. This can be related to the increased density of the pest, which tends to reduce sampling errors. The sample size taken in the trials used in this study was 50 stalks/plot, and the analysis shows that errors ranged between 10 and 25% in the initial surveys but dropped to below 10% in the final surveys. Sampling errors based on larval numbers were larger, being between 20 and 50% in the initial surveys and between 10 and 30% in the final surveys. Where levels of damage and larval numbers are expected to be low, a larger sample size is to be preferred; though to match the precision shown in the final surveys, the sample size required may be unacceptably large.

Sequential sampling can be a useful tool allowing decision making with a small sample size. In the examples given here, the measure %IB has been used. The analyses reported here were conducted using trial data derived from sampling plots of research trials, whereas normal industrial surveys sample much larger blocks of sugarcane (10 ha or more) and the values developed using trial data cannot be used for large scale surveys. They do, however, indicate the value of the trends that can be derived from field surveys, and their use may improve the efficiency of industrial surveys. The sequential sampling plan discussed here was based on damage estimates. It is possible to generate plots based on larval numbers as used in
industrial surveys. However, because of the large errors associated with sampling larval numbers, the reliability of such plans in decision making would require testing.

As shown in this study, Eldana damage tends to be greatest in the lower part of sugarcane stalks where sucrose accumulates. This confirms the general understanding of Eldana damage, which is recognised as having a greater effect on sugarcane quality than on cane tonnage (King, 1989). However, as shown in this study, damage can occur along the length of stalks and while damage remains concentrated in the lower/middle sections of stalks in older sugarcane, the proportion occurring in the upper parts of stalks increases over time. The reasons why Eldana preferentially selects the lower parts of the stalk is unclear, but may be related to the differential levels of plant defences (Rutherford et al., 1993). The analyses of measures used to assess borer damage and numbers have shown the possible value arising from their use to improve sampling efficiency. Further studies are required with industrial data to confirm their value in commercial scouting operations.

Conclusions

Eldana damage and larval numbers can, on average increase four and nine-fold, respectively, in carry-over cane.
Sampling for Eldana damage is more reliable than sampling for Eldana larval numbers. There is a reasonable association between the measures %IB and %SB that may permit more rapid assessment of Eldana damage in industrial surveys. Sequential sampling methods may allow more time efficient assessment of Eldana damage in industrial surveys.
Eldana damage occurs mainly in the lower section of the stalk but, as the crop ages, damage can occur higher up the stalk.

REFERENCES