

Cotton Research and Development Corporation

Project UQ24C

Heliothis migration and pest management: Effects of
movements within and between cropping regions

Final report

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1 Background

Conventional insecticides are the primary tools for controlling *Helicoverpa* in Australian cotton (Shaw 2000). Despite the introduction of transgenic cotton varieties, conventional chemicals will continue to be important in the foreseeable future. The important chemicals will continue to include those such as synthetic pyrethroid that are under pressure from resistance (Fitt 1994).

Over-reliance on conventional insecticides has induced resistance in the pest, disrupted beneficials and resulted in damaging levels of environmental contamination. To counter these problems the cotton industry has adopted integrated pest management (IPM) measures that aim to reduce insecticide use while maintaining profitability (Shaw 2000).

Field-level IPM aims to find the best balance between low insecticide use and high yield for the prevailing levels of pest pressure and insecticide resistance. Because *Helicoverpa* moths are highly mobile and breed on a variety of host plants, pressure and resistance are characteristics of the cropping region rather than of individual fields, and must therefore be managed at a regional level (Zalucki et al. 1998). Insecticide resistance is managed at a regional level with resistance management strategies. Such strategies are successfully maintaining the efficacy of insecticides such as synthetic pyrethroids. Similarly, area-wide management is currently being trialled as a method for reducing pest abundance at a regional level (CRDC project DAQ85C).

Area-wide management controls the pest within the entire agroecosystem rather than individual fields (Knippling & Stadelbacher 1983). It aims to reduce the incidence of resistant overwintering pupae, reduce early season buildup, and reduce mid-season pressure. Methods include trap cropping, planting windows, pupa busting and mowing of non-crop hosts (Fitt 1994).

Because area-wide management treats the pest at a regional level, its methods rely on assumptions about the movement of moths within, into and out of the region (Schneider et al. 1989). For example, pupa busting assumes that the contribution of overwintering pupae to spring abundance is significant relative to that of migration into the region. Trap cropping assumes that moths move among hosts and preferentially lay eggs on attractive hosts. It also assumes that the contribution of early season breeding to mid-season abundance is significant relative to that of migration.

We have information on some of these assumptions. For example, the contribution of overwintering pupae in northern NSW has been inferred from pheromone trap catches, emergence trap data, emergence models and insecticide resistance frequencies (Fitt & Daly 1990). For other assumptions we can make predictions based on our knowledge of flight behaviour, but have not yet tested whether these predictions hold in the field. For example, mark-recapture studies indicate that moths will undertake non-migratory flights of more than 10 km within a cropping region. However, we have not yet measured the effects of such movements on abundance in crops.

2 Objectives and their achievement

The aim of this project was to test whether observed patterns in historical *Helicoverpa* abundance data were consistent with our understanding of moth flight behaviour, and to measure the effects of moth movement on these abundance patterns. The specific aims, and the extent to which they have been achieved, are as follows:

4 Results

4.1 Summary of seasonal activity

The seasonal pattern of *Helicoverpa* abundance was similar for the Brookstead and Jimbour study areas and for the 1997–98 and 1998–99 seasons (figure 1). Oviposition peaked in late November, mid-January and February. The densities of eggs and large larvae increased throughout the season.

4.2 Lifetable statistics

Survival between lifestages and generations was estimated by comparison of densities for times at which the same insects would have been at different lifestages. Development times were estimated with the development model. Survival was estimated for individual fields and the region as a whole.

Regional survival from eggs to large larvae increased during the season from $\sim 0.1\%$ to $\sim 1\%$. This increase was due to greater survival of small to large larvae. Survival of eggs and very small larvae declined. Survival varied among fields. It was often zero in the majority of fields, and often varied by a factor of 10 within its interquartile range at other times. Consequently, the abundance of large larvae in a field was not significantly correlated with the abundance of eggs at the start of the generation.

4.3 Moths from within the field

If a cotton field is generating enough moths to produce the eggs being laid in the field, then the number of large larvae in the field in the previous generation must have been at least the required number of moths. Although average fecundity in the laboratory is 1000–1500 eggs per female (or 500–750 eggs per moth), fecundity will be lower in nature where food is limiting and environmental conditions are suboptimal. Also, survival between the large larva and adult stages is less than 100%. We would therefore expect substantially fewer than 500–750 eggs from each large larva.

Before late February the majority of cotton fields experienced egg lays despite having no detectable large larvae in the previous generation. Even after late February the percentage of such fields was generally above 25%. Some, and often the majority, of the fields therefore received many more eggs than could have been produced by the moths they produced themselves.

If moths tend to lay eggs within their fields of origin, then oviposition in a field should be correlated with the number of moths emerging from the field (when the number of moths is sufficient to produce a substantial proportion of the eggs being laid in the field). If pupal survival and moth fecundity are not too variable, then oviposition in a field will also be correlated with the number of large larvae in the field in the previous generation. Such a correlation was not present—even at the end of the season when oviposition in the majority of fields was low enough to be explained by within-field breeding. There was therefore no detectable tendency for a moth to lay most of its eggs within its field of origin.

If breeding on crops of all types within the region contributes significantly to regional moth abundance, then oviposition will feature peaks at intervals of one generation (under various logical conditions not listed here). More than one series of peaks may occur if there are multiple immigration or emergence events. More generally, oviposition at a given time will be related to oviposition one generation before that time. We tested the hypothesis by calculating serial correlograms of regional average egg density with sample times converted to *Helicoverpa* physiological time. The expected increase in correlation at a lag of one generation was present at Brookstead in 1997-98 and 1998-99 and at Jimbour (the smaller and therefore less self contained region) in 1998-99 only.

4.6 Moths from outside of the region

Migration is difficult to detect with pheromone trap or egg count data because the data are affected by moth activity. Variation in catches or counts due to variation in activity is often larger than the variation in abundance we are trying to measure. We suspect migration when there is a rise in oviposition that cannot be explained by abundance in the previous generation. Such an increase occurred around 10 December 1997 at Brookstead and Jimbour following good conditions for migration from the north-west. Because this method only detects immigration when it causes changes in abundance that cannot be explained by local breeding, it cannot indicate when migration is not occurring. In particular, migration from nearby regions with similar generation times is unlikely to be detected. Multivariate time series analysis (see section 5.3) will provide a more sensitive method for detecting immigration.

4.7 Spatial pattern of oviposition

Patterns in the weekly distribution of *Helicoverpa* eggs and larvae were detected with maps of spatially interpolated density (e.g. figure 2) and spatial autocorrelation analysis. On average, egg density was autocorrelated out to 2-3 km. Eggs therefore tended to be distributed in patches about 5 km across. Patchiness was less for larvae and declined with the age of the insects.

Persistence of the egg patterns was tested with correlation analysis and ANOVA. Correlation between the density of eggs in a field and the density of eggs in the field one generation earlier was variable but often significantly positive. ANOVA for the effect of time and field across the season indicated that the field effect varied among seasons and consultants, but was often significantly positive. Patterns in oviposition therefore persist to some degree, but are not constant.

4.8 Effects of trap crops

The logical approach for testing the effectiveness of trap crops in reducing the abundance of moths would be to run a controlled experiment involving a number of regions and seasons (Schneider et al. 1989); however, such an experiment would be expensive. One method for testing whether trap crops attract moths away from their surroundings is to test whether oviposition is lower on cotton that is near a trap crop. Our preliminary analysis was inconclusive because data on the locations of the trap crops were incomplete. Addition of complete data on the trap crops plus data for a second trap cropping season (now available) will strengthen this analysis.

the difference in oviposition during January can be explained by increased breeding on cotton rather than a greater contribution from non-cotton crops.

Non-spatial analyses were also repeated for Emerald. (Spatial analyses could not be performed because the Emerald data were not geocoded.) To date, we have simply transferred the results to Dr Sequeira, and have not interpreted them in detail.

5 Discussion

5.1 Impact of movement

These results are consistent with biological studies of moth movement and host selection. Such studies indicate that moths move among fields within a region and preferentially lay eggs on attractive hosts (Fitt 1991). The distribution of eggs in a region depends on moth host selection behaviour and the distribution and phenology of host plants in the region. Host selection includes location of host patches and selection of plants within patches. The distribution and phenology of host plants affects the expression of host preferences: they affect the way moths encounter host plants in the present (Fitt 1991) and the experience moths have had with hosts in the past (Cunningham et al. 1999).

Oviposition varied among cotton fields. It was not related to estimated moth production by the field. It must therefore have been determined by the number of moths entering and leaving the field and by the number of eggs laid by moths when in the field. These numbers are determined by the abundance of moths within reach of the field and the attractiveness of the field relative to that of its surroundings.

Oviposition varied in patches multiple kilometres across. The patches persisted to some extent, but were not constant. Patchiness in oviposition arises from spatial variation in moth emergence or crop attractiveness. Variation in emergence is unlikely to explain all of the patchiness in oviposition because patchiness in the abundance of the large larvae that gave rise to the moths was less than patchiness in oviposition. Crop attractiveness therefore appears to vary in patches multiple kilometres across. The variation may be due to features of the fields themselves (e.g. cotton variety, management practices) or to features of the landscape (e.g. surrounding crops and native vegetation).

Cotton is unlikely to have been the primary source of moths until at least January. The January peak in oviposition appears to have at been at least partly driven by emergence from cotton. Abundance patterns from January onwards can be explained in the absence of migration from outside of the region. High January pressure in 1997-98 relative to that in 1998-99 appears to have been due to a greater input of moths from non-cotton crops or from outside of the region rather than to increased survival on cotton. In contrast, high January pressure at Brookstead relative to that at Midkin can be explained by increased survival on cotton.

The above interpretation of the project results relies on two untested assumptions. The first is that the fertility of moths in the field is less than fecundity measured in the laboratory, and probably of the order of 100-200 eggs per female. If fertility is much lower, then the contribution of cotton will be lower. The second assumption is that pupal survival under cotton is reasonably high (> 50%) and reasonably constant between fields. If pupal survival is particularly low, then the contribution of cotton will again be lower. If pupal survival is variable, then oviposition variability attributed to moth movement may in fact be due to variability in pupal survival.

- Time series analysis based on *Helicoverpa* physiological time is a promising analysis method. With this method we detected the effect of previous generation abundance on current pressure at the regional scale. Multivariate time series analysis will enable us to partition out the effects of previous generations and environmental factors. We will then be able to more accurately determine when movement from non-cotton crops or other regions has occurred. We have successfully used multivariate time series analysis to separate the effects of temperature and migration on *Helicoverpa* pheromone trap catches in Victoria (Rochester 1999). The time series analysis method used here is the same as that used in economic forecasting. Analyses based on this method may lead to easily implemented models for providing short-term forecasts of pressure within regions.
- Important unknowns when interpreting results from this project and planning area-wide management strategies are the proportions of *Helicoverpa* moths that originate in cotton, non-cotton crops and weeds at different times during the season. One approach to the problem would be to estimate the proportions based on analysis of crop areas and any existing survey data we can obtain. Gaps in the data could then be filled in with targetted field surveys.
- Our databases and analysis tools provide an ecological framework for developing sampling strategies and interpreting results of the genetic markers project (UQ32C). Population statistics from our databases can be used to assist in the development of effective sampling plans. Our migration model, development model and environmental databases provide ecological information required to interpret the genetic data.

6 Project technology

The project did not develop technology of commercial value.

7 Information developed as part of the project

The project developed a substantial database of historical crop scouting data and related data. We have examined just a few of many questions on *Helicoverpa* dynamics that could be addressed with this database. We have developed methods for generating analysable data from large, imperfect datasets, and have developed software for mapping and performing highly repetitive analyses on large databases.

Our first step in analysing the Darling Downs and Midkin datasets was to summarise the *Helicoverpa* monitoring data with various maps and graphs (e.g. figures 1 and 2), and to distribute the summaries to collaborators via the WWW. The same methods could be used in a WWW-based information service for growers, consultants and extension scientists.

8 Exploiting project technology

A significant challenge for the project was the need to enter, clean and standardise data collected with different sampling methods. Widespread adoption of the CottonLOGIC

Zalucki, M. P., Rochester, W. A., Norton, G. A., Maelzer, D., Fitt, G. P. & Adamson, D. (1998) IPM and heliothis: What we have to do to make it work. In: Zalucki, M. P., Drew, R. & White, G. (eds.), *Pest Management—Future Challenges. Proceedings of the Sixth Australian Applied Entomological Research Conference, Brisbane, 29 September – 2 October 1998.*, vol. 2, pp. 107–114.

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Final report: Plain english summary

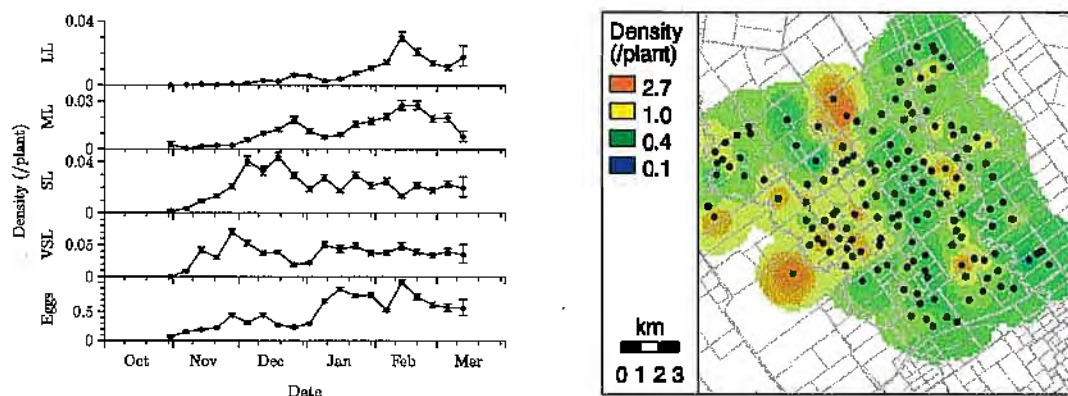
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Over-reliance on conventional insecticides for heliothis control induces resistance in the pest, disrupts beneficials and contaminates the environment. However, despite the introduction of transgenic cotton, conventional chemicals will continue to be important in the foreseeable future. The cotton industry is therefore taking steps to better manage the use of these chemicals. For example, field-level integrated pest management minimises insecticide use while maintaining profitability under the prevailing levels of pest abundance and resistance. It does not attempt to control regional abundance or resistance. For this we use area-wide management (AWM) and insecticide resistance management (IRM).

Although IRM has effectively maintained the efficacy of insecticides such as synthetic pyrethroids, AWM is still in the trial stage. Because AWM treats the pest at a regional level, its methods (e.g. trap cropping and pupa busting) rely on assumptions about the movement of moths within, into and out of the region. We can predict the likely effects of moth movement from what we know of moth behaviour. Our project tested whether the infestation patterns we see in the field are consistent with these predictions. We determined infestation patterns from crop scouting data obtained from the QDPI Darling Downs AWM trial (CRDC project DAQ85C), Auscott Midkin, Dr Richard Sequeira at Emerald, and the SIRATAC database. Our analysis methods included digital mapping, graphing, conventional and spatial statistics and simulation modelling.

Infestation patterns agreed with the theory that heliothis moths move freely among crops and lay more eggs on the most attractive hosts. Oviposition 'hotspots' multiple kilometres across were common. They appeared to be related to the attractiveness of crops or their surroundings rather than to moth production by individual fields. The hotspots often persisted across generations, but were not permanent. The results are consistent with a system in which AWM could *potentially* work, but further research is required to determine whether it *actually* works. The results also support research into manipulation of crop attractiveness (e.g. using behaviour modifying chemicals) as a method for reducing oviposition in crops.

The project developed a large information base and methods for analysing large, imperfect datasets. We hope to use these resources to help analyse data from other AWM projects and to provide ecological information to help collect and interpret data of the genetic markers project.



Heliothis abundance and example egg distribution at Brookstead in 1997-98