Development of a day-degree model to predict generation events for lightbrown apple moth *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) on grapevines in Australia.

D.G. Madge and **S.C. Stirrat**, Sunraysia Horticultural Centre, P.O. Box 905, Mildura, Victoria 3502, Australia.

Summary

Lightbrown apple moth (LBAM) *Epiphyas postvittana* (Walker) is a significant pest of grapevines. Table grape production suffers most as LBAM can severely affect fruit quality and it is a quarantine pest in important export markets. Serious infestations can also affect dried fruit and wine grape production. A simple computer model based on day-degree (dd) accumulation is being adapted as a management tool for LBAM in the Sunraysia district of Victoria and New South Wales. Use of historical data has shown the model can predict the timing of LBAM egg hatch and moth emergence. These predictions are being used to help fruit growers effectively time applications of control treatments.

Introduction

Lightbrown apple moth is endemic to Australia and has a wide host range, including many introduced horticultural crops (Danthanarayana 1975). It belongs to the "leaf roller" group of moths, the larvae of which create sheltered feeding sites. In grapevines, a feeding site is formed when a larva attaches silk-like webbing to the surface of a leaf which is pulled into a tube-shaped shelter as the webbing dries. Bunches become preferred feeding sites when fruit develops (Buchanan 1977). In bunches the larvae attach berries to one another, to stems, pedicels, or to leaves.

The leaf rolling behaviour makes the larvae of LBAM difficult to control as they are sheltered from insecticide applications during most of their development. Timing of insecticide application is very important. If larvae are to be controlled effectively, insecticides must be applied to the vines before the majority of eggs hatch and the larvae establish feeding sites. First instar larvae are most susceptible as they cannot create true leaf rolls and are therefore relatively exposed. Treatments may also be applied at moth emergence to reduce moth numbers before egg-laying commences. Prior knowledge of the emergence of both larvae and moths can therefore be a powerful tool for effectively controlling this pest.

To help growers exporting table grapes to Canada, testing and application of a predictive model for LBAM control in vineyards in Sunraysia near Mildura, Victoria, began in the 1987/88 season. A condition of the export protocol with Canada was that growers achieve a pre-harvest target of less than 0.1% bunch infestation by LBAM. The model was used to advise growers about accurate timing of their spray treatments. Each week throughout the season the growers were informed of the status of LBAM populations in the district and when control measures were necessary. With this information, most growers achieved the required control target. The strategy was also used in a table grape export program for New Zealand where similar quarantine restrictions apply. A description of the development and early evaluation of the model follows.

The model

The LBAM model is based on dd accumulation and was originally written as a Lotus spreadsheet, for use in codling moth control (Williams 1988). It was adapted for use on LBAM and later re-written using the single-sine method of dd calculation (Zalom *et al* 1983). It is run on an IBM personal computer and has been maintained as a Lotus (v2.2) spreadsheet for ease of use and modification. While the model is still being refined, the spreadsheet will be used manually for data entry and output, although these functions may be automated later. The model is configured to predict the dates of moth flight and egg hatch peaks. The following parameters are necessary for the prediction of these events.

Biofix date

This is the date at which dd accumulation commences and was initially set at July 1.

Temperature thresholds

These define the range over which development of the model's subject will occur. The LBAM model uses thresholds of 7° C and 29° C based on the work of Danthanarayana (1975) and Geier and Springett (1976). It does not take into account effects of temperatures outside these thresholds. Day-degree accumulation in the model ceases at the thresholds while in reality it continues but at an altered rate (Danthanarayana 1975).

Day-degree requirements

The initial dd requirements for each development stage were taken from Danthanarayana (1975). The values used were preoviposition 30, egg development 130, larval development 350 and pupal development 140, totalling 650 dd per generation.

Meteorological data

The dd calculations are based on daily maximum and minimum temperatures. At the start of each season average monthly maximum and minimum temperatures are used by the model to calculate the predictions. Each week during the season, daily maxima and minima for the previous week are collected from the Bureau of Meteorology weather station (Mildura) and entered into the spreadsheet. This up-to-date data refines the predictions as the predicted dates are approached.

Monitoring

The historical data of moth catches initially used to validate the model consisted of weekly records from lure traps containing 10% port wine solution. Some historical data on age distribution and abundance of larvae were also available. Since 1987 monitoring has been intensified to gather reliable data for testing the model. Nine wine lures (10% portwine), in a 0.5 ha patch of untreated vines, were checked twice weekly from bud burst and replenished when necessary. Larvae were monitored weekly by inspection of vines in the same patch and were separated into four arbitrary size classes to indicate age. Larvae were considered recently hatched when they were up to 4 mm long and uniformly lightbrown. Small larvae were between 4 mm and 7 mm long. At this stage they were either light green with a brown head capsule, or were becoming light green. Medium larvae were 7 mm to 12 mm long and large larvae were longer than 12 mm. The appearance of large numbers of recently hatched and small larvae in the sample was taken as the most accurate indication of the start of egg hatch of a new generation.

Results and discussion of model validation

Local moth catch data from seven years, and larval survey results from two years were used to validate the model. Timing of peak moth flights was determined by visual appraisal of graphs of field data. The flight peaks were confirmed where possible, with larval survey data which more accurately indicate the timing of generations. The 650 dd total fitted the spring and early summer peaks in these graphs, and apparent peaks that occurred later in the season. However, the results of more intensive monitoring of moth and larva numbers from the 1987/88 to 1989/90 seasons did not support a 650 dd generation time. Generation times based on all available moth and larval monitoring data were therefore adopted. Although data from field monitoring of larvae is considered more reliable for determining the timing of LBAM generations, the current model has been developed and validated largely using moth trap data due to its greater availability. As more larval data is collected, it will be used to further modify the model's parameters.

During validation, it was noted that the prediction of generation events was more consistent when related to budburst rather than a biofix of July 1. For this reason budburst is now used as the biofix date. Using vine budburst as a biofix, the interval to the first moth peak averages 233 dd. Subsequent generation times are 782, 767 and 797 dd.

Appraisal of the moth catch data for all 10 years showed that 23 obvious moth flight peaks could be attributed to distinct generations. Using the modified generation times, the dates of predicted flight peaks were within seven days of the observed event for 20 of the 23 peaks. Because most of the generations appear to have extended over at least four weeks, timing of control treatments using the model should effectively target the periods when a high number of moths and susceptible larvae are present.

Graphs of moth and larva numbers with model predictions are presented in figures 1 and 2. These demonstrate the performance of the model during years when it was used for practical LBAM management decisions. The graphs indicate several trends of population development of LBAM in Sunraysia. The first and second generations, spring and early summer respectively, are relatively large in most seasons, the second often being the largest. The second generation is also commonly extended, numbers often staying high for up to six weeks. After the second generation in December the numbers usually decline in the third and fourth generations, late summer and autumn respectively. This may be a result of high temperatures which kill eggs and larvae (Danthanarayana 1975). If high temperatures do not persist the population may recover in the fourth generation. High temperatures vary in their effect each season as they must coincide with periods of egg development to have a detrimental effect on the population.

An obvious inconsistency in prediction accuracy occurs in the first generation of 1987/88 (Figures 1a and 2a). The prediction is about three weeks early. However, there was a lack of data to validate this peak because monitoring of moths did not commence until October 13. This was also the only generation in all the data, where the prediction was apparently so inaccurate. The inconsistency is unusual because the second generation prediction was accurate.

At present, larval counts are performed once weekly, and moth counts twice weekly. Based on larval counts, the model can only be validated to within 7 days. To determine whether the predictions are more accurate than appears from current data requires intensive daily monitoring in subsequent years. This would be a labour intensive and costly exercise of doubtful practical value. Effectiveness of control is more likely to be improved by attention to spray application techniques than by attempts to increase the accuracy of the model by such laborious validation methods. This accuracy is best increased by modification with additional monitoring data following each season of use.

Figures 1 and 2 also indicate the effects of several phenomena that make validation of the model difficult. High temperatures that kill eggs cause low moth catches in the ensuing generation so determination and validation of later moth peaks is difficult. This was evident in 1987/88 (Figure 2a) and 1989/90 (Figure 2c) when high temperatures were experienced during egg development in mid-late December. Egg mortality is suspected of causing low moth numbers in January.

Egg mortality can also affect the accuracy of ensuing predictions by displacing the observed peak. For example, if mortality occurs early in the development of eggs of one generation, the

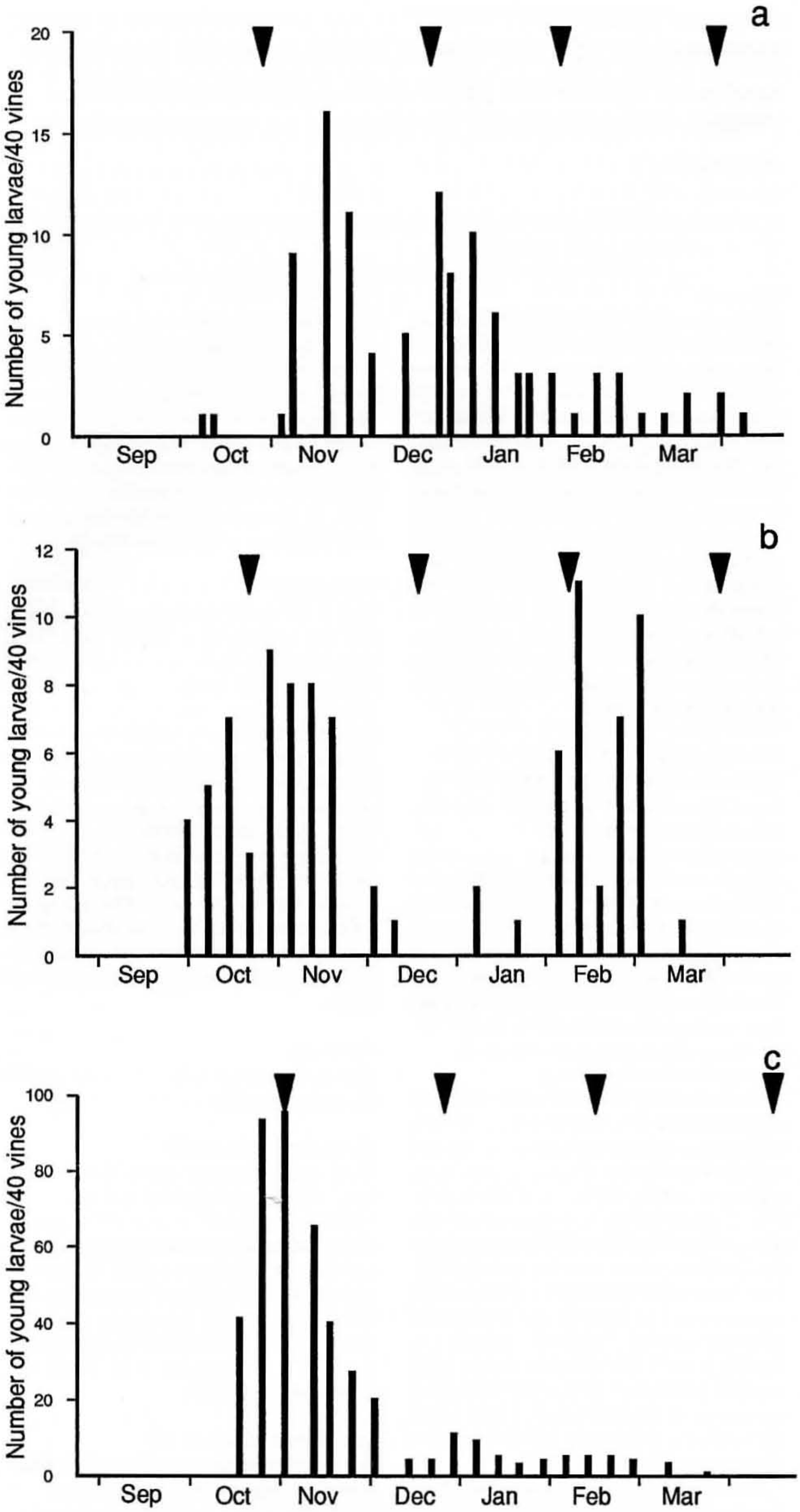

Figure 1. Weekly totals of recently hatched lightbrown apple moth larvae per 40 vine samples, with predicted peaks arrowed. (a)1987/88, (b) 1988/89, (c) 1989/90

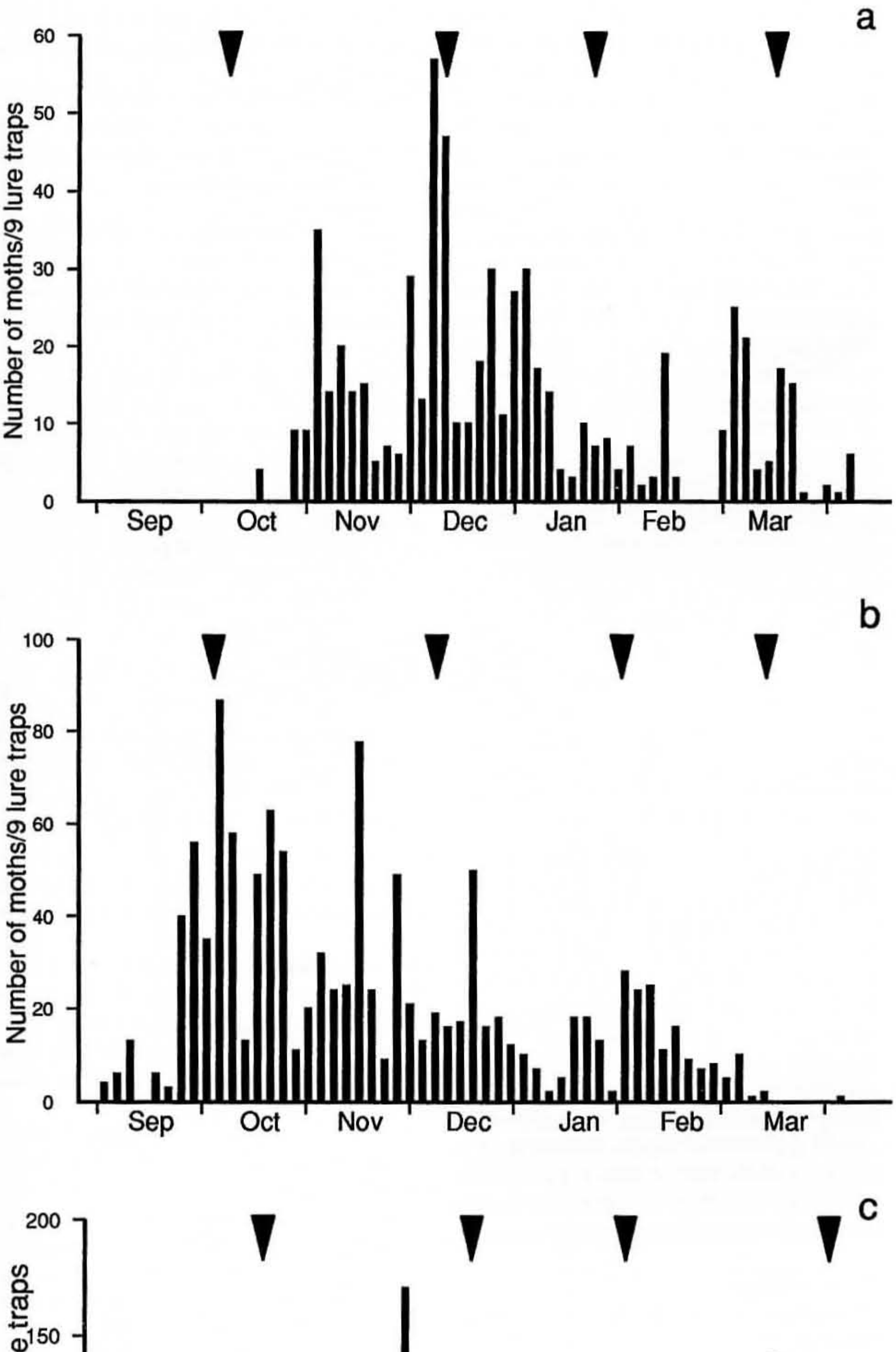

Figure 2. Weekly totals of lightbrown apple moth adults per 9 wine lure traps, with predicted peaks arrowed. (a)1987/88, (b) 1988/89, (c) 1989/90

ensuing moth emergence will peak later than predicted. This is because most of the moths will result from eggs laid after the high temperatures occurred. The model does not take this influence into consideration and assumes the insects are not affected. This phenomenon is apparent in the third generation in 1987/88 (Figure 2a). If the disruption does not occur, or the population recovers in the fourth generation, the model predicts this generation accurately.

There are also instances where catches of large numbers of moths occur between predicted generation peaks early in the season, when fewer moths would be expected. These large catches could lead the observer to assume that an additional generation had occurred. However, this has not been supported by monitoring larva development.

General discussion

Applications of the model in grapevine production

There are two applications of this model for LBAM management.

1. The predictions may be used directly to time the application of spray treatments to control moths and larvae. This would result in more efficient pesticide use compared to routine spray programs. This approach has been used in table grape export programs to achieve better control of LBAM in fruit destined for export markets.
2. The predictions can be used to improve the efficiency of the monitoring procedure. Where an economic threshold for larval infestation is known, monitoring is essential to determine whether a treatment is needed. The model can predict egg hatch periods, which are the critical times for monitoring, and so obviate the need for monitoring in unimportant periods during the season.

The high value table grape industry has much to gain from LBAM modelling as a management tool. Because the tolerance for LBAM infestation or damage in table grapes is very low, some form of management is always required. Any LBAM damage in mature fruit results in crop loss and increased labour costs for cleaning fruit. Damage can be the site of fungal infections which also downgrade fruit quality. Use of the model to time spraying during periods of high risk will increase the efficiency of expensive control measures. In contrast, production of dried fruit does not require such a high level of management and, depending on the severity of the infestation, fewer control measures are applied by many growers. However, the LBAM model has potential to help these growers to better target their limited treatments.

Even if sprays for LBAM are timed correctly using the model, the number of treatments required during the season may not be reduced because LBAM has a relatively short generation time. However, use of the model could lead to modification of the timing of these treatments from the traditional regular spray program. If applied to other pests with longer generation times, the model has real potential to reduce the number of spray applications necessary, especially where regular cover sprays are used as preventative treatments.

The model can also assist growers who prefer to use selective larvicides such as *Bacil-*

lus thuringiensis to promote biological control of LBAM and other pests. This bacterial insecticide is a commonly used control agent which is short lived and is effective only against larvae. By using the model to refine spray timing, growers can intensify treatments for the period in each generation when the larvae are susceptible. Biological control is facilitated by the use of such treatments which do not adversely affect beneficial organisms (Buchanan 1977). Emphasis on this integrated pest management approach is likely to increase as growers become more aware of effects and marketing implications of synthetic chemical use.

The model also showed that a fourth generation of LBAM can occur during the grape season. This is indicated in 1987/88 (Figure 2a). It has previously been assumed that only three generations were likely (Danthanarayana 1975, Baker and Lang 1983). This is important for growers of late table grape varieties which do not mature until March-April. Control measures need to be maintained on these varieties, especially if they are destined for export to countries with quarantine restrictions on contaminants.

Model refinement

The accuracy of model predictions is currently limited by the available information on growth parameters of LBAM. Although the predictions of the model fit the majority of the historical data, anomalies exist where predictions do not match apparent generation peaks. Further refinement of the model requires clarification of the dd requirements and threshold temperatures for LBAM in Sunraysia. The growth parameters determined by Danthanarayana (1975) were based on LBAM cultures from South East Victoria for which he found constant temperatures above 31°C were lethal for eggs and larvae. Based on this result he concluded that "regions with long, hot summers will not support *Epiphyas* populations". However, large populations of LBAM do exist in Sunraysia, where high temperatures are experienced periodically for several months of the year. This survival may be explained by the fact that constant high temperatures do not occur in field situations. Exposure to these temperatures occurs for only a few hours daily. An alternative explanation could be the adaptation of LBAM to Sunraysia's more extreme temperature regimes.

Application of dd models for other pests and regions

Practical application of the model in other horticultural areas has potential and needs testing to determine regional differences in LBAM characteristics. Extrapolation of LBAM dd requirements from one area to another appears tenuous, so application of the model to other regions will require the collection of appropriate dd data.

Application of the model to other pests also has potential. Fuller's rose weevil and longtailed mealybug are two important pests of citrus and vines respectively in Sunraysia and the Riverland. Fuller's rose weevil causes problems in export citrus because unhatched eggmasses on the fruit are a quarantine concern in Japan. These eggmasses are generally found under the button of the fruit. To ensure that harvested fruit is free of unhatched eggs, adult weevils emerging from in-soil pupation must be excluded from the trees prior to harvest. The exclusion period is based on weevil longevity and the number of dd required for egg development. The starting date of this period could be predicted by the model using egg development rates and anticipated harvest time (Lakin and Morse 1989). The exclusion of weevils from the trees from that date onwards should ensure that any viable eggs present on the fruit have hatched before harvest.

Longtailed mealybug can be very destructive, especially in table grape production. It has a synchronous life cycle and reproduces three times during the growing season. Good control relies on growers being able to target periods of reproduction when nymphs are active and susceptible to treatment. Once settled and feeding, mealybugs are more difficult to control as they prefer sheltered sites. Using a predictive model, growers will be able to confidently restrict spray treatments to the times when they are most effective.

Disease management

The simple dd model for LBAM management described in this paper is one example of the potential use of computer technology in pest management. Weather-based computer models are also being developed for management of grapevine diseases like downy mildew (Magarey *et al* 1991). Such models have the potential to significantly increase the efficiency of pest and disease management, to ensure continuity of supply of clean fruit to export markets, and to reduce the environmental hazards from agri-chemical use by enabling growers to time sprays appropriately.

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