



CSIRO Entomology



FINAL REPORT

CSE103C: The impact of Area Wide Management (AWM) on beneficial Arthropod and Helicoverpa populations.

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A final report prepared for the Cotton Research and Development Corporation

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Executive Summary

This project validated and enhanced the use of the BDI as a measure of the relative disruption ('softness'/'hardness') of the insecticide regimes applied to cotton fields. The project focused on two Area-Wide Management groups in Northern NSW: The Boggabilla landcare group in the Macintyre valley, and the Two Rivers areawide management group (TRAMS) near Pilliga, NSW. Intensive sampling of pest and beneficial insects was undertaken on fields within both groups, and the paddock level data was analysed in association with agronomic, spray and yield data provided by growers and consultants.

The project quantified how the insecticide programs applied to individual cotton fields affected populations of beneficial insects and spiders present in those fields. The project also compared the abundance and diversity of insects and spiders in Bt and conventional cotton fields. A comparison of the effectiveness of different sampling methods for measuring the density of both pests and natural enemies was also undertaken.

By exploring the relationships between pests, beneficials, spray regimes and economic performance of individual fields within AWM groups, this project has collected a unique large scale and multi-season data set. The results have been analysed within the context of area-wide management. The results strongly suggest that IPM applied on an areawide scale is at least as profitable as more disruptive approaches, whilst minimising environmental impacts and potentially reducing the risk of resistance to insecticides increasing.

By quantifying the linkages between beneficial arthropods, *Helicoverpa* densities, spray regimes and the economic performance of individual fields this project provides information that will assist AWM groups to better manage their insect pests (particularly *Helicoverpa*) in a sustainable and profitable manner.

Project CSE103C has been interwoven with the Macintyre Valley IPM / IRMS Trial. In particular, M. Dillon was a member of the Trouble Shooting Committee for this trial, provided assistance with the analyses of insecticide use and bug checking data arising from the trial, and helped present findings to the TIMS Committee. The trial data were supplemented with invertebrate data collected independently in this project, and earlier studies (especially through interactions with the Boggabilla Landcare group when developing the BDI concept).

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1. Introduction and background

A common goal of many Area-Wide Management (AWM) groups is to strive to preserve and nurture beneficial insect abundance and diversity for as long as possible during the growing season. Many groups do this by implementing IPM practices and reducing their dependence on insecticides, particularly broad-spectrum pesticides that kill insects indiscriminately. The work of Dillon, Hoque and Farquharson (2000, 2001) on a 3 year data set from 12 farms in the Boggabilla Landcare Group suggests that preserving beneficial arthropods in cotton fields by using selective insecticides may be at least as profitable as conventional approaches. In some seasons it may even provide significant economic benefits. The results indicate that on average, growers that were able to use target-specific sprays and hence minimise the Beneficial Disruption Index (BDI) of sprays applied per unit of pest pressure, did at least as well economically. However the analysis did not consider actual beneficial densities in the fields studied. Therefore the results are based on the inference that low BDI's led to a greater beneficial impact and reduced *Helicoverpa* damage.

There is a strong perception amongst the growers and consultants of the Boggabilla landcare group that the overall effectiveness of beneficial insects within the groups' area (approx 100 km²) has been substantially enhanced by their cooperative approach. This project directly measured beneficial abundance and diversity in specific fields, and assessed how beneficials are affected by insect management strategies applied to those fields. The data collected in this project potentially allows the linkages between spray regimes and the economic performance of individual fields to be quantified.

This project follows on from Mr Dillon's work on trap crops (CSE86C) and the economic analysis undertaken in collaboration with Ziaul Hoque and Dr Bob Farquharson (NSW DPI) comparing IPM strategies applied to individual cotton fields within the Boggabilla landcare AWM group. An important outcome of this collaboration was the development of the Beneficial Disruption Index (BDI) which is being rapidly adopted by the industry.

This project aimed to provide some of the background research necessary to validate the BDI. In particular, intensive sampling for beneficial arthropods in commercial cotton fields was completed during the project. This data set has been valuable for comparing the efficacy of different sampling methods, and for comparing the communities of arthropod fauna present in large scale commercial Bt and conventional cotton fields.

2. Project objectives and achievements

2.1 Objective 1

To determine how the diversity and abundance of Beneficial arthropods and Helicoverpa are affected by field level insect management strategies and resulting Beneficial Disruption Index (BDI) in commercial cotton fields within two Area-Wide Management groups

Achieved: Sampling was undertaken within the Boggabilla Landcare group near Goondiwindi, Queensland, and the Two Rivers Areawide Management (TRAMS) group near Pilliga, NSW. Thousands of samples of arthropod counts were collected from commercial cotton fields in these two AWM groups over the three seasons from 2002/03 to 2004/05. Spray data has been collected for most fields from the Boggabilla Landcare group, but only partial spray history data has been successfully retrieved from the TRAMS group. An analysis of the data was undertaken in collaboration with Dr Sarah Mansfield and Dr Mary Whitehouse (CSIRO Entomology), and the resulting manuscript has been accepted for publication in the international journal Agriculture, Ecosystem and Environment and is currently in press (see Attachment 7). In association with this objective, a preliminary analysis comparing the arthropod fauna in commercial BT and Conventional cotton fields has also been undertaken and is included in this report. A manuscript presenting this comparison is being prepared in collaboration with Dr Mary Whitehouse, Sandra Deutscher (CSIRO Plant Industry) and Steve Harden (NSW DPI). A detailed description of the research addressing objective 1 is presented in section 3.1 of this report



Plate 1. Martin Dillon and Trudy Staines demonstrating beat-sheet sampling for beneficial arthropods in a cotton field in the Two Rivers AWM group

2.2 Objective 2

To determine and analyse the linkages between Helicoverpa pressure, field spray regimes and BDI scores, and the economic performance of individual fields

Partially achieved: A substantial body of agronomic, yield, spray and pest count data has been collated from the Boggabilla group for the seasons 1998/99 through to 2001/02. This project has subsequently added to this data set and a combined collaborative analysis of all the data is currently underway. Yield data (and estimated gross margins) have been successfully collected from most of the fields within the Boggabilla Landcare group over the 2002/03 and 2003/04 seasons, and are still being collated for the 2004/05 season. However agronomic and yield data was forthcoming for only a limited number of fields in the TRAMS group. Analyses for this work are still being undertaken in collaboration with Dr Bob Farquharson, Ziaul Hoque, Steve Harden and Bruce McCorkell (NSW DPI) and Dr Mary Whitehouse (CSIRO Entomology). This analysis will build on previous work of Hoque *et al* (2000, 2002). A brief description of the manuscript in preparation is given in section 8.9. A description of the previous and current research addressing objective 2 is presented in section 3.2 of this report



Plate 2. An IPM field-workshop on identifying beneficial arthropods in the Boggabilla Landcare group, and a close up of a Lynx spider preying on a Green Mirid.

2.3 Objective 3

To compare the beat sheet sampling technique with established methods for sampling pest and predator abundance in cotton

Achieved: A sampling regime comparing beat sheets with visual, D-Vac, Sweep netting and/or absolute counts was undertaken at regular intervals on a large number of cotton fields in the Namoi and Macintyre valleys throughout the duration of this project. Particularly high quality data was collected during the 2002/03 and the 2004/05 seasons because the sampling for this objective was undertaken in conjunction with CRC Summer Student projects in those seasons. Carla McKinnon (University of Western Sydney) was co-supervised by Martin Dillon and Sandra Deutscher (CSIRO Plant Industry) in 2002/03. Caragh Threlfall was supervised by Sandra Deutscher in 2004/05. The results and analysis of the 2002/03 dataset is presented in this report, and manuscripts presenting and discussing the sampling comparison study from both these seasons are currently being drafted in collaboration with Sandra Deutscher and Dr Mary Whitehouse. A Cottongrower article reporting the results of this work has also been published (Attachment 4). A detailed description of the research addressing objective 3 is presented in section 3.3 of this report.



Plate 3. Trudy Staines, Sandra Deutscher and Carla Mackinnon comparing different sampling methods

2.4 Objective 4

To collate data for monitoring the operation and impact of the Macintyre Valley trial IPM/IRMS strategy

Achieved: Field level data on spray applications and where available on beat sheet counts of beneficial predator densities was collected from consultants for a subset of fields from all participating farms throughout the Macintyre valley for the 2002/03 and 2003/04 seasons. Only limited data were forthcoming during the 2004/05 season. The data for each season were summarised and presented to the Macintyre Valley End of Season reviews, as well as to TIMS committee meetings. A detailed description of the research addressing objective 4 is presented in section 3.4 of this report.



Plate 4. Aerial photo mosaic of the Boggabilla Landcare group's cotton farms occupying a 100km² area south of the Macintyre River in northern NSW. And Martin Dillon sampling for insects in cotton.

3. Detailed description of research

3.1 Objective 1

3.1.1 Aim

To determine how the diversity and abundance of Beneficial arthropods and *Helicoverpa* are affected by field level insect management strategies and resulting Beneficial Disruption Index (BDI) in commercial cotton fields within two Area-Wide Management groups

3.1.2 Methods

Study Sites

The study was conducted on Australian commercial cotton farms within the Namoi and Macintyre Valley regions of Northern NSW. Study sites were established on commercial farms within two Area-wide Management Groups, namely the Boggabilla Landcare group and the Two Rivers Area-wide Management group (TRAMS) The Boggabilla Landcare area is an ideal region in which to conduct such a study, as farms contained within this AWM group are contiguous across a fairly uniform area. Thus there are unlikely to be significant confounding variations in arthropod abundance due to uncontrollable factors such as local variation in geography or topology. Furthermore, the chemical spray regime used within the Macintyre Valley is extremely close to the Australian average for both conventional and Bt cotton (conventional cotton in the Macintyre Valley received on average 11.1 chemical treatments per acre during the growing season in 2003/04, whereas Bt cotton received only 3.3 treatments (Boyce et al 2004). Experimental study sites were also established on un-sprayed fields of cotton at the Australian Cotton research Institute (ACRI) near Narrabri that was split into a BT and conventional portions.

Arthropods were sampled in ten cotton farms over the four year duration of the project, with six different farms sampled in any given year (Table 1). Each farm contained discrete fields of Bt cotton and conventional cotton that were sampled separately. Each farm was sampled on multiple dates between 2-7 times (mean number of sample dates per farm = 4.3 ± 1.3 (s.d.) days). Over the course of the study, the earliest that farms were sampled in any growing season was 12 November and the latest was 5 March.

Table 1. Field sites (farm names) used over the four year duration of the study

| Year 1 (01/02) | Year 2 (02/03) | Year 3 (03/04) | Year 4 (04/05) |
|----------------|----------------|----------------|----------------|
| Alcheringa | ACRI | Boolorong | Alcheringa |
| Boolorong | Eumorella | Eumorella | Boolorong |
| Eumorella | Korolea | Fairfield | Eumorella |
| Fairfield | Morella | Korolea | Fairfield |
| Korolea | Sandhurst | Morella | Korolea |
| Morella | Scotsburn | Royston | Morella |

Where possible, agronomic and entomological data was collected from consultants and growers for every field within each AWM group studied. This data set included insect counts, agronomic information, insecticide application records and usually lint yield data. Much of this data was collected on the basis of maintaining confidentiality of the identity of the farms involved (Table 2).

A regular sampling regime was established to undertake visual, D-Vac, and beat sheet sampling of beneficial arthropods and *Helicoverpa* at each study site. Where possible, pairs of neighbouring fields of Bt and conventional cotton were selected for study from each participating farm.

Table 2. Location, date and type of fields sampled at the ten farms from November 2001-March 2002. A BDI of 0 indicates the field was not sprayed with insecticide throughout the season. Insecticide scores used to calculate the BDI are given in Table 3

| Valley | Farm | Field number | Variety | Sample dates | Cumulative BDI* |
|-----------|------|--------------|--------------|--|-----------------|
| Macintyre | A | 1 | Conventional | 21 Dec 2001, 24 Jan 2002 | 6 |
| | B | 2 | Conventional | 21 Dec 2001, 24 Jan, 6 Mar 2002 | 9 |
| | | 3 | Ingard | 21 Dec 2001, 24 Jan, 6 Mar 2002 | 7 |
| | | 4 | Conventional | 29 Nov, 21 Dec 2001, 24 Jan 2002 | 21 |
| | D | 5 | Ingard | 29 Nov, 21 Dec 2001, 24 Jan, 6 Mar 2002 | 17 |
| | | 6 | Conventional | 24 Jan 2002 | 10 |
| | | 7 | Ingard | 29 Nov 2001 | 0 |
| | | 8 | Ingard | 20 Dec 2001, 6 Mar 2002 | 4 |
| | E | 9 | Conventional | 20 Dec 2001, 25 Jan, 6 Mar 2002 | 21 |
| | | 10 | Ingard | 20 Dec 2001, 25 Jan 2002 | 6 |
| | F | 11 | Conventional | 29 Nov, 20 Dec 2001, 24 Jan, 6 Mar 2002 | 14 |
| | | 12 | Ingard | 29 Nov, 20 Dec 2001, 6 Mar 2002 | 12 |
| Gwydir | G | 13 | Ingard | 22 Nov, 13 Dec 2001, 10 Jan, 13 Feb 2002 | 0 |
| | | 14 | Ingard | 22 Nov, 13 Dec 2001, 13 Feb 2002 | 6 |
| Namoi | H | 15 | Conventional | 4, 19 Dec 2001, 17, 31 Jan, 19 Feb 2002 | 0 |
| | | 16 | Conventional | 15 Nov, 12 Dec 2001, 3, 11 Jan, 7, 20 Feb 2002 | 0 |
| | I | 17 | Conventional | 15 Nov, 12 Dec 2001, 3, 15 Jan, 6, 22 Feb 2002 | 18 |
| | | 18 | Ingard | 15 Nov, 12 Dec 2001, 3, 16 Jan, 6, 22 Feb 2002 | 4 |
| | J | 19 | Conventional | 21 Nov, 11 Dec 2001, 14 Jan, 12 Feb 2002 | 22 |

*Cumulative Beneficial Disruption Index

Sampling

Arthropods were sampled using a beat sheet (Scholz et al., 2001). This consists of a yellow plastic sheet (1.5 x 2 m) that is placed below the sample row, stretched along the ground and up over the adjacent row. A 1 m section of plants was shaken 10 times vigorously with a stick, working from the base to the top of the crop canopy, causing insects and spiders to fall from the plants onto the sheet. Usually 12 beat sheet samples were taken on each sampling occasion – randomly distributed within each field, however for some fields in the 2002/03 season 20 beat sheets samples were collected. In total, 1225 beat sheets were conducted in conventional cotton crops, and 1072 beat sheet samples were conducted in Bt cotton crops. To avoid pseudo-replication, the mean densities of each taxon per field per day were used for analysis. An assessment of the efficacy of beat sheet sampling is addressed in Objective 3 (section 3.3) of this report.

During sampling, the number of individuals within each arthropod taxon were immediately counted in-situ and recorded onto field data sheets. The insect fauna of Australian cotton crops is well described and generally can be readily identified to species in the field, however the spider fauna is less well known (Pyke and Brown, 1996). For statistical analysis all arthropods were classified to family with the following exceptions. The less common taxa, lacewings (Neuroptera) and predatory or parasitic wasps (Hymenoptera) were not classified beyond order, although ants were taken to family (Formicidae). Ladybirds (Coccinellidae) were separated into subfamilies; this classification enabled the separation of several predominantly aphid-feeding species (Coccinellinae) from a species that relies primarily on other types of prey (Coccidulinae). Juvenile arthropods (larvae, nymphs, spiderlings) were counted along with conspecific adults, when they were present in the samples.

Visual samples were also collected in many fields. 12 individual metres were randomly selected and carefully searched to count and record arthropod taxa present.

Sampling dates were chosen to avoid fields that had been subject to insecticide applications within the previous 48 hours. Otherwise, the time between insecticide applications and subsequent sampling was not controlled, and varied between fields.

The Beneficial Disruption Index

The Beneficial Disruption Index (BDI, Hoque *et al.*, 2002) was used as a generalized measure of insecticide impacts on beneficial arthropods in the sampled cotton crops. A detailed description of how the BDI is derived is provided in section 3.2.2 below. Each type of insecticide is given a score from 1 – 10 that reflects the proportional reduction in beneficial arthropod abundance observed after a single application of that insecticide compared with beneficial arthropod abundance prior to application. Therefore when comparing different insecticides, a product with a lower score is considered to be more selective than a product with a higher score. The assigned scores for each particular insecticide (Table 3) have been derived from the “overall ranking” in Wilson *et al.* (2002). This scoring system only considers the active ingredient of each insecticide applied. It does not consider explicitly the concentration (i.e. dosage) of the product at the time of application. The BDI for a particular cotton field on a specified date is determined by summing together the scores of each insecticide treatment applied to that field up to the specified date. The lower the final score, the more selective the overall regime applied to the field of interest. A score of zero denotes no insecticide treatment whatsoever. At the beginning of the growing season, all cotton fields will have a BDI of zero prior to planting. The BDI of each field will increase in a cumulative fashion with each insecticide application (including in furrow treatments) until the crop is harvested.

Table 3. Chemicals used in cotton and their assigned 'Beneficial Disruption Index' (BDI) derived from Wilson *et al.* (2002)

| Insecticide | Overall impact | % reduction in beneficials after application | BDI |
|--|-----------------------|---|------------|
| Bt (<i>Bacillus thuringiensis</i>) | very low | <10% | 1 |
| NPV (<i>Nuclear polyhedra virus</i>) | very low | <10% | 1 |
| Aldicarb (carbamate) – in furrow | very low | <10% | 1 |
| Phorate – in furrow | very low | <10% | 1 |
| Methoxyfenozide | very low | <10% | 1 |
| Petroleum Oil | very low | <10% | 1 |
| Pirimicarb | very low | <10% | 1 |
| Dicofol (organochlorine) | low | 10-20% | 2 |
| Diafenthurion (thiourea) | low | 10-20% | 2 |
| Indoxacarb | low | 10-20% | 2 |
| Spinosad (spinosyn) | low | 10-20% | 2 |
| Abamectin | moderate | 20-40% | 4 |
| Emamectin | moderate | 20-40% | 4 |
| Amitraz (formamidine) | moderate | 20-40% | 4 |
| Propargite | moderate | 20-40% | 4 |
| Endosulfan (organochlorine) | moderate | 20-40% | 4 |
| Fipronil (phenyl pyrazol) | moderate | 20-40% | 4 |
| Imadacloprid (chloronicotinyl) | moderate | 20-40% | 4 |
| Chlorpyrifos | high | 40-60% | 6 |
| Chlorfenapyr (pyroll) | high | 40-60% | 6 |
| Methomyl (carbamate) | high | 40-60% | 6 |
| Organophosphates | high | 40-60% | 6 |
| Thiodicarb (carbamate) | high | 40-60% | 6 |
| Pyrethroids | very high | >60% | 8 |

Statistical analysis – influence of insecticide regime on arthropod communities

A subset of the data has been analysed to explore the impacts of a field's insecticide spray regime and the beneficial faunal community present within the field. A detailed description of this analysis is presented in Mansfield et al (2005) (Attachment 7). Mean beneficial arthropod abundance was plotted against time for all observations from fields that were sampled three or more times. Analyses were conducted separately for beneficial insects and spiders. Then mean beneficial arthropod abundance on the last sample date was plotted against BDI. Non-linear regressions were performed using SigmaPlot version 8.0 (SPSS, 2000)

The relationship between physical variables and beneficial arthropod species composition was examined by conducting direct canonical correspondence analyses (CCA), on those fields that had both beneficial insect and spider samples identified to family. CCA were conducted using CANOCO version 4.5 (ter Braak and Smilauer, 2002). To test that the environmental variables in the CCA explained significant variance permutation tests were conducted using the Monte Carlo method (available within the program CANOCO) on all canonical axes, with the Julian date and farm as co-variates. Environmental variables were BDI (at the time of the sample) and crop type (Bt or conventional). Each farm was represented as a dummy variable in the analysis.

Statistical analysis – comparison of arthropod communities in Bt and Conventional fields.

A statistical modelling approach was used to compare the diversity and abundance of arthropods in conventional and Bt cotton fields. Because the data were collected from a series of farms that were sampled repeatedly during the course of the study, the data obtained from any particular farm may not have been independent. In addition, some farms and fields were sampled more frequently than others. Therefore, in order to circumvent the potential statistical problems of (i) dependence associated with multiple sampling and (ii) an unbalanced design, mixed models were fitted using the residual maximum likelihood (REML) technique (Genstat 7.1) incorporating the random factor, 'farm name'. This procedure counteracts any excessive biases that may have been caused by unusual events occurring on any particular farm. Variables of interest included 'year', 'Julian date', 'crop area', 'crop density' (plants per metre), 'crop age' (number of nodes), 'air temperature', 'wind speed', 'time of day', and, 'crop type' ('conventional' or 'Bt cotton').

Full fixed models were initially fitted that contained potentially explanatory variables and their interaction terms. Significance was determined by sequentially eliminating all non-significant ($P > 0.05$) variables and interaction terms from the model, causing a change in deviance that approximates a chi-square distribution. The significance of terms discarded early in the model were re-evaluated by observing the change in deviance when re-entering them into the final model (none were significant). Final models were selected once only significant terms remained.

Diagnostic residual plots were examined for unequal variance and deviance from normality to ensure the validity of all final, parsimonious models. Data are presented as means and standard errors throughout, unless otherwise stated. Results are presented graphically to facilitate rapid interpretation, and presented in table form in the Appendix to allow a more detailed analysis.

3.1.3 Results

Effect of BDI on arthropod faunas

Beneficial insects comprised 42% of all arthropods collected and were dominated by predatory Coleoptera, particularly the red and blue beetle, *Dicranolaius bellulus* (Guerin-Meneville). This species comprised 22% of all arthropods collected. Neuroptera were the least abundant taxon of beneficial insects (1% of all arthropods collected). Although beneficial arthropod abundance increased from November 2001 to March 2002, predatory Coleoptera and Hemiptera peaked in abundance during February, whereas the abundance of Hymenoptera (predominantly ants) peaked in January (Figure 1).

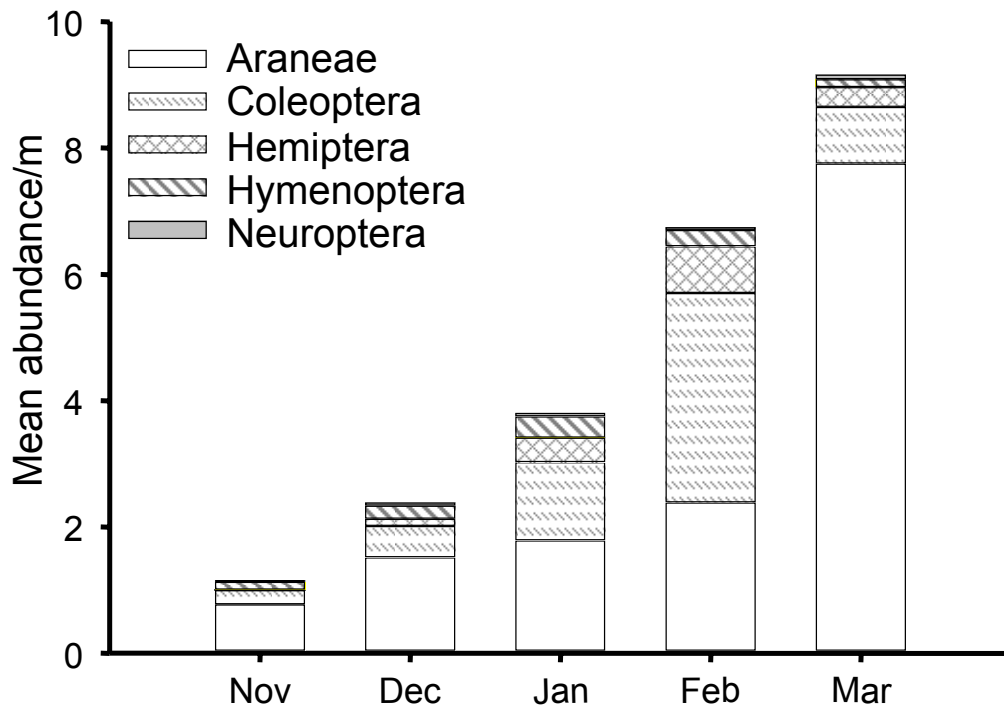


Figure 1. Average beneficial arthropod abundance and composition per metre of cotton, measured by beat sheet samples for all fields from November 2001 to March 2002.

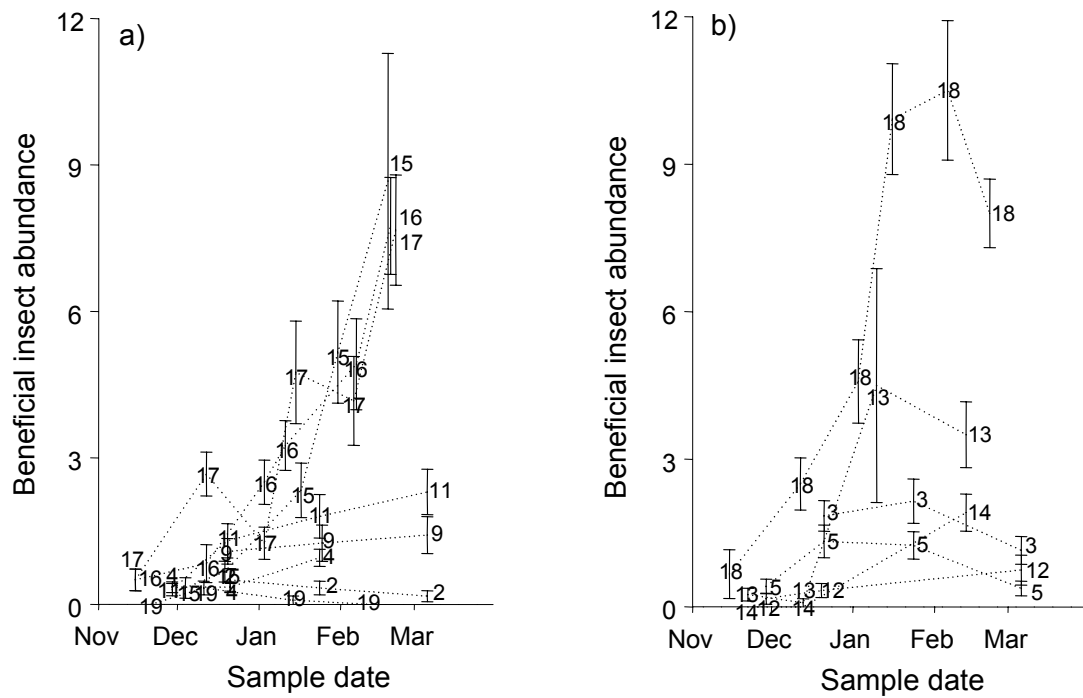


Figure 2. Beneficial insect abundance (mean \pm se) through time for a) conventional and b) INGARD® fields sampled three or more times during the 2001-02 season. The numbers plotted correspond to the fields sampled (Table 2).

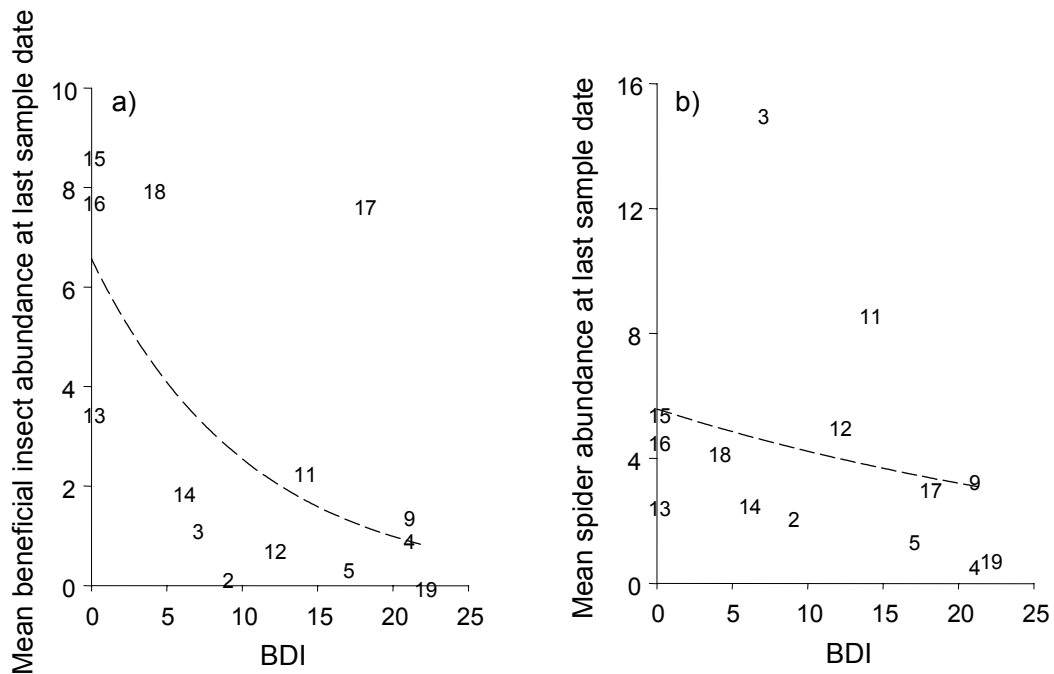


Figure 3. Mean beneficial arthropod abundance on the last sample date against BDI for a) beneficial insects and b) spiders. The numbers plotted correspond to the fields sampled (Table 2).

The mean BDI of conventional fields was 12 (range = 0 to 22) compared with a mean BDI of 6 (range = 0 to 17) for INGARD® fields. At the start of the cotton season, few beneficial insects were present in any of the fields. Most fields with a BDI less than 10 showed a rapid increase in beneficial insect abundance as the season progressed, for both conventional (Figure 2a), and INGARD® crops (Figure 2b). Field 17 with a BDI of 18 showed a similar increase in beneficial insect abundance. However fields 2 and 3, which were both at the same farm, showed a decline in beneficial insect abundance despite a BDI of 9 and 7 respectively. Mean beneficial insect abundance on the last sample date declined exponentially with increasing BDI (abundance = $6.57e^{(-0.09BDI)}$, $F_{1, 12} = 7.20$, $P = 0.02$, $r^2 = 0.32$, Figure 3). When the outlier (field 17) is excluded, the relationship is strengthened (abundance = $6.92e^{(-0.14BDI)}$, $F_{1, 12} = 20.48$, $P = 0.001$, $r^2 = 0.62$). An exponential decay curve was considered more suitable than a linear regression for describing the relationship between beneficial arthropod abundance and BDI, because it is possible for the BDI of a particular field to continue to increase after beneficial arthropod abundance has declined beyond the limits of detection by direct sampling.

The two environmental variables, crop type and BDI, were not strongly associated with insect family composition, although there was a trend (Monte Carlo test of all canonical axes, $F = 2.18$, $P = 0.068$, 499 permutations). The covariables explained 46% of the variance in the data. After eliminating the covariables, the environmental variables (BDI and crop type) explained 33% of the variance, of which 81% was explained by the first axis. BDI, with the longer arrow, had a stronger influence than crop type. The majority of insects were associated with cotton fields that had a low BDI (Figure 4) and INGARD® crops favoured some insects (Coccinellinae and Geocoridae). Nabidae were strongly associated with non-Bt cotton, and, along with Melyridae, were more abundant in crops with a high BDI in comparison to other insects. Few Pentatomidae and no Reduviidae were found in the cotton fields sampled.

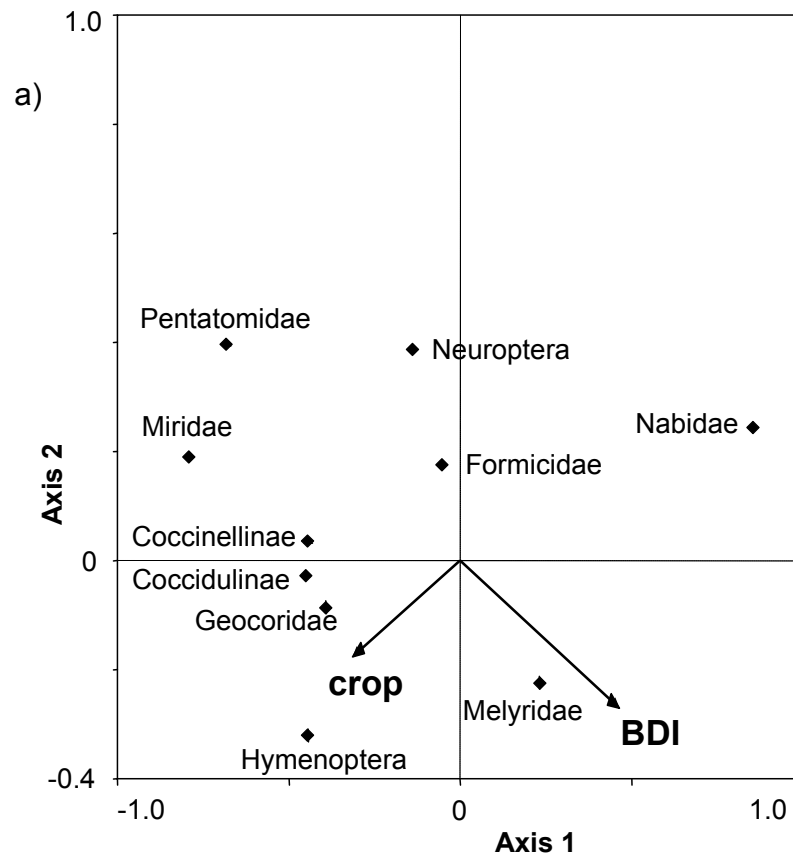


Figure 4. Ordination diagram of the first two axes of a canonical correspondence analysis for beneficial insects and two environmental variables (crop type: Bt or non-Bt; and BDI). Julian date and farm (each farm was a dummy variable) were covariates. Arrows represent directions of greatest change in environmental variables.

The majority of all beneficial arthropods collected were spiders (58% of all arthropods collected) and spiders were the most abundant beneficial arthropods in all months sampled except February (Figure 1). Spider abundance increased from November 2001 to March 2002 for most conventional and INGARD® fields sampled (Figure 5). This increase was particularly marked in field 3, which had a large influx of Theridiidae in the March sample. Only field 5 with a BDI of 23 showed a decline in spider abundance over the 2001-2002 season. However mean spider abundance on the last sample date did not change significantly with increasing BDI ($F_{1, 12} = 1.07$, $P = 0.32$, $r^2 = 0.01$, Figure 3b). Exclusion of the outlier (field 3) did not affect the outcome of the non-linear regression.

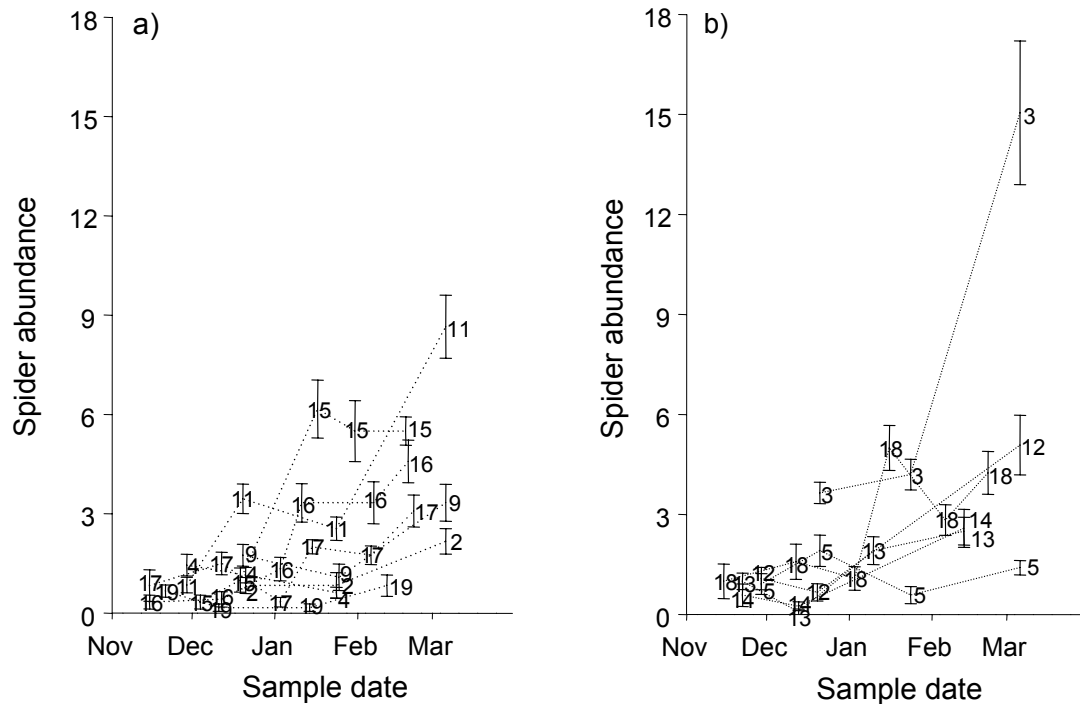


Figure 5. Spider abundance (mean \pm se) through time for a) conventional and b) INGARD® fields sampled three or more times during the 2001-02 season. The numbers plotted correspond to the fields sampled (Table 2).

The two environmental variables, crop type and BDI, were associated with spider family composition (Monte Carlo test of all canonical axes, $F = 2.94$, $P = 0.026$, 499 permutations). The covariables explained 58% of the variance in the data. After eliminating the covariables, the environmental variables BDI and crop type explained 40% of the variance, of which 75% was explained by the first axis. BDI, with the longer arrow, had a stronger influence than crop type. Particular spider families were more associated with conventional cotton (Araneidae and Salticidae) while others were more associated with INGARD® cotton (Uloboridae and Linyphiidae; Figure 6). Salticidae were more likely to be associated with fields that had a higher BDI than other spider families.

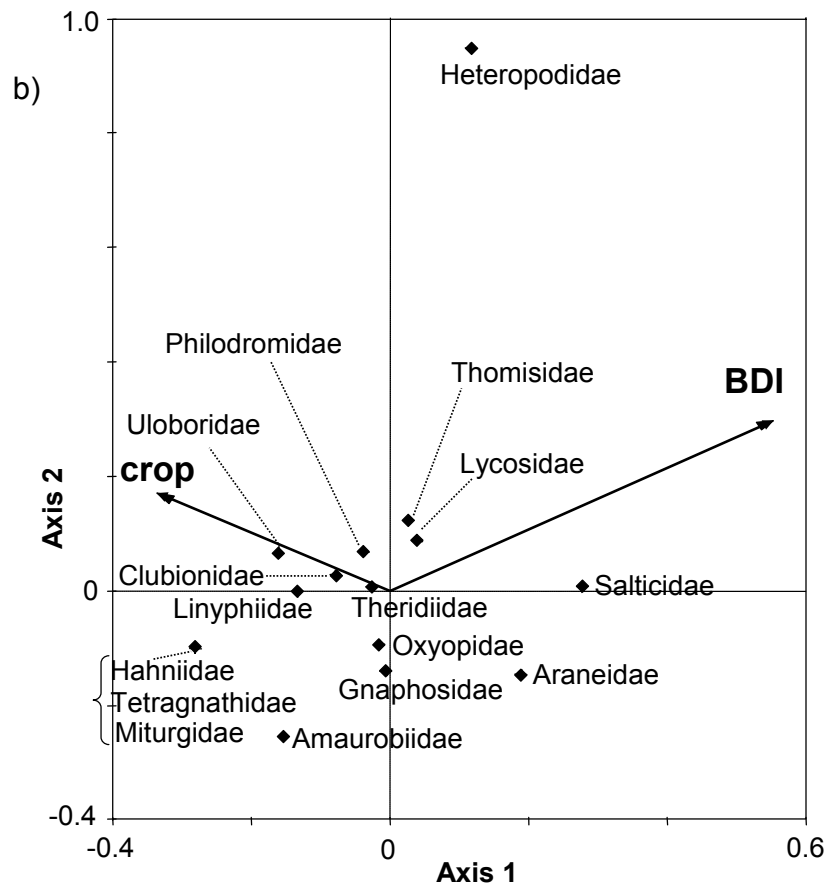


Figure 6. Ordination diagram of the first two axes of a canonical correspondence analysis for spiders and two environmental variables (crop type: Bt or non-Bt; and BDI). Julian date and farm (each farm was a dummy variable) were covariates. Arrows represent directions of greatest change in environmental variables.

Comparison of arthropod communities in Bt and Conventional fields

Total arthropods

The beat sheet data revealed considerable variation in the number of arthropods between field seasons ($\chi^2_3=179$; $P<0.001$), and between crop type (ie Bt or conventional cotton: $\chi^2_1=51.7$; $P<0.001$: Figure 7).

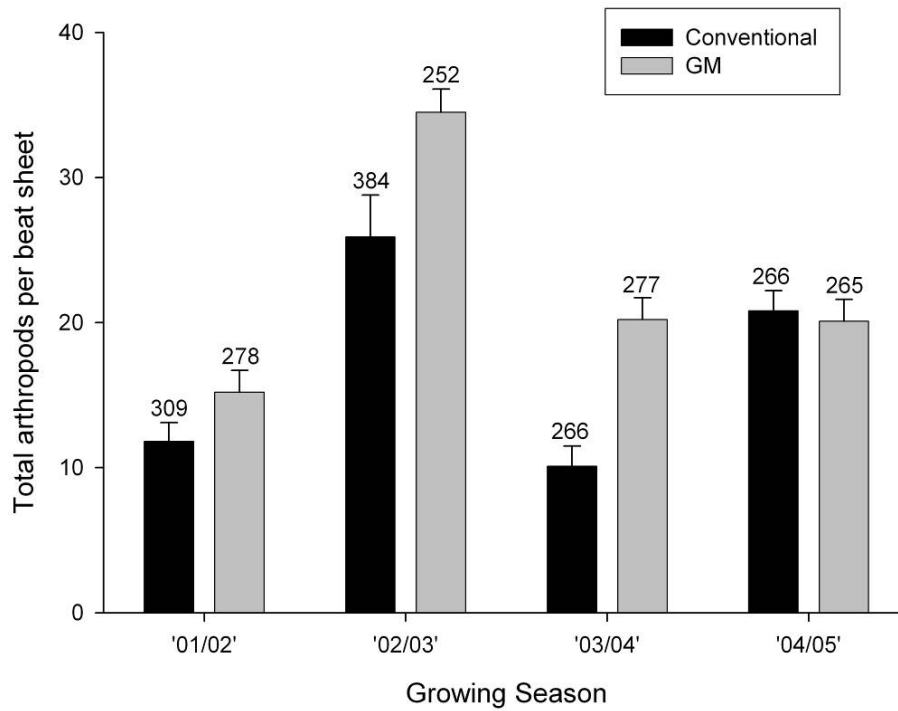


Figure 7. Differences in the total number of arthropods sampled on beat sheets between conventional and *Bt* cotton crops across four field seasons. Figures above bars denote sample sizes of beat sheets.

Helicoverpa

There was no significant difference between the number of *Helicoverpa* eggs on conventional and Bt cotton ($\chi^2_1=0.4$; $P=0.8$), even when controlling for potential differences between seasons. However, as expected, *Helicoverpa* larvae of all size classes are considerably more common on conventional than Bt cotton (crop type: $\chi^2_1=103.1$; $P<0.001$; year: $\chi^2_3=40.0$; $P<0.001$; Figure 8). Similar results are revealed by the visual sampling technique.

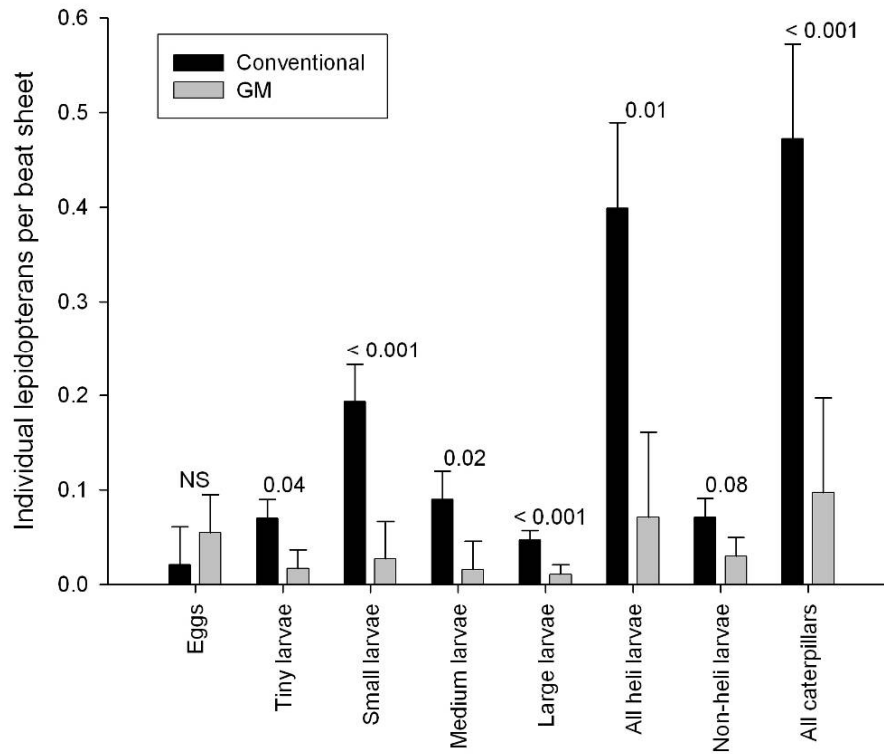


Figure 8. Differences in the total number of *Helicoverpa* and other (non-heli) lepidopterans sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Total pests and total beneficials

When lepidopterans are excluded from the sample, there is a significant increase in total arthropod fauna in *Bt* cotton ($\chi^2_1=5.78$; $P=0.02$), as well as significant differences between field seasons ($\chi^2_3=33.0$; $P<0.001$) and during the course of a season (with arthropod fauna increasing as the season progresses: $\chi^2_1=46.1$; $P<0.001$). Importantly, there were significant increases in both (i) the abundance of total predatory arthropods and (ii) total minor pests within *Bt* cotton fields (Figure 9).

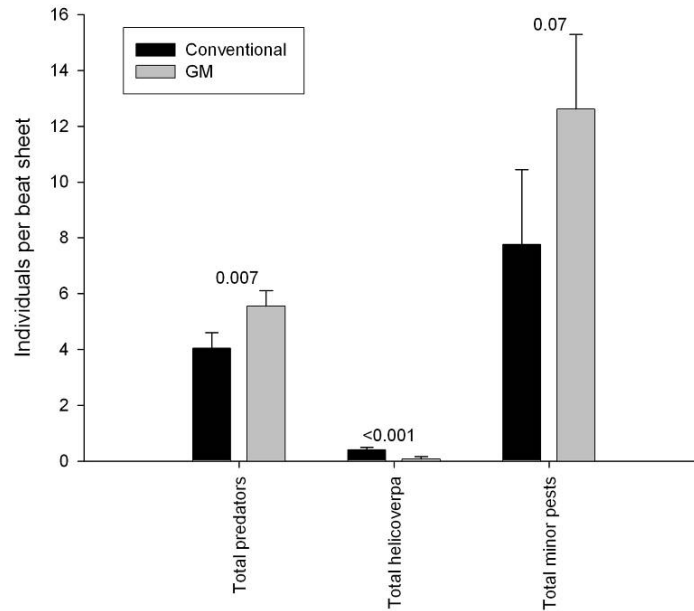


Figure 9. Differences in the total number of beneficial arthropods, major pests (*Helicoverpa*) and minor pests sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Minor pests

There was a non-significant increase in the abundance of total minor pests in Bt cotton ($\chi^2_1=3.28$; $P<0.07$: Figure 10), when including variation in abundance due to both inter-seasonal and intra-seasonal differences (growing season: $\chi^2_3=23.6$; $P<0.001$; Julian date: $\chi^2_1=18.3$; $P<0.001$). However, this subtle increase was driven predominantly by the non-significant increase in the abundance of Jassids ($\chi^2_1=3.04$; $P<0.08$; growing season: $\chi^2_1=20.6$; $P<0.001$; Julian date $\chi^2_3=23.8$; $P<0.001$). No other minor pest species exhibited anything approaching a significant change in abundance (all $P>0.24$). Thus, when eliminating Jassids from the sample, there was no evidence for an increase in the total abundance of all minor pest species in Bt cotton ($\chi^2_1=1.77$; $P=0.2$: Figure 10).

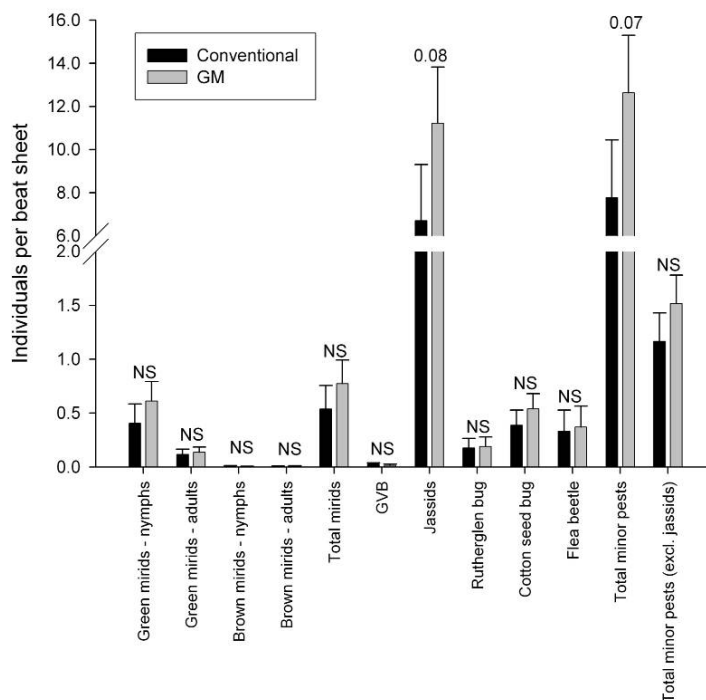


Figure 10. Differences in the total number of minor pests sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Predatory bugs

There was a significant increase in the abundance of big-eyed bugs in Bt cotton fields ($\chi^2_1=5.86$; $P<0.02$: Figure 11). Interestingly, there was a large and significant *decrease* in the abundance of Damsel bugs in Bt cotton fields (ie Nabis) ($\chi^2_1=10.4$; $P<0.001$; Julian date: $\chi^2_1=23.8$; $P<0.001$), indicating that either Bt cotton *per se*, or the AWM practices associated with it are causing reduced densities in Bt fields relative to conventional (and more heavily sprayed) fields. When excluding from the sample both the significant increase in big-eyed bugs and the significant decrease in Damsel bugs, there was no evidence that the total abundance of predatory bugs was significantly affected by the insecticidal regimes applied to either Bt or conventional cotton ($\chi^2_1=0.7$; $P=0.4$: Figure 11).

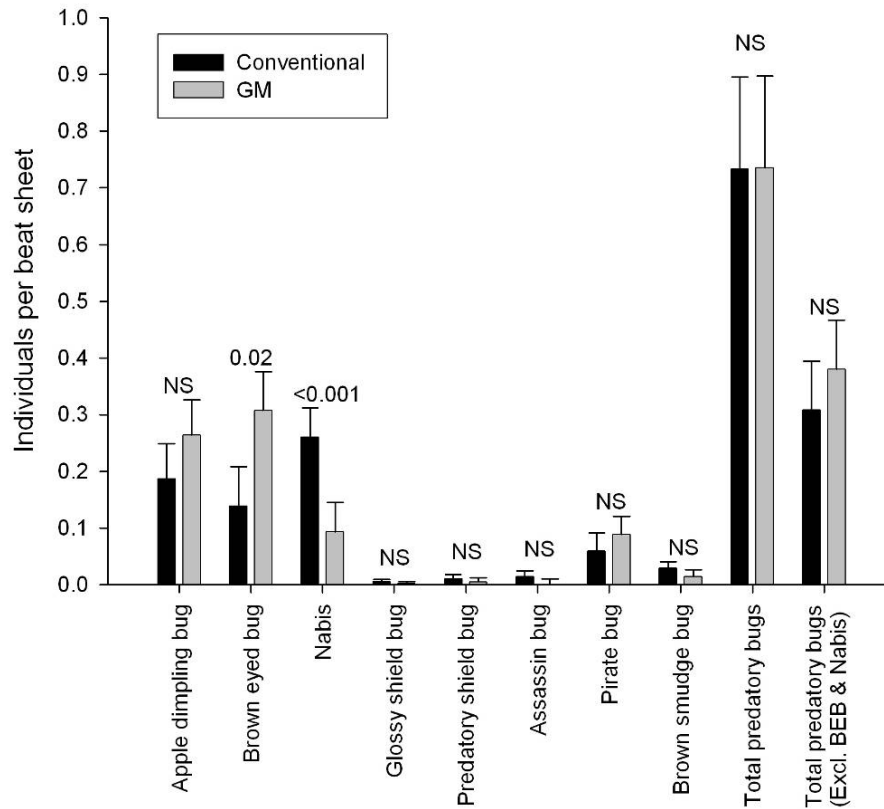


Figure 11. Differences in the total number of predatory bugs sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Predatory beetles

With the exception of a non-significant increase in the abundance of ladybeetle larvae and red and blue beetles in Bt cotton ($\chi^2_1=2.96$; $P=0.09$), and the total abundance of all predatory beetles combined ($\chi^2_1=2.7$; $P=0.1$), there was little evidence to suggest that the abundance of predatory beetles was significantly affected by Bt versus conventional cotton (Figure 12).

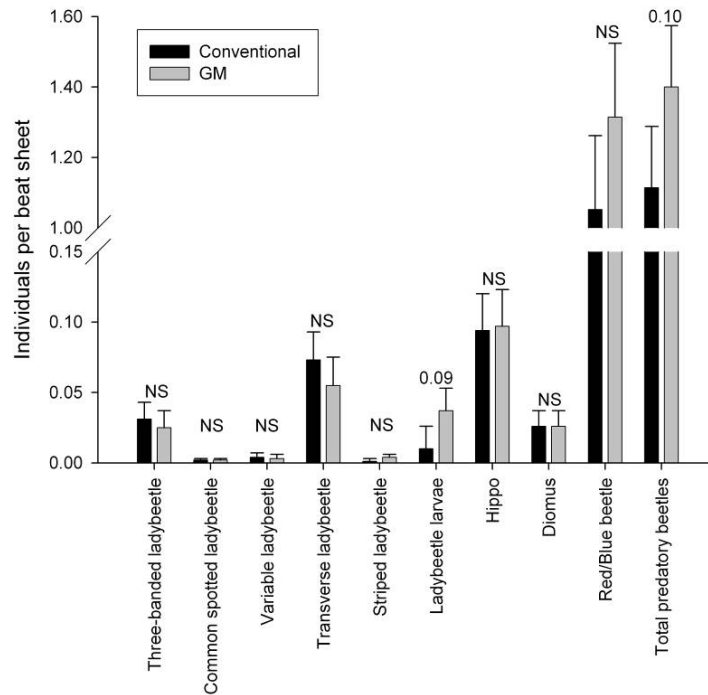


Figure 12. Differences in the total number of predatory beetles sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Spiders

With the exception of lepidopterans, spiders appear to be the taxa most affected by the variation in insecticide spray or arthropod communities associated with Bt or conventional cotton farming (Figure 13). There were significant increases in the abundance of yellow night stalker spiders (*Cheiracanthium spp*) ($\chi^2_1=4.98$; $P=0.03$) and lynx spiders (Oxyopidae) in Bt cotton ($\chi^2_1=4.84$; $P=0.03$), and some evidence of an increase in the abundance of ‘other spiders’ in Bt cotton ($\chi^2_1=3.51$; $P=0.06$). There was a marginally significant increase in the combined abundance of all other spiders sampled ($\chi^2_1=3.67$; $P=0.06$), meaning that the total abundance of all spiders increased considerably in Bt cotton fields compared with conventional cotton fields ($\chi^2_1=6.67$; $P=0.01$: Figure 13).

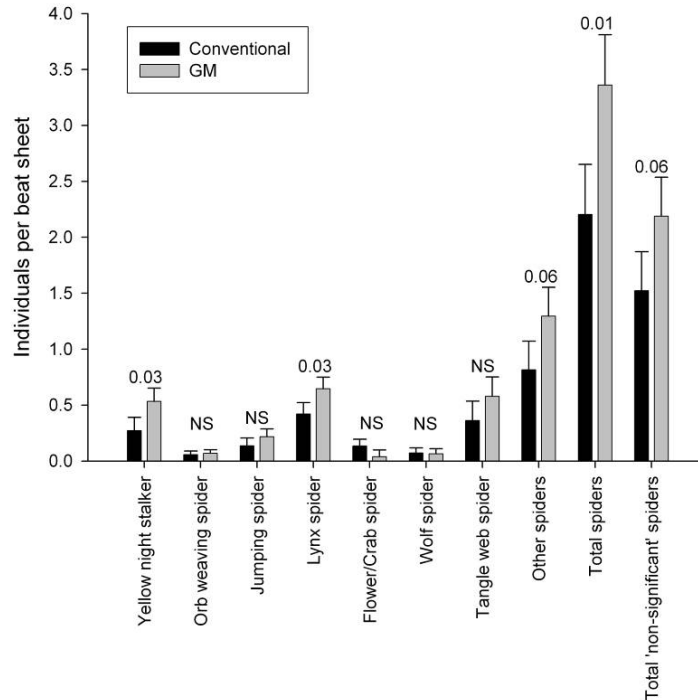


Figure 13. Differences in the total number of spiders sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Other predators

Apart from a slight non-significant increase in average density in Bt cotton, there was no indication that the abundance of either small ants, large ants, or all ants combined were affected by Bt versus conventional cotton and their associated insecticidal regimes or arthropod communities (all $P > 0.4$; Figure 14). Lacewing larvae declined non-significantly in response to the increased insecticides associated with conventional cotton farming ($\chi^2_1 = 3.61$; $P = 0.06$). However, there was no evidence to suggest that the total abundance of 'other predators' was influenced by cotton type ($\chi^2_1 = 0.04$; $P = 0.83$; Figure 14).

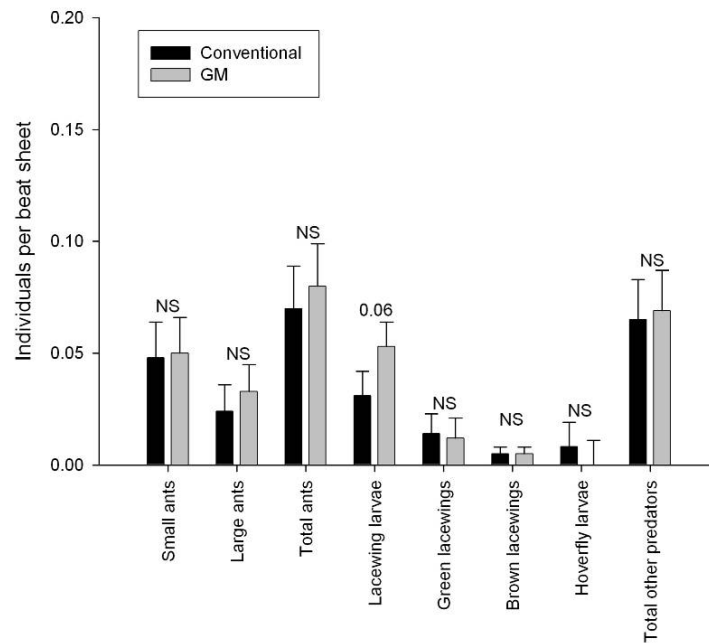


Figure 14. Differences in the total number of spiders sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Neutral taxa

The abundances of neutral arthropod taxa were not significantly affected by the type of cotton grown (all $P > 0.18$, Figure 15)

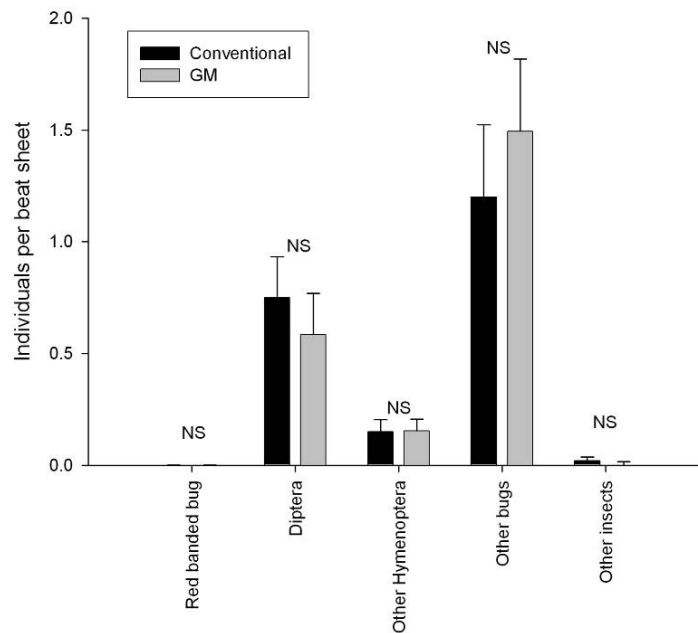


Figure 15. Differences in the total number of neutral taxa sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons. Figures above bars describe the level of statistical significance (NS > 0.1).

Resolving power of small sample sizes

The relative infrequency of several arthropods analysed in this study meant that several taxa were represented only by small sample sizes. Thus the ability of statistical tests to determine significant differences between treatments is limited. It is therefore pertinent that the likelihood that a taxa exhibited significant differences between cotton types was significantly related to the abundance of that taxa in the sample ($\chi^2_1=9.98$; $P=0.003$; Figure 16). Thus caution must be applied to data indicating that no significant difference exists in the abundance of arthropods that are represented in the sample relatively infrequently.

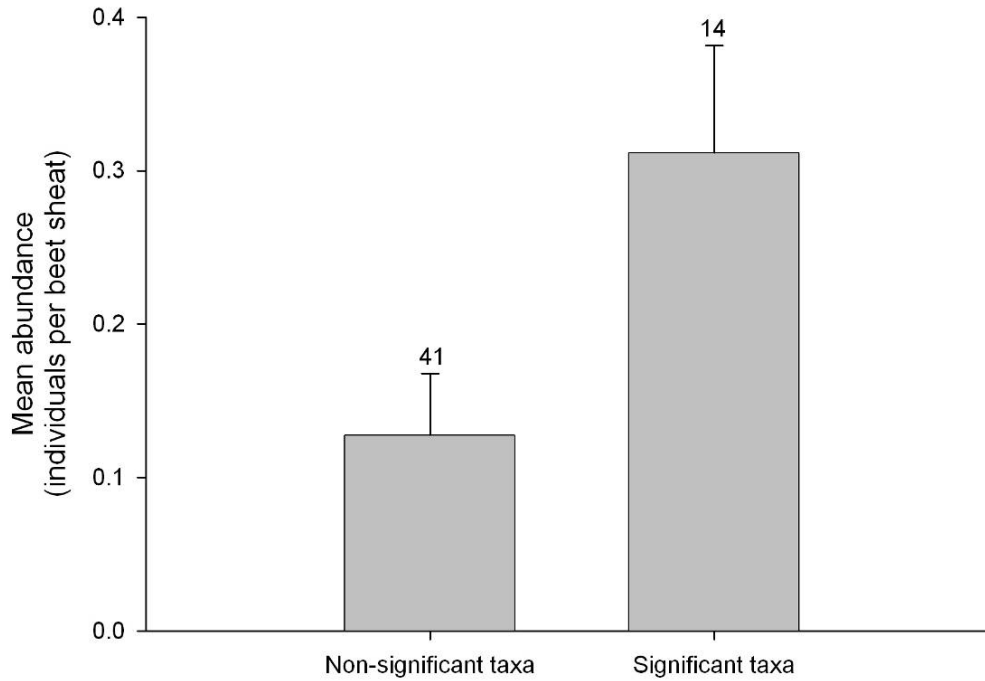


Figure 16. Taxa in which significant differences in abundance were detected versus taxa in which such differences were absent as a function of the mean abundance of each taxa. Figures above bars denote the number of taxa per category.

The ratio of predators to *Helicoverpa* and to other pests in conventional and Bt cotton:

When pooling the beat sheet data presented above, conventional cotton has 10.1 arthropod predators for every *Helicoverpa* larvae detected on a beat sheet. In comparison, Bt cotton has 78.2 predators per *Helicoverpa*. There is little difference in the ratio of beneficial arthropods to minor pests between the two cotton types. Conventional cotton fields had 0.49 predators per minor pest, whereas Bt cotton had 0.43 predators per minor pest.

3.1.4 Discussion

Effect of BDI on arthropod faunas

In this study, beneficial insect abundance declined exponentially with increasing BDI as the season progressed. This effect was more pronounced in conventional cotton crops that had broader spectrum insecticide regimes compared with INGARD® Bt crops. These results have confirmed that the BDI is an important tool for assessing the effect of insecticide regimes on the beneficial insect community.

However there were exceptions to this general finding. Repeated prophylactic sprays of selective (non-disruptive) control options, lead to a relatively high BDI that was not indicative of disruption in field 17 on farm I. This particular farm has also been managed to conserve beneficial species for several years by applying no insecticides to extensive areas of cotton, so that these areas act as refuges for beneficial predators and parasites. It therefore appears that the BDI is an imperfect measure of beneficial disruption in cotton fields subject to repeated applications of highly selective insecticides. Differences in BDI did not affect community composition in beneficial insects, although there was a trend. For example, the red and blue beetle, *D. bellulus*, was associated with more disruptive insecticide regimes. This species has a soil dwelling larval stage, which is not collected in beat sheet samples, and the adults frequently retreat into the soil when disturbed (Stanley, 1997). These traits may offer some protection from foliar insecticides or this species may be physiologically more tolerant of such treatments. The less disruptive regimes applied to INGARD® cotton fields generally resulted in more abundant beneficial insect populations, particularly aphid-feeding ladybirds (Coccinellinae) and the big-eyed bug, *Geocoris lubra*, although the damsel bug, *Nabis kinbergii* was more common in conventional cotton fields, a finding supported by Whitehouse et al. (2005).

A number of other studies have documented the impact of insecticide regimes applied to Australian cotton fields on the beneficial arthropods within them. Ma et al. (2000) found a synthetic pyrethroid (bifenthrin) severely disruptive to insect predators in conventional cotton crops, whereas biorational pesticides such as neem extracts and Bt did not affect predator abundance. Predator abundance was also higher in experimental cotton plots treated with Bt, nuclear polyhedrosis virus (Gemstar®) or a selective insecticide (spinosad) compared with conventionally managed cotton crops (Mensah, 2002b). Wilson et al. (1998) found that in small plot trials methomyl caused significant reductions in all beneficial groups sampled, while thiodicarb, dimethoate and endosulfan caused a significant reduction in at least four of the five predator groups sampled.

Changes in community composition were more strongly associated with BDI and crop type in spiders than they were in insects. There are many possible factors driving this difference. For example, nocturnal ground-burrowing lycosids may be less exposed to diurnal, foliage sprays. This may explain why Lycosidae in this study were less likely to be associated with selective insecticide regimes (low BDI) than other spiders. Ballooning spiders were likely to have contributed to the observed differences in spider communities. Spiders balloon into crops throughout the growing season (Pearce et al., 2005), providing a population source for spider communities after insecticide treatment. However, if there is a bias in the families represented by spider aeronauts (Suter, 1999) recolonization may cause a shift in the spider community composition of the field. Biases in spider aeronauts will also affect the ability of the spider community to control pests because a) there is a predominance of Linyphiidae among ballooning spiders (Suter, 1999) and b) ballooning spiders are small, including many spiderlings (Suter, 1991). The amount of prey that spiderlings are able to capture is much lower than that of adult spiders, and may dilute the overall impact of spiders on pests.

This study has demonstrated that the insecticide regime applied to cotton fields, as measured by the BDI, had a significant effect on the beneficial arthropod community. Beneficial insect abundance decreased with an increase in BDI, although community composition was less affected. In contrast, spider abundance was less affected by an increase in BDI, although community composition changed. These differences may indicate that a high BDI has a more uniform effect on beneficial insects than it does on spiders. The insecticide scores used to calculate the BDI do provide a means to compare the selectivity of different products. However other factors such as the type and abundance of pests

present, local resistance management strategies and application costs are likely to have more weight in the decision making process for growers. Perhaps the most important application of the BDI is the ability to directly compare the selectivity of insecticide regimes applied to cotton fields on different farms or in different seasons, using crop management information that is readily available. The BDI can help in the evaluation of growers' pest control strategies and act as a research tool because it is situation specific and easy to calculate, yet provides a valid index of insecticide disruption to beneficial arthropods in Australian cotton crops.

Comparison of arthropod communities in Bt and Conventional fields

The visual and beat sheet data reveals that *Helicoverpa* eggs are equally prevalent on conventional and Bt cotton, yet larvae of any size are less likely to be found on Bt cotton. In other words, (i) *Helicoverpa* do not appear to discriminate between conventional and Bt cotton in their selection of oviposition sites (Liu et al., 2002), and (ii) larvae die rapidly after ingesting Bt cotton and/or succumb rapidly to the higher numbers of predators present in Bt fields. Alternatively, larvae may actively avoid feeding on Bt plants and relocate to conventional cotton (Bates et al. 2005). However, this seems unlikely and implausible given the generally large internal size of commercial cotton fields and the large distances between conventional and Bt crops in these trials. Thus, these data indicate that the Bt crops have been very successful in reducing the number and density of *Helicoverpa* caterpillar feeding on the plants.

The only other arthropod in this analysis that had significantly lower densities in Bt cotton compared to conventional cotton were damsel bugs (*Nabis kinbergii*). This appears to be a counter-intuitive result, because the conventional cotton fields in this study were subject to a significantly more severe insecticide regime than Bt cotton fields (they had higher BDI's), and the higher abundance of arthropods in Bt fields would appear to provide a better source of prey for a predatory bug like damsel bugs. However Damsel bugs have been reported as being less common in Bt fields in a number of other field studies (Whitehouse 2005, David Murray unpublished, Naranjo 2005, Daly and Buntin 2005). There is an inference that Bt cotton may have a direct negative effect on damsel bugs – to the extent that they are more abundant in fields more heavily treated with insecticides. However, laboratory studies assessing direct toxicity of Bt to damsel bugs or of *Spodoptera* larvae that have fed on Bt have not reported any evidence of negative effects on damsel bug development, fecundity or survival (Ponsard et al. 2003). There is an alternative and simple explanation that cannot be discounted and that remains to be tested in the field: It could be that damsel bugs choose to colonise or reside in cotton fields that have higher densities of caterpillar larvae. For example, they may be directly attracted by sensory cues arising from lepidopterans or from plant kairomones released from cotton plants in response to caterpillar feeding damage. Lepidoptera in general, and *Helicoverpa* densities and plant damage related to *Helicoverpa* attack will always be substantially higher in conventional fields compared with Bt cotton fields.

Overall Bt cotton fields had higher abundance and diversity of arthropod fauna than conventional cotton fields. Almost all taxa exhibited a trend for higher abundance in Bt fields even though this difference often wasn't statistically significant. Three taxa were significantly more abundant in Bt cotton fields than in conventional cotton fields. These were big eyed bugs *Geocoris lubra*, yellow night stalker spiders *Cheiracanthium* spp., and lynx spiders (Oxyopidae).

3.2 Objective 2

3.2.1 Aim

To determine and analyse the linkages between *Helicoverpa* pressure, field spray regimes and BDI scores, and the economic performance of individual fields.

3.2.2 Methods

In collaboration with Dr Bob Farquharson, Ziaul Hoque, Steve Harden and Bruce McCorkell (all NSW DPI), we undertook a financial evaluation of cotton field productivity and profitability from the Boggabilla landcare group. This group consists of 12 contiguous cotton farms near Boggabilla NSW. The cotton fields belonging to this group are concentrated within an area approximately 10km by 10km (i.e. 100 km²). The members of the Boggabilla landcare group feel strongly that disruptive sprays applied to individual fields within their area directly or indirectly affect neighbouring fields and farms. The close concentration of the farms within the group also suggest that as a whole cotton fields within the area are likely to be subject to similar amounts of *Helicoverpa* pressure. Information was obtained from the growers and their consultants for every cotton field in the group each season. The number of fields varied from 60 to 154 per season, depending on the availability of irrigation water and the incidence of hail storms. The data included details of insect counts, agronomic details, insecticide sprays and lint yields. We used Scott's (1999) 'Farm Budget Handbook: Northern Irrigated Crops' to standardise variable input costs. In order to compare the relative degree to which individual cotton fields were managed with IPM principles, we analysed the types of sprays applied to each field and related these data to the pest pressure experienced by each field.

The Beneficial Disruption Index (BDI)

To compare the insecticide spray regimes applied to each field, we scored each type of insecticide according to its relative impact on beneficial insects and summed these scores (multiplied by the number of sprays) to compute a Beneficial Disruption Index (BDI) for each field (Table 3). The insecticide spray scores were derived from the information compiled by Wilson *et al* (2002). They categorised insecticides according to their disruptive effects on beneficial groups such as predatory beetles (ladybeetles etc), predatory bugs (big-eyed bugs etc), spiders, wasps and ants, and thrips. Based on data from extensive field trials over several years, Wilson *et al* (2002) rated the overall impact of insecticides (percentage reduction in beneficials following application) as very low (less than 10%), low (10-20%), moderate (20-40%), high (40-60%) and very high (> 60%). We applied scores to these overall ratings on the basis of 1 point for every 10 percentage points of impact. The resulting scores for each impact category were as follows: Very low 1, Low 2, Moderate 4, High 6 and Very High 8. The last category is conservatively set at 8 because the range of impact is broad – potentially from 60 to 100%.

BDIPP

In some of our analyses we also normalised the BDI derived for each field relative to the *Helicoverpa* pest pressure experienced by each field. We did this by dividing each field's BDI by the average *Helicoverpa* egg density experienced by that field over the whole season. We called this the Beneficial Disruption Index per unit of Pest Pressure (BDIPP). We used average *Helicoverpa* egg densities as our measure of pest pressure because in most seasons *Helicoverpa* is the predominant pest and, relative to larvae, eggs are subject to less mortality from sprays, natural enemies or Bt toxins. Egg counts therefore give a good indication of the pest pressure that each field is actually subject to. However, it is important to note that in this analysis we have not yet considered other pests like mirids, mites and aphids in our measure of pest pressure. In the 2000/2001 season these secondary pests were often the predominant trigger for insecticide sprays applied to fields in our data set.

Soft versus Hard

To provide an overall comparison between pest management strategies, the spray regimes applied to fields from each season were classified as either ‘Hard’ or ‘Soft’ on the basis of their BDI scores. INGARD® and Conventional fields were treated separately for each season, and in each case the 50% of fields with greater than the median BDI value for that season were classified as ‘Hard’ while the 50% with lower BDI values were classified as ‘Soft’.

3.2.3 Results

The first three seasons of historical data (1998/99 to 2000/01) was incidentally collected in a previous project (CSE86C: Quantifying behavioural responses of *Helicoverpa* moths to trap crops for areawide management). Two cotton conference papers (Dillon et al., 2002 and Hoque et al 2002) and a Cottongrower magazine article (Hoque et al. 2000) have been published describing aspects of this data set. The following results present some material from the first three seasons that has not been formally reported previously, and then presents combined information from the analysis of five seasons data. The overall data set is currently subject to a complete re-analysis, and results are not yet available. A brief description of the forthcoming manuscript is given in section 8.9 below.

Table 1 summarises details for the top 20% of fields that had the highest Gross Margins (gross returns less variable costs) (GM) in each season between 1998/99 and 2000/01, and compares them with the average values for the remaining fields. The figure of 20% was chosen to allow comparison with the Australian Cotton Comparative Analysis (Boyce Chartered Accountants 2001).

Table 4. A comparison of the top 20% of most profitable fields (highest Gross margins) with the remaining fields.

| | Conventional | | INGARD® | |
|-------------------------------------|--------------|------------|---------|------------|
| | Top 20% | Lowest 80% | Top 20% | Lowest 80% |
| 1998/1999 Season | | | | |
| Average <i>Helicoverpa</i> (eggs/m) | 4.09 | 4.84 | 2.42 | 4.14 |
| BDI | 19 | 125 | 56 | 92 |
| BDIPP | 32 | 30 | 28 | 24 |
| No. of sprays | 12.6 | 13.4 | 6.9 | 9.1 |
| Total Spray Cost (\$/Ha) | 686 | 765 | 372 | 583 |
| Yield (Bales/Ha) | 8.34 | 7.39 | 8.91 | 7.54 |
| GM (\$/Ha) | 2478 | 1849 | 2971 | 1967 |
| 1999/2000 Season | | | | |
| Average <i>Helicoverpa</i> (eggs/m) | 1.14 | 1.02 | 0.93 | 0.70 |
| BDI | 19 | 21 | 9 | 6 |
| BDIPP | 18 | 22 | 8 | 9 |
| No. of sprays | 5.3 | 6.4 | 2.1 | 2.1 |
| Total Spray Cost (\$/Ha) | 295 | 334 | 93 | 104 |
| Yield (Bales/Ha) | 9.73 | 8.67 | 10.70 | 8.86 |
| GM (\$/Ha) | 3680 | 3024 | 4284 | 3206 |
| 2000/2001 Season | | | | |
| Average <i>Helicoverpa</i> (eggs/m) | 0.76 | 1.41 | 0.59 | 0.79 |
| BDI | 34 | 32 | 10 | 12 |
| BDIPP | 48 | 40 | 18 | 18 |
| Number of spray applications | 7.7 | 7.7 | 2.3 | 2.4 |
| Total spray cost (\$/Ha) | 499 | 498 | 118 | 153 |
| Yield (Bales/Ha) | 8.26 | 6.85 | 9.42 | 7.39 |
| Gross Margin (\$/Ha) | 2620 | 1808 | 3522 | 2309 |

The relationship between BDI and GM for each season is illustrated in Figure 17 (98/99), Figure 18 (99/00) and Figure 19 (00/01). The 1998/99 season was characterized by intense *Helicoverpa* pressure and had up to three times higher BDI figures compared with subsequent seasons. There is a clear overall trend in 1998/99 for fields with high BDIs to have lower GMs. This trend is even more apparent for INGARD® fields. The 1999/2000 season was relatively light in terms of pest pressure. The overall BDIs are much lower, and there is no obvious trend in profits as BDI increases. The 2000/2001 season was characterized by high densities of sucking pests. INGARD® fields show a downward trend in profits relative to BDI, but Conventional fields had the opposite trend.

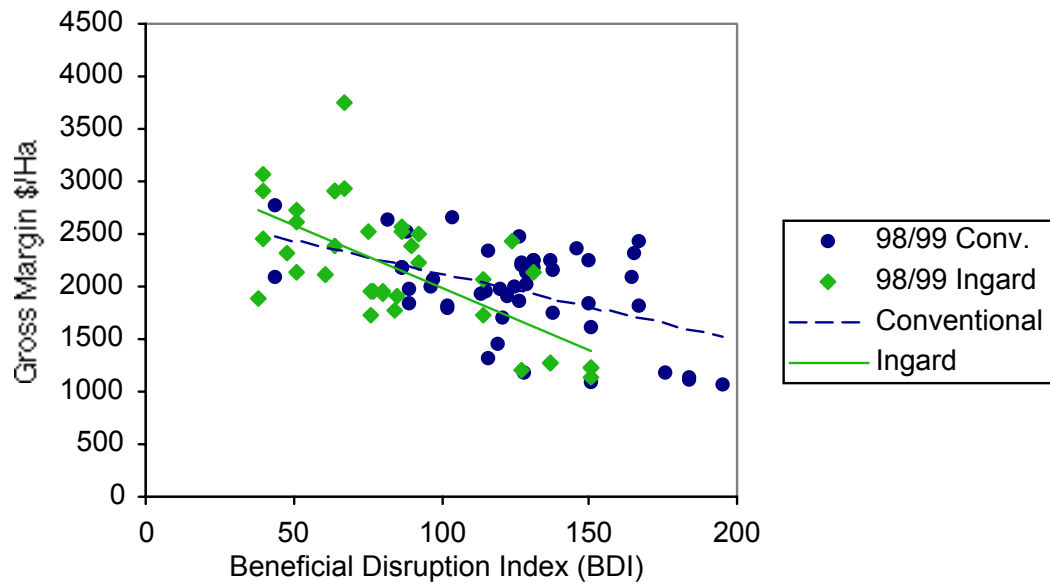


Figure 17. The relationship between GM (\$/Ha) and BDI in 1998/99. Dark dots and the dashed line represent Conventional fields, light dots and solid line represent INGARD® fields. INGARD® GM= 3184.9 - 11.95 BDI (R-squared = 0.461) Conventional GM= 2762.45 - 6.349 BDI (R-squared = 0.242).

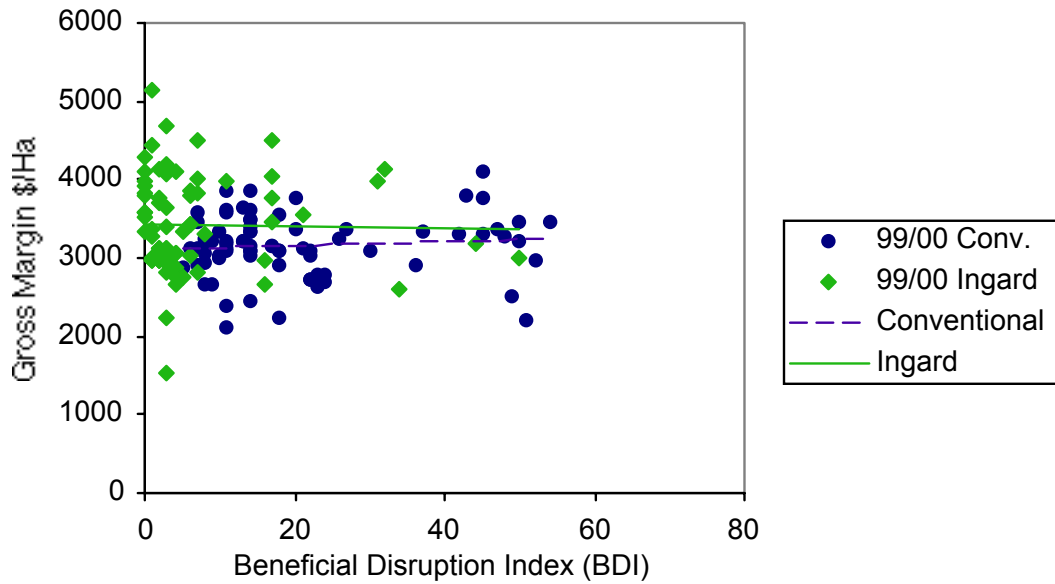


Figure 18. The relationship between GM (\$/Ha) and BDI in 1999/00. Dark dots and the dashed line represent Conventional fields, light dots and solid line represent INGARD® fields. INGARD® GM= 3437.15 - 1.3724 BDI (R-squared = 0.0005) Conventional GM= 3103.85 + 2.3326 BDI (R-squared = 0.007).

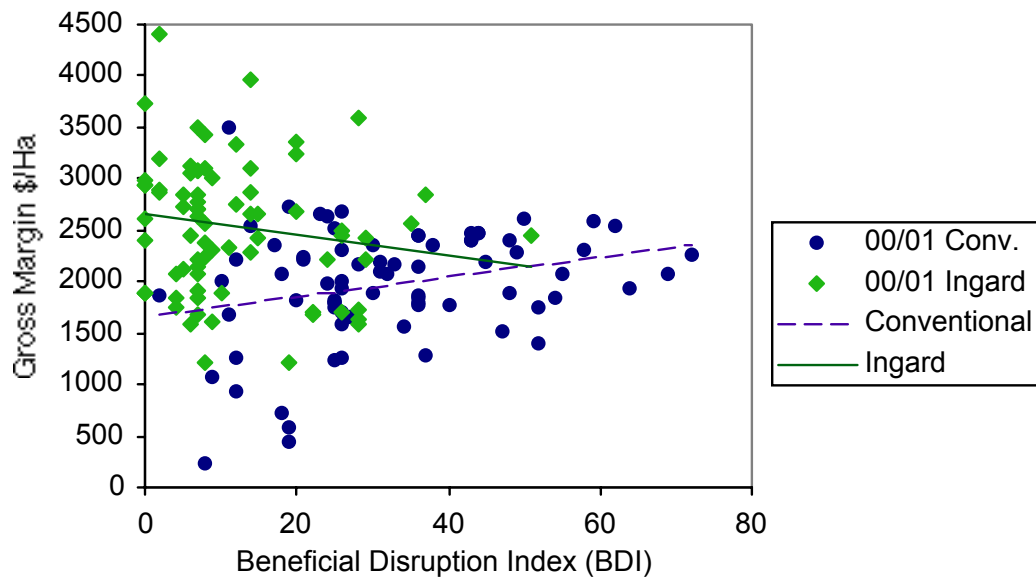


Figure 19. The relationship between GM (\$/Ha) and BDI in 2000/01. Dark dots and the dashed line represent Conventional fields, light dots and solid line represent INGARD® fields. INGARD® GM= 2664.05 - 10.1581 BDI (R-squared = 0.024) Conventional GM= 1653 + 9.8402 BDI (R-squared = 0.073).

Crop scouting data from the consultants was used to plot the average *Helicoverpa* egg density (as a general indicator of pest pressure) experienced over the five seasons from 1998/99 to 2002/03 within the Boggabilla Landcare group (Figure 20). Average egg densities were higher in conventional fields in every season.

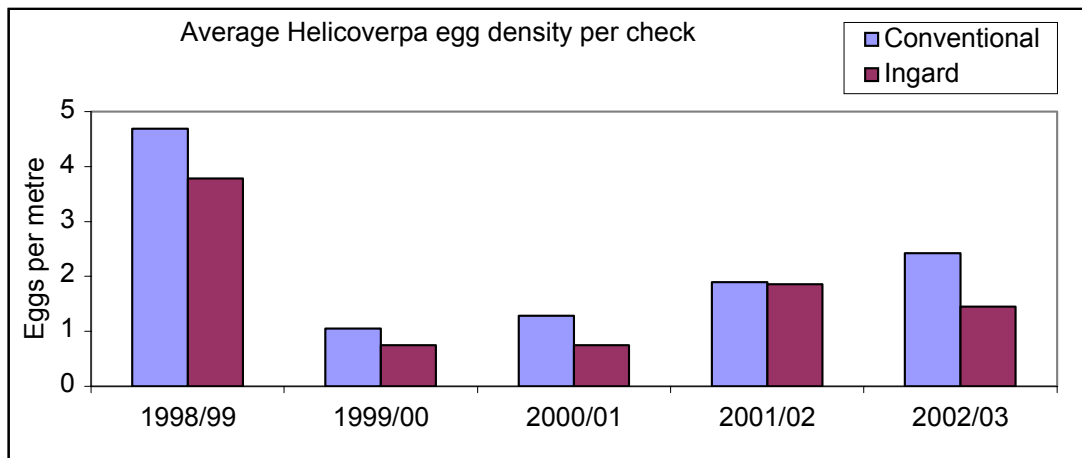


Figure 20. Boggabilla Landcare group average *Helicoverpa* White + Brown egg pressure per check in Conventional versus INGARD® cotton fields over 5 seasons.

Spray application data from the consultants was used to plot the average number of sprays applied to Ingard and conventional fields over the five seasons from 1998/99 to 2002/03 within the Boggabilla Landcare group (Figure 21). Average numbers of sprays were higher in conventional fields in every season.

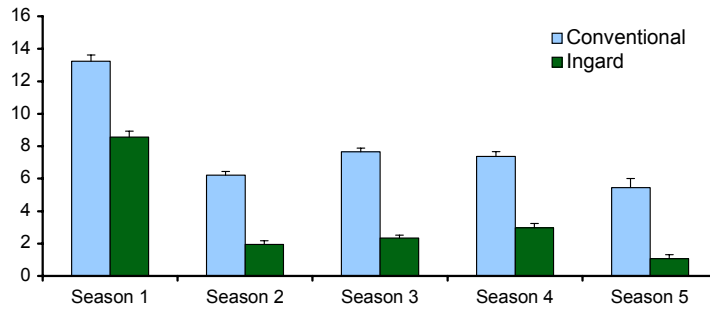


Figure 21.Boggabilla Landcare group average number of spray applications in Conventional versus INGARD® cotton fields over 5 seasons (1998/99 to 2002/03).

Spray data for each cotton field was used to calculate the average cumulative BDI (Figure 23) and in association with the pest pressure data the BDIPP (Figure 25) applied to Ingard and conventional cotton fields over the five seasons from 1998/99 to 2002/03 within the Boggabilla Landcare group.

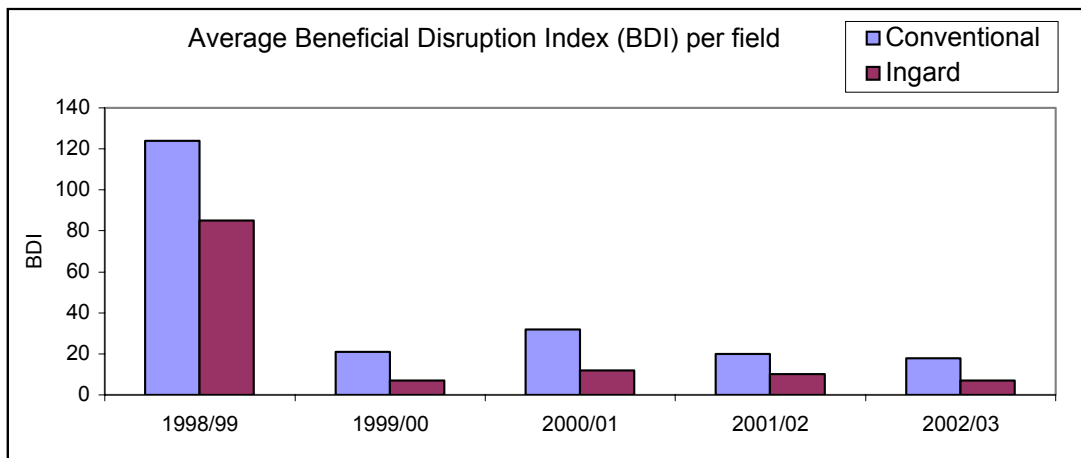


Figure 22.Boggabilla Landcare group Beneficial Disruption Index (BDI) in Conventional versus INGARD® cotton fields over 5 seasons.

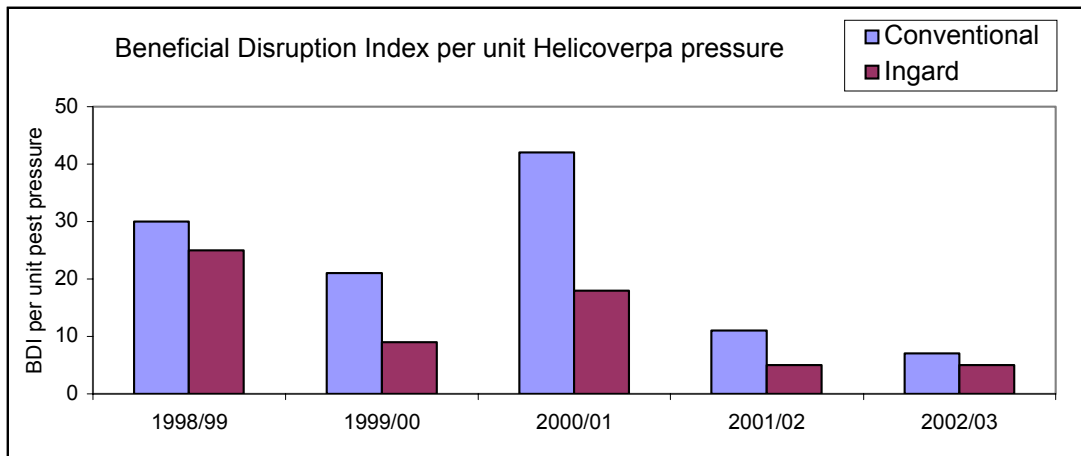


Figure 23.Boggabilla Landcare group Beneficial Disruption Index per unit pest pressure (BDIPP) in Conventional versus INGARD® cotton fields over 5 seasons.

Data on average beneficial arthropod density is only available for a subset of fields sampled by CSIRO staff during the three seasons 2000/01, 01/02, and 02/03 (Figure 26). However it is likely to be indicative of the general trends present within cotton fields in the Boggabilla landcare group.

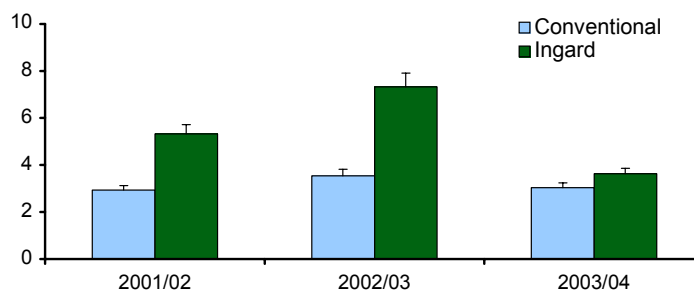


Figure 24. Boggabilla Landcare group average density of beneficial insects (density per metre) in Conventional versus INGARD® cotton fields over three seasons.

A comparison of each season’s average lint yields for ‘Soft’ and ‘Hard’ INGARD® fields is presented in Figure 27a. The light bars represent the 50% of INGARD® fields that had the lowest BDI’s, while the dark bars represent the 50% of INGARD® fields with the highest BDI values. In all three seasons there is a trend for the Soft INGARD® fields to have higher Yields than Hard INGARD® fields, but this difference was only statistically significant in 1998/99 as indicated by the arrow. This trend is reversed for Conventional fields (Figure 27b), where the softly managed fields averaged slightly lower yields than the Hard fields. Once again this difference is only statistically significant in one season (2000/01).

Figure 28 shows the average GM for the Soft and Hard fields in each season. The variations in profits from season to season are predominantly caused by differences in insect control costs. For INGARD® fields (Figure 28a) the higher yields and lower BDI values translate directly into higher average profits in all three seasons, but only 1998/99 is statistically significant as indicated by the arrow. For conventional fields (Figure 28b) the softly managed fields resulted in higher profits in 1998/99 and 1999/00, but not in 2000/01 when softly managed fields averaged a statistically significant lower GM.

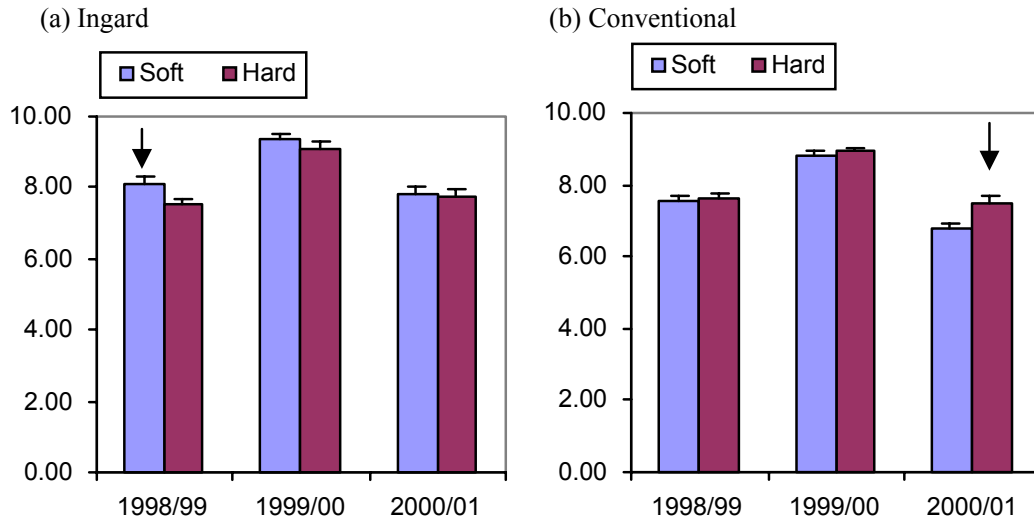


Figure 25. Comparison of Yields (Bales/Ha) between (a) Ingard 'Soft' and 'Hard' fields for each season, and (b) Conventional 'Soft' and 'Hard' fields for each season. Note bars with arrows above are significantly greater (t-test comparing mean yields where $p < 0.05$).

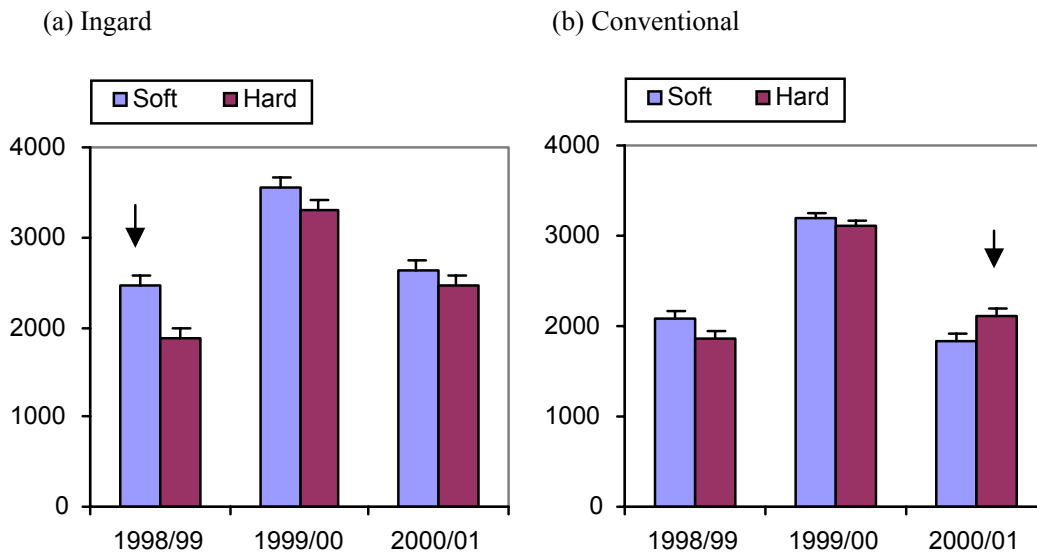


Figure 26. Comparison of Gross Margins (\$/Ha) between (a) Ingard 'Soft' and 'Hard' fields for each season, and (b) Conventional 'Soft' and 'Hard' fields for each season. Bars with arrows above are significantly greater (t-test comparing mean GM where $p < 0.05$).

The average GM for the Soft and Hard fields in each season from 1998/99 to 2002/03 is presented in Figure 27 (conventional) and Figure 28 (INGARD®). The variations in profits from season to season are predominantly caused by differences in insect control costs, and this inter-seasonal variation far outweighs the difference between hard and soft within seasons. For conventional fields (Figure 27) the higher yields and lower BDI values translate into higher average profits in four out of five seasons. For Ingard fields (Figure 28) the softly managed fields resulted in higher profits in the first three seasons but not in 2001/02 and 02/03.

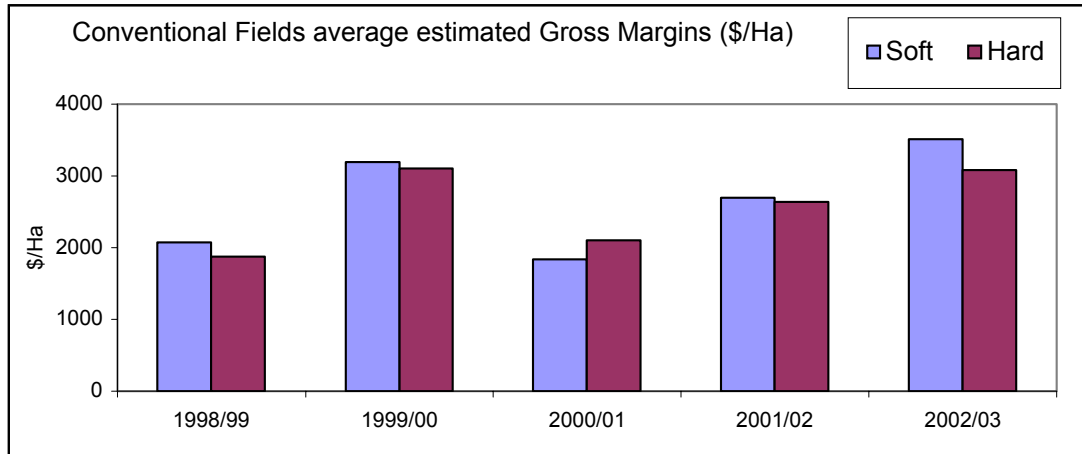


Figure 27. Estimated gross margins (\$/Hectare) in 'Soft' versus 'Hard' Conventional cotton fields in the Boggabilla Landcare group over 5 seasons. Within each season the median Beneficial Disruption Index was used to classify fields into equal sized soft and hard categories. The median BDI value is different for each season. Data provided by Ziaul Hoque (NSW Agriculture).

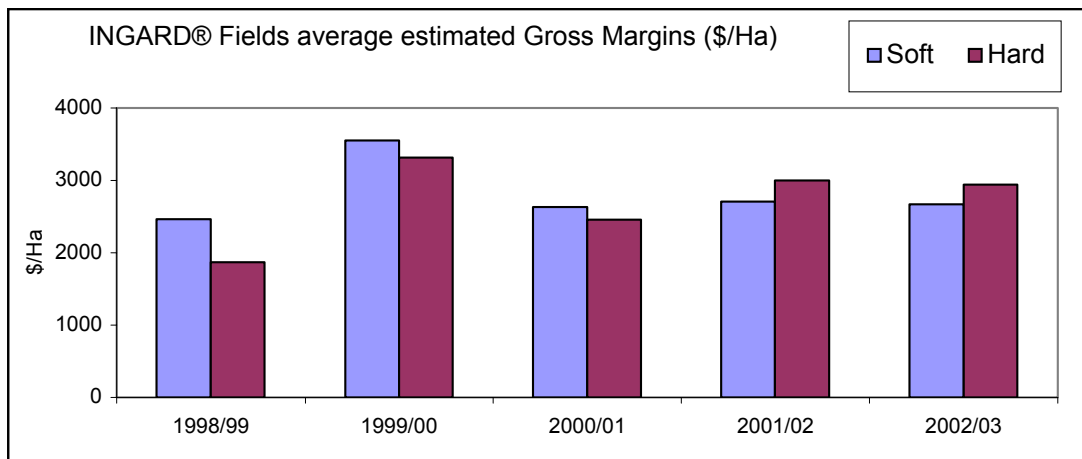


Figure 28. Estimated gross margins (\$/Hectare) in 'Soft' versus 'Hard' INGARD® cotton fields in the Boggabilla Landcare group over 5 seasons. Within each season the median Beneficial Disruption Index was used to classify fields into equal sized soft and hard categories. The median BDI value is different for each season. Data provided by Ziaul Hoque (NSW Agriculture).

3.2.4 Discussion

Estimated gross margins for the fields in the dataset vary widely both between and within seasons. However on average, fields that were managed softly – i.e. they fell within the 50% of fields below the median BDI for each season – performed comparably with fields that were managed with harder spray regimes. For conventional fields (Figure 27), a harder spray regime seems to have been slightly more profitable in only one season out of five: 2000/01. For INGARD® fields (Figure 28), only in the last two seasons were the 50% of fields managed with a harder spray regime slightly more profitable than the more softly managed fields.

Conventional cotton fields had consistently higher average egg densities than Ingard fields (Figure 20). Given that egg laying *Helicoverpa* moths are not known to distinguish between Bt and conventional cotton there are two plausible explanations for this difference. The first is that Ingard fields support higher densities of beneficial arthropods (because they receive less pesticides and accrue lower BDI's than conventional fields) (Figure 24), and these beneficials may prey on eggs and reduce their density before they can be counted by scouts. The second possibility is that more *Helicoverpa* complete their life cycles and emerge as moths in conventional fields than in Ingard crops. If these locally produced moths have a tendency to lay eggs close to where they emerged it may result in higher egg densities in conventional crops.

1998/99 was an intense pest season, and average *Helicoverpa* egg numbers have generally declined since then. Figure 23 shows the average Beneficial Disruption Index (BDI) applied to Conventional and INGARD® fields. The reduced pest pressure in 1999/00 and thereafter has resulted in a dramatic reduction in spray intensity to relatively low levels. Figure 23 shows the average BDI normalised for *Helicoverpa* egg pressure experienced by each field. In general the intensity of spray regimes per unit *Helicoverpa* pressure has been declining since 1998/99. The higher BDI per unit pest pressure in the 2000/01 season are probably in response to slightly higher pressure from secondary pests including mirids, aphids and mites that season.

In 2000/2001 softly managed conventional fields had lower yields and produced lower profits than hard fields in that season. The difference is even more apparent in Table 4, which shows that the most profitable top 20% of conventional fields in 2000/2001 had higher BDI and BDIPP values than the average for the rest of the fields. Compared with the earlier seasons, many of the insecticide sprays in 2000/2001 were targeted at mirids and other sucking pests. In contrast to control options for *Helicoverpa*, there are no completely target-specific insecticides for sucking pests. For example, the main insecticides used against mirids (e.g. Fipronil, Imidacloprid, Endosulfan, Organophosphates) all have a BDI of 4 or higher. The implications of this are that any insecticide spray directly targeting sucking pests will also disrupt beneficial insects, often substantially. Once beneficials are no longer abundant within a cotton field, it is likely that pests will reach economic threshold levels more often, chemical intervention is likely to be required more often, and the relative benefit of softer sprays is likely to be reduced.

There are other down sides associated with chemical management strategies. These include potential environmental contamination, and the risk of increased resistance to insecticides and insecticide groups. The use of larger numbers of sprays influences the selection pressure exerted on the insect population, and the resulting impact on future susceptibility to insecticides. This is an important economic problem that the industry is currently facing. AWM groups that strive to preserve and nurture beneficial insects and spiders within the landscape are likely to provide their members with a better and less risky platform for implementing IPM. We do not yet have all the answers for managing pests, especially sucking pests, but overall our results show that an IPM approach is generally no less profitable than old fashioned approaches to pest management, with the added benefit of reduced environmental impacts.

Given the inherent risks of an over reliance on chemical insecticides the Boggabilla landcare group's successful implementation of IPM on an areawide scale appears to be paying off. As a whole the group is steadily progressing towards a pest management approach that is sustainable without sacrificing profitability.

3.3 Objective 3

3.3.1 Aim

To compare the beat sheet sampling technique with established methods for sampling pest and predator abundance in cotton.

3.3.2 Methods

Data for this analysis was collected in conjunction with a CRC Summer Scholarship to Carla McKinnon (University of Western Sydney). Martin Dillon and Sandra Deutscher (CSIRO Plant Industry) co-supervised the study, and along with technical staff, participated in all aspects of the project. The study took place over 16 weeks during the 2002-2003 season. Sampling was conducted on irrigated commercial cotton farms in six sites located in the Namoi and McIntyre Valleys (Table 5). Overall data from more than 2000 one metre samples were collected, recording over 50,000 individual arthropods.

Table 5. Location of sample sites for the comparison of sampling methods.

| Experiment | Field ID | Farm Name | Region | Variety grown |
|-------------------|-----------------|------------------|---------------|----------------------|
| 1 | 24 | Scotsburn | Namoi | Conventional |
| | 25 | Scotsburn | Namoi | Conventional |
| 2 | 3 | Sandhurst | Namoi | Conventional |
| | 5 | Sandhurst | Namoi | Ingard |
| 3 | A1 | ACRI | Namoi | Conventional |
| | A1 | ACRI | Namoi | Ingard |
| 4 | A1 | Morella | McIntyre | Conventional |
| | A4 | Morella | McIntyre | Ingard |
| 5 | 4 | Eumorella | McIntyre | Conventional |
| | 6 | Eumorella | McIntyre | Ingard |
| 6 | 6 | Korolea | McIntyre | Conventional |
| | 8 | Korolea | McIntyre | Ingard |

A team of four, sometimes five checkers conducted sampling in each field. Samples were collected between 7am and 12 noon or after 5pm to minimize diurnal effects on arthropod abundance. Each site was sampled approximately every fortnight. A check sheet of key beneficial and pest taxa was used to record data from each sampling method. The temperature, wind speed, irrigation status, and stage of the plants were recorded for each field as well as the time of each check and the name of the checker, so that these factors could also be considered in the analysis.

All data collected was processed in field and only those arthropods visible to the naked eye were counted, therefore reducing handling and simulating conditions that growers and consultants would normally work in. To reduce variability between the sampling methods they were all conducted on a per metre basis.

Visual Checks

Twelve visual checks were conducted in each field. Each checker completed three or four visuals consisting of one metre of row each, randomly selected within the field. A metre stick was placed next to the row of plants and the cotton plants in the metre were carefully inspected visually. The visual inspection covered the whole plant, and the squares and bolls were opened to check for potential arthropods hidden within. The total numbers of insects and spiders of each taxa observed on all the plants in each metre of row were recorded on the check sheets.

Beat Sheets

The sheet used was a 1.5m x 2m piece of yellow Canvacon with a 25mm diameter piece of timber in each end to prevent the wind lifting it from the ground. The sheet was placed behind the metre of row to be sampled and up along the adjacent row of cotton therefore acting as a wall for insects, particularly flying ones, to land on.

Two people conducted each beat sheet sample to ensure all insects were counted before they left the sheet. Once the sheet was laid out by one checker, the other used a one metre long stick (plastic electrical conduit) to vigorously push (rather than 'beat') the plants 10 times, while steadily moving the metre stick from the base to the tops of the plants. The insects and spiders dislodged from the plants onto the canvas were counted and recorded. Twelve beat sheet samples were done in each field on each sampling occasion.

D-vac Suction samples

A Stihl BG72 garden blower/vacuum with a fine mesh collecting bag inside was used to suck insects from a one metre row of cotton. One checker randomly picked 12 metres in the field to sample. A metre stick was placed beside the row of cotton and the d-vac was passed several times over the metre going over the sides and top of the plants. Once this was done the d-vac was left idling so that excess leaves could be carefully removed without the insects escaping, the top of the bag was then knotted and the bag removed. After twelve samples from the field had been collected the knotted bags were put in a plastic box in which two dental wicks dipped in chloroform had been placed to kill the collected insects and spiders.

After the arthropods had been killed the contents of the d-vac bag were tipped into a small clear plastic box. Any large cotton bolls or leaves were brushed and taken out so that the insects could be clearly seen, and then were counted and recorded. This was usually undertaken at the site from which the samples had been collected.

Absolute counts

To more accurately calibrate the three sampling methods, we counted the absolute number of key pests and predators present in one metre sections of cotton row to compare against the relative numbers gathered from the other sampling methods.

We designed a technique to trial within this project in order to gather this information. This technique was referred to as the 'pounce net'. The net was made from a 2m x 3m piece of white organza mesh, which was made into a bag with 2 m of elastic threaded around the edge so it could stretch to approximately 1.5 metres in diameter. It also had a drawstring attached above the elastic. The process involved two people carefully and stealthily approaching a random metre of cotton row measured out with a metre stick. The pounce net was then stretched open and quickly pulled over the one metre of cotton row, at which point two other people quickly cut the enclosed cotton plants off at the base with secateurs, while the net was drawn close using the drawstring. The net containing the plants was tied at the top so that insects and spiders could not escape.

The pounce nets were taken back to the laboratory and placed in a cold room while awaiting processing. Each net was placed in a 200 litre drum fumigated with chloroform for at least 10 minutes to kill the captured insects and spiders. The enclosed cotton plants were then carefully shaken to dislodge arthropods, and then removed and placed in another net while the first net was placed in a smaller container containing chloroformed wicks. The collected arthropods and plant debris was then poured into large white plastic sorting trays and inspected in the same manner as the d-vacs. The plants were then also placed in the trays and were cut up into thirds and visually checked for insects.

The ‘pounce nets’ were only used in one field of unsprayed conventional cotton at ACRI and only 4 m were sampled on each occasion because this method was very labour and time intensive. On three dates in 2003 absolute samples were collected along with beat, visual and d-vac samples as described above.

Observer bias experiment

This experiment was conducted twice during 2003 in a field of unsprayed conventional cotton at ACRI. Five scouts with a range of checking experience conducted equal numbers of visual and beat sheet samples in a Latin Square design (Figure 29). Letters were randomly assigned to determine the position of each scout in the design. One visual and one beat sheet sample was taken at each point. This design controlled for any natural spatial variation in arthropod abundance within the field sampled. At each sample point a scout took one beat sheet and one visual sample in adjacent sections of cotton.

| | | | | |
|---|---|---|---|---|
| A | B | E | C | D |
| B | C | A | D | E |
| C | D | B | E | A |
| D | E | C | A | B |
| E | A | D | B | C |

Figure 29. The Latin Square design used for the observer bias experiment, where each letter represents one scout.

Statistical Analysis

All abundance data was $\log(x+1)$ transformed prior to statistical analysis, which was conducted using SAS version 8. The abundance of all beneficial taxa recorded (Table 6) was compared between the different sampling methods over the course of the season using ANOVA. The abundance of *Helicoverpa* spp. eggs and larvae was compared using multivariate analysis of variance (MANOVA). Pillai’s Trace (V) is the test statistic reported for MANOVA tests.

Unlike *Helicoverpa* spp. and beneficial arthropods, green mirid adults and nymphs (*Creontiades dilutus*) were not highly abundant at any of the sites sampled in 2002-03. To compare the effectiveness of the beat, visual and d-vac methods for this pest a data set was created that excluded those observations where no mirid adults or nymphs were found by any method (triple zeros). In order to create a data set containing sufficient samples containing mirids for a robust analysis, I have pooled data across a number of seasons and locations from four sources: this project, and data sets provided by Sandra Deutscher (CSIRO Plant Industry), Dr Mary Whitehouse (CSIRO Entomology) and Dr Mozzaem Khan (Qld DPI). All paired beat sheet / visual sampling data in which green mired adults or nymphs were detected from 2002/03 to 2004/05 were pooled to derive a conversion relationship between beat sheets and visual checks. Standard linear regression has been used to derive a conversion relationship. However it should be noted that this is a work in progress and future analyses will be presented in a forthcoming manuscript (see section 8.9).

3.3.3 Results

A list of the insect and spider taxa detected during the sampling study is presented in Table 6.

Table 6. Beneficial taxa identified for all sampling methods.

| Family | Scientific name | Common name |
|--------------------|---------------------------------|-----------------------------|
| Coccinellidae | <i>Coccinella transversalis</i> | Transverse ladybird |
| | <i>Diomus notescens</i> | Minute two spotted ladybird |
| | <i>Harmonia conformis</i> | Common spotted ladybird |
| | <i>Harmonia octomaculata</i> | Three banded ladybird |
| | <i>Hippodamia variegata</i> | White-collared ladybird |
| | All individuals found | Ladybird larvae |
| Melyridae | <i>Dicranolaius bellulus</i> | Red and blue beetle |
| Anthocoridae | <i>Orius</i> spp. | Minute pirate bug |
| Lygaeidae | <i>Geocoris lubra</i> | Bigeyed bug |
| Miridae | <i>Deraeocoris signatus</i> | Brown smudge bug |
| Nabidae | <i>Nabis kinbergii</i> | Damsel bug |
| Pentatomidae | <i>Cermatulus nasalis</i> | Glossy shield bug |
| | <i>Oechalia schellenbergii</i> | Spiny shield bug |
| Order Neuroptera | All individuals found | Lacewing larvae |
| Chrysopidae | All individuals found | Green lacewing adults |
| Hemerobiidae | All individuals found | Brown lacewing adults |
| Formicidae | All individuals found | Ants |
| Syrphidae | All individuals found | Hoverfly larvae |
| Clubionidae | <i>Cheiracanthium</i> spp. | Yellow nightstalker |
| Oxyopidae | All individuals found | Lynx spiders |
| Salticidae | All individuals found | Jumping spiders |
| Theridiidae | All individuals found | Tangleweb spiders |
| Thomisidae | All individuals found | Crab spiders |
| All other families | All individuals found | Other spiders |

Comparing methods with the absolute count

The beat sheet method was very effective for sampling beneficial insects and spiders. Counts collected using a beat sheet consistently recorded a greater abundance of beneficial arthropods than visual or d-vac samples collected in the same field on the same day. However beneficial arthropod abundance was still greater in the absolute samples than the beat sheet samples ($F_{3, 164} = 103.31$, $P < 0.0001$, Figure 30). Total abundance of beneficial arthropods increased from the first to the last sample date for all four sampling methods ($F_{2, 164} = 32.66$, $P < 0.0001$).

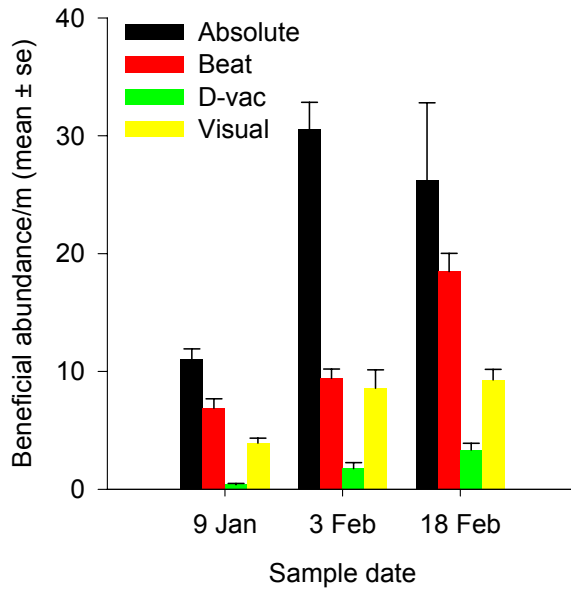


Figure 30. Comparison of sampling methods for total predator numbers against the pounce net absolute counts taken at the same time.

Variation between checkers

Spatial variation in beneficial and pest arthropod abundance between rows and columns of the sample grid was not significant, however there was temporal variation in abundance between the two sample dates. Visual sampling was significantly influenced by scout bias for both beneficial arthropods ($F_{4, 32} = 10.43$, $P < 0.0001$, Figure 31a) and pests such as green mirid nymphs ($V = 1.66$, $P < 0.0001$, Figure 31c). On the other hand, there were no significant differences between checkers using beat sheets to count the abundance of beneficial arthropods ($F_{4, 32} = 1.19$, $P = 0.33$, Figure 31b) and pests ($V = 0.91$, $P = 0.16$, Figure 31d).

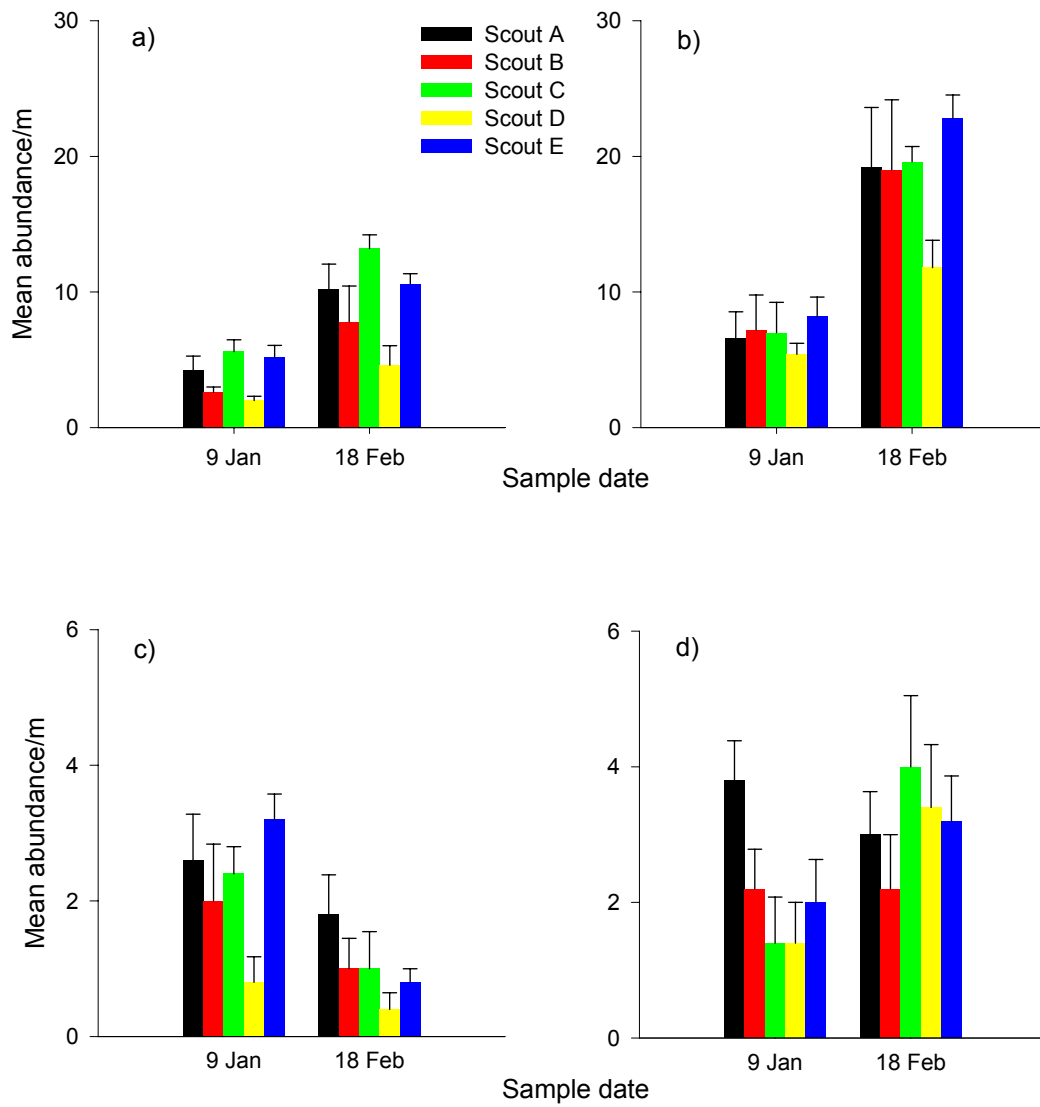


Figure 31. Mean (\pm se) abundance of all beneficial arthropods (a-b) and green mirid nymphs (c-d) measured by five scouts using visual checks and beat sheets respectively.

Statistical analysis of the observer bias experiment.

The results of the statistical analysis for the observer bias experiment are presented in Table 7 and Table 8.

Table 7. Statistical analysis of All beneficials - ANOVA

| <i>Beat sheet</i> | <i>Factor</i> | <i>df</i> | <i>F</i> | <i>P</i> |
|-------------------|---------------------|-----------|--------------|--------------------|
| | <i>Date</i> | <i>1</i> | <i>39.25</i> | <i>< 0.0001</i> |
| | <i>Checker</i> | <i>4</i> | <i>1.19</i> | <i>0.334</i> |
| | <i>Row</i> | <i>4</i> | <i>1.23</i> | <i>0.316</i> |
| | <i>Column</i> | <i>4</i> | <i>1.55</i> | <i>0.211</i> |
| | <i>Date*checker</i> | <i>4</i> | <i>0.67</i> | <i>0.615</i> |
| <i>Visual</i> | <i>Date</i> | <i>1</i> | <i>47.11</i> | <i>< 0.0001</i> |
| | <i>Checker</i> | <i>4</i> | <i>10.43</i> | <i>< 0.0001</i> |
| | <i>Row</i> | <i>4</i> | <i>0.84</i> | <i>0.511</i> |
| | <i>Column</i> | <i>4</i> | <i>1.56</i> | <i>0.209</i> |
| | <i>Date*checker</i> | <i>4</i> | <i>2.29</i> | <i>0.081</i> |

Table 8. Statistical analysis of Helicoverpa eggs and larvae – MANOVA

| <i>Beat sheet</i> | <i>Factor</i> | <i>V</i> | <i>P</i> |
|-------------------|---------------------|--------------|--------------------|
| | <i>Date</i> | <i>0.712</i> | <i>0.0001</i> |
| | <i>Checker</i> | <i>1.129</i> | <i>0.256</i> |
| | <i>Row</i> | <i>1.036</i> | <i>0.413</i> |
| | <i>Column</i> | <i>1.065</i> | <i>0.359</i> |
| | <i>Date*checker</i> | <i>1.139</i> | <i>0.240</i> |
| <i>Visual</i> | <i>Date</i> | <i>0.860</i> | <i>< 0.0001</i> |
| | <i>Checker</i> | <i>2.053</i> | <i>0.0002</i> |
| | <i>Row</i> | <i>1.157</i> | <i>0.606</i> |
| | <i>Column</i> | <i>1.133</i> | <i>0.650</i> |
| | <i>Date*checker</i> | <i>1.466</i> | <i>0.132</i> |

Sampling time

When we examined the average time taken to sample by beat sheets and visuals, beat sheets were substantially quicker. Sampling a metre of cotton row using the beat sheet method took between 3 to 5 minutes throughout the season, while the visual checks took increasingly longer as the crop developed (Figure 32).

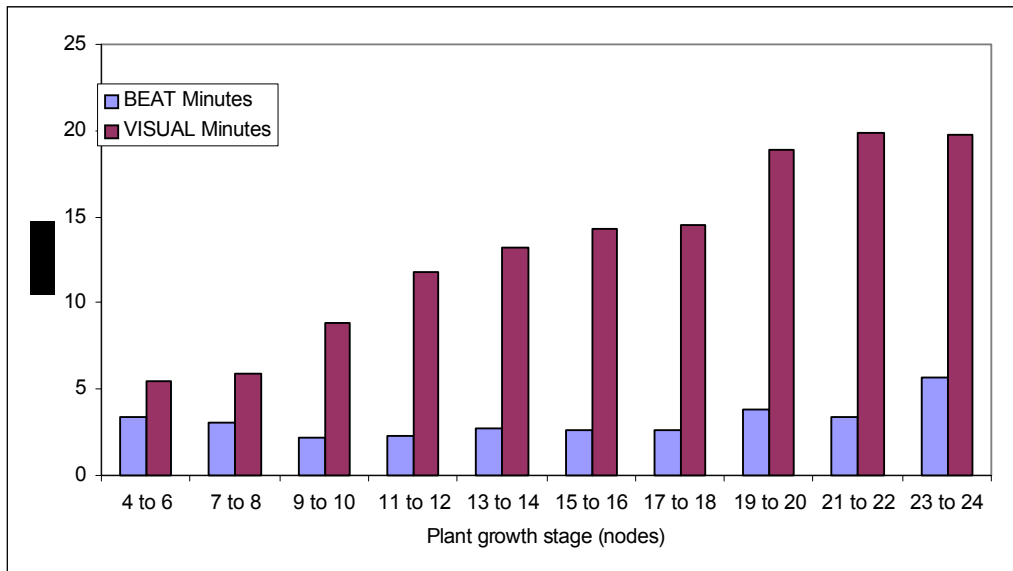


Figure 32. Average time taken to sample one metre of row for beat sheet and visual sampling methods at different stages of crop development.

The time taken to collect D-vac samples in the field were recorded, however the additional time of fumigating, sorting and counting the samples was not recorded and therefore is not included in this comparison.

Effectiveness of different sampling methods throughout the season

Different types of insects vary in their detectability by each sampling method. These differences are due to the nature of the arthropod being sampled. For example eggs tend to stick to the plant and may not be easily dislodged or may be difficult to see on the beat sheet. Similarly caterpillar larvae tend to secrete themselves within bracts or to burrow into bolls and squares and may not be easily beaten or sucked out. Conversely mobile insects such as green mirids are flighty and easily dislodged from the plant. Some insects are better camouflaged than others, although even some brightly coloured insects (e.g. red and blue beetles) were more easily detected using a beat sheet than by visual sampling.

Visual sampling was clearly superior to D-vac or beat sheet for monitoring all *Helicoverpa* spp. life stages ($V = 0.181$, $P < 0.0001$, Figure 33a). In contrast, beat sheets were more effective for counting a mobile pest such as mirids ($F_{2, 287} = 13.42$ and $F_{2, 578} = 83.03$ for adults and nymphs respectively, $P < 0.0001$, Figure 33b). Therefore sampling methods may need to be combined in order to get an accurate assessment of the overall insect populations.

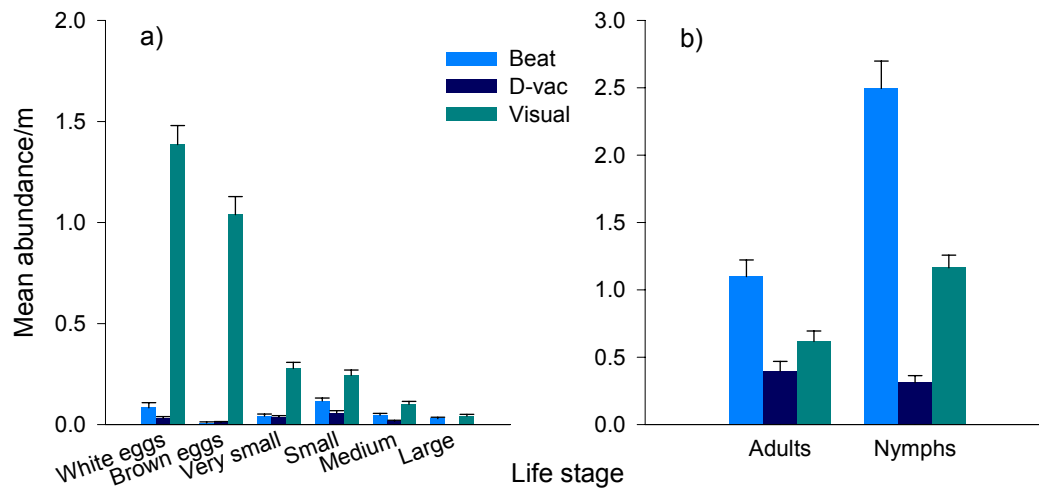


Figure 33. Average abundance (\pm se) of a) *Helicoverpa* spp. and b) green mirids measured by beat sheet, d-vac and visual methods over all sites and dates sampled.

At the start of the season (8 plant nodes or less) each sampling method produced similar results, but as the cotton grew the beat sheet method generally found twice as many predators than visual samples (Figure 34).

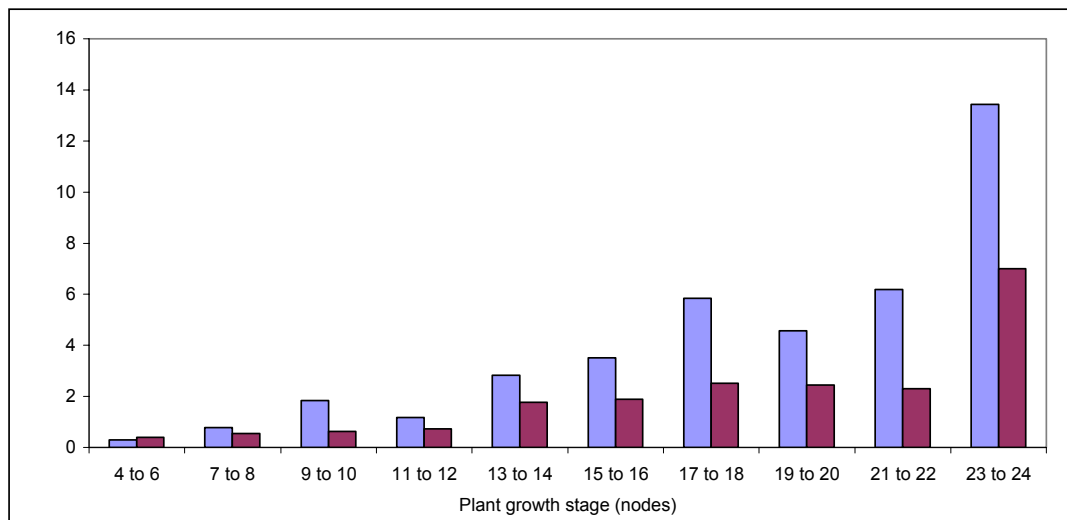


Figure 34. Comparison of beat sheet and visual counts of total predator numbers at different stages of crop development.

Green Mirids

On average beat sheets are three times more effective than visual sampling for counting mirid densities. The data set of paired beat sheet and visual counts undertaken in the same field on the same sampling date is dominated by low mirid densities and is somewhat lacking in high mirid density sample data, particularly for adult mirids.

The relationship between the density of green mirid nymphs counted by beat sheet sampling and by visual sampling is presented in Figure 35. (Linear regression slope 0.275, intercept 0.147, r^2 0.62,

n=48). The relationship between beat sheet counts and visual counts for green mirid adults is presented in Figure 36. (Linear regression slope 0.399, intercept 0.024, r^2 0.67, n=39). The relationship between beat sheet counts and visual counts for total green mirid (nymphs and adults combined) is presented in Figure 37. (Linear regression slope 0.311, intercept 0.146, r^2 0.71, n=60).

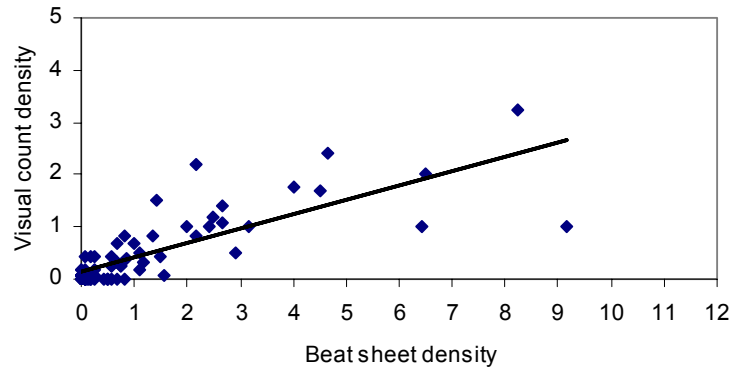


Figure 35. The relationship between the density per metre of green mirid nymphs counted by beat sheet sampling and by visual sampling.

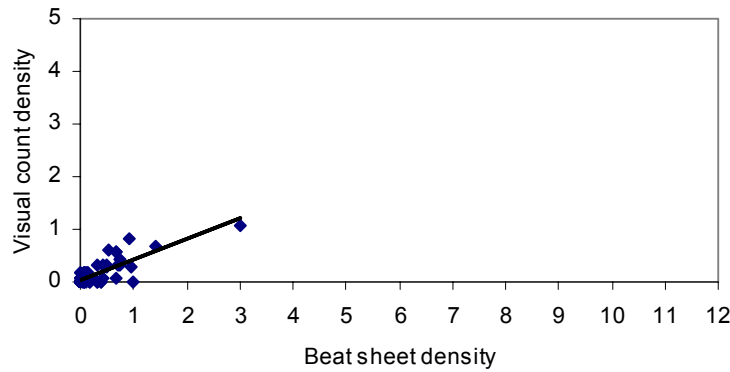


Figure 36. The relationship between the density per metre of green mirid adults counted by beat sheet sampling and by visual sampling. Note the lack of data for high densities of adult mirids.

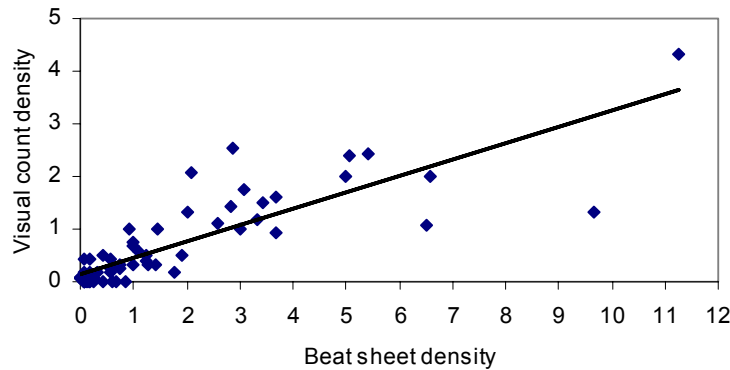


Figure 37. The relationship between the density per metre of total green mirid nymphs and adults counted by beat sheet sampling and by visual sampling.

3.3.4 Discussion

When counting the abundance of beneficial arthropods, the beat sheet method gave estimates that were closer to absolute counts than either the visual or d-vac methods. Beat sheets were also less subject to scout bias because they do not require the same amount of experience and skill as visual searching. Visual sampling was less consistent because individual scouts vary in their searching techniques and level of plant disturbance.

The beat sheet method was generally not time consuming. The time to complete a single beat sheet sample averaged between three to five minutes throughout the season. In contrast, individual visual checks of a metre of whole plants took up to 20 minutes by the end of the season because the surface area and volume of crop canopy increased with plant growth.

Different types of insects vary in their detectability by each sampling method. These differences are due to the nature of the arthropod being sampled. For example eggs tend to stick to the plant and may not be easily dislodged. Their small size and immobility also make them relatively difficult to see on the beat sheet. Caterpillar larvae tend to hide in squares, burrow into bolls or possibly simply firmly hold onto the plant surface and may not be easily beaten or sucked out. Conversely mobile insects such as green mirids are flighty and easily dislodged from the plant. Visual sampling is clearly superior to d-vac or beat sheet for monitoring all *Helicoverpa* spp. life stages in cotton. In contrast, beat sheets are more effective for counting almost all beneficial insects and spiders and mobile pests such as mirids. These results emphasize the need for scouts to use more than one sampling method in order to get an accurate assessment of the overall insect populations.

Very small pests that are not detected by the beat sheet method (i.e. mites, aphids, thrips and whitefly) have specific sampling methods mainly based on leaf collections. These very effective sampling methods have been standardized for the cotton industry and remain fundamental in assessing the insect status of a crop

The stage of plant growth affected the efficiency of the three methods tested. Near the beginning of the season (at five nodes) there was little difference in the number of predators found by beat sheet, d-vac and visual checks, however as the crop progressed, differences in efficiency for the total number of predators emerged. From about ten nodes onwards, consistently more predators were found with beat sheets than visuals and d-vacs.

While the efficiency of beat sheets and visuals remain relative as the season progresses, the d-vac method declines in efficiency. This decline is most likely due to the increase in surface area and volume of crop canopy as the season progresses. When using a d-vac to sample early in the season, the checker is able to pass the machine over the majority of foliage within the metre and consequently collect a high percentage of insects present. However using a d-vac later in the season limits the collection as the d-vac passes over a smaller sample of cotton within the metre

To use beat sheet counts of predators in management decisions, for example with the predator-prey ratio described by Mensah (1999), they should be converted into visual densities. Our results suggest that once a crop reaches 9 to 10 nodes or more, beat sheet predator densities can be converted by dividing the density by 2. The converted count can then be used with the predator to pest ratio. For example, on average a beat sheet sample that detected 10 predators per metre would be equivalent to 5 per metre counted in a visual sample. For a reliable estimate of insect densities it is a good idea to regularly beat a similar number of metres as the visual checks.

While visual checks of insect densities in cotton are essential, particularly for *Helicoverpa* spp., beat sheets provide a fast, effective and robust method for monitoring beneficial predators and some mobile pests.

Green Mirids (*Creontiades dilutus*) are not very effectively sampled by visual assessments. This is likely to be due to (i) their cryptic colouration and behaviour, and (ii) their mobility and tendency to fly or crawl away from a scout commencing a visual check of a section of cotton. The linear

regressions presented in figures 35-38 suggest that beat sheets detect around three times more mirids than visual counts. The inefficiency of visual counts for mirids, combined with low action thresholds for these pests is likely to lead to a relatively high incidence of poor management decisions. That is, the uncertainty of density estimates of visual mirid counts may lead to decisions to spray when it may not be needed, or conversely to a decision not to spray when in fact it may be warranted. Clearly a better method of assessing mirid densities should be employed. Beat sheets offer a more efficient method, however sweep nets may also be a viable and efficient alternative. Further work is required to assess optimal sampling methods and action thresholds for green mirids.

3.4 Objective 4

3.4.1 Aim

To collate data for monitoring the operation and impact of the Macintyre Valley trial IPM/IRMS strategy.

Background

The cotton growers and consultants within the Macintyre valley have the highest participation rates in areawide management groups of any large scale cotton growing region in Australia. A common theme of most of the Macintyre valley AWM groups is to minimise the use of disruptive (hard) insecticides wherever possible. However the standard warm area Insecticide Resistance Management Strategy (IRMS) applicable to the region limited the availability of non-disruptive (soft) options at crucial times during the season.

In 2002/03 the Macintyre valley was successful in gaining approval from the Transgenic and Insecticide Management (TIMs) committee to implement a valley-wide trial of their own specific Insecticide Resistance Management Strategy (IRMS). The trial IRMS summary chart is presented in Figure 38.

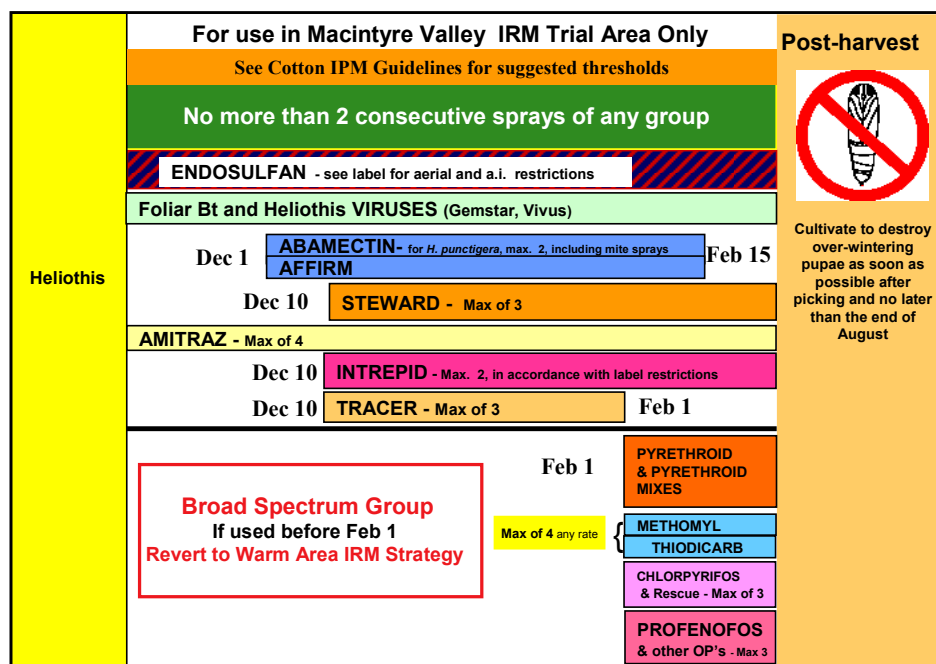


Figure 38. The trial Macintyre Valley IPM system IRMS strategy for 2002/03.

The trial IRMS was tailored to avoid the need to use broad spectrum products and to give growers the flexibility to maintain beneficials season long. The trial had the aim of establishing an area wide IPM approach to managing insect resistance to insecticides. The underlying tenets of the trial were:

- Non-consecutive use of pesticides (except Bt and Virus pre Dec 10).
- Windows for some soft products were broadened relative to the Warm Area IRMS.
- The number of applications of key products restricted.
- Pupae busting under all crops mandatory.
- Thresholds based on the IPM Guidelines.
- Establishment of a Macintyre Valley IRMS Trial trouble shooting committee.
- Resistance monitoring in the Macintyre and another area the validate results.
- Provision of spray and agronomic data to CSIRO for independent analysis.

The trial IRMS strategy was voluntary, on the condition that growers adhered to it. In the event that they could not adhere to the recommended windows, growers had to revert to the standard warm season IRMS strategy for their entire farm. Growers were not permitted to have some fields in and some fields out of the trial. A major concern both within the Macintyre Valley and throughout the industry was that the trial may lead to over-use of soft option insecticides and thereby exacerbate the risk of resistance developing prematurely or at faster than normal rates to these valuable products. To counter this concern, the trial participants agreed to supply data that could be presented to the TIMS committee to assess the success of the trial, and they also agreed to participate in a comprehensive *Helicoverpa armigera* resistance testing program coordinated by Dr Louise Rossitor (NSW DPI).

The trial was continued in 2003/04 with a modified IRMS summary chart as presented in Figure 38.

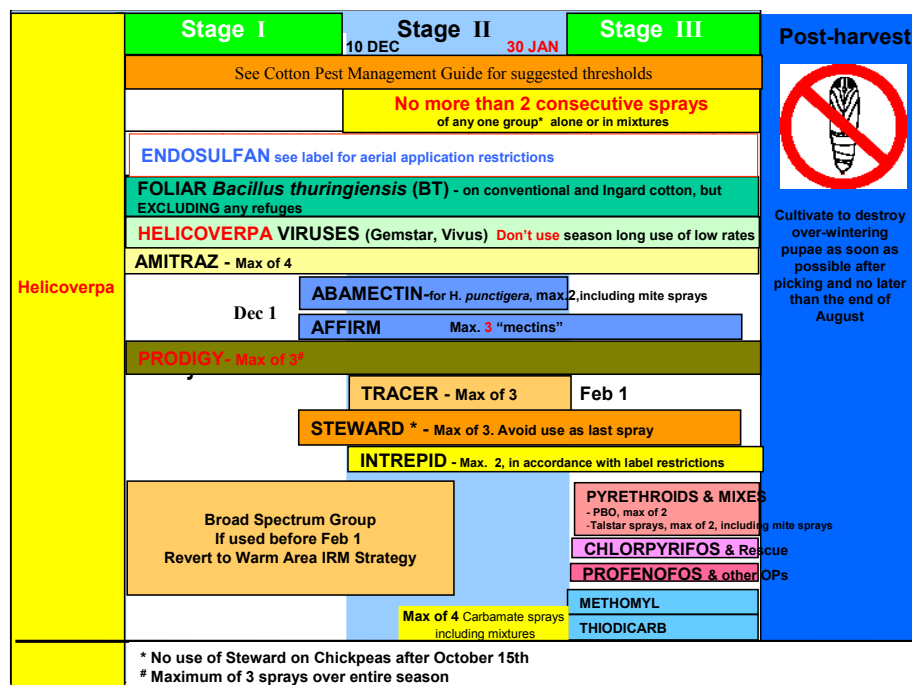


Figure 39. The trial Macintyre Valley IPM system IRMS strategy for the second season: 2003/04

3.4.2 Methods

Field level data on spray applications and beat sheet counts of beneficial predator densities was collected from consultants for a subset of fields from all participating farms throughout the Macintyre valley for the 2002/03 and 2003/04 seasons. Only limited data were forthcoming during the 2004/05 season. Each consultant was asked to provide data for at least one field per management unit, or at least three fields per farm involved in the trial.

As far as possible, the following data was collected from each consultant within the Macintyre valley:

General Crop Information

- Planting date ,
- Variety,
- Date and type of Insecticide applications
- Method of insecticide application

Insect checks

Consultants were asked to complete at least 4 by 1 meter (or 8 by 0.5 meter) whole plant visual checks per field across the field prior to the trial starting. And complete whole plant visual checks at least

twice per week throughout the season. To retain consistency between consultants, they were asked to record all *Helicoverpa* larval stages and eggs (white/brown) as per industry guidelines (i.e. medium larvae >8mm). The consultants were also asked to conduct beat sheet assessment once per month in each field.

A printed check sheet for visual checks and beat sheet counts of pests and predators was developed and distributed. The sheet contained a list of the most common insect and spider taxa likely to be recorded during cotton scouting checks. Mites were to be sampled as per industry guidelines on at least 50 plant per management unit. Likewise industry standard sampling methods for aphids and whitefly as described in the IPM guidelines (Wilson *et al.* 2002) were also to be used.

Crop maturity / Plant damage / Yield

Consultants were asked to record the date of first open boll and date of defoliation, to record the degree to tip damage, and to record retention and or fruiting factors every 7 to 10 days. They were also asked to provide yield data for the selected fields.

Insecticide resistance sampling

Two dedicated egg collectors operated from Goondiwindi (Qld DPI) to collect *Helicoverpa* eggs from across the Macintyre valley for resistance testing by Dr Louise Rossitor's team at NSW DPI.

Trouble shooting committee

A trouble shooting committee was set up to help in direction of the trial and to deal with any issues that arise. The committee consisted of two researchers, two growers, two consultants, and an IDO.

The data for each season were summarised and presented to the Macintyre Valley End of Season reviews, as well as to TIMS committee meetings at the end of each season. The *Helicoverpa* resistance monitoring data for the valley was also presented to the TIMS committee at the end of each season.

3.4.3 Results

Insecticide spray applications

A summary of the total insecticide usage for a sub-sample of 278 commercial cotton fields for the first year of the trial, the 2002/03 season is presented in Table 9. In general the sprays are dominated by soft and non-disruptive options. The average Beneficial Disruptive Index (BDI) per field in this season was 11.2 and the average number of total sprays applied to each field was 5.12.

Table 9. Macintyre Valley 2002/03 insecticide usage. Data from 278 cotton fields.

| Product | n | Sprays/field | %Heli sprays | Stage I | Stage II | Stage III |
|-------------------------|-----|--------------|--------------|---------|----------|-----------|
| Dipel | 326 | 1.17 | 22.9% | 96% | 4% | |
| Steward | 270 | 0.97 | 19.0% | | 68% | 32% |
| Tracer | 229 | 0.82 | 16.1% | | 79% | 21% |
| Affirm | 194 | 0.70 | 13.6% | 23% | 57% | 20% |
| Virus | 192 | 0.69 | 13.5% | 12% | 44% | 44% |
| Endosulfan | 77 | 0.28 | 5.4% | 52% | 40% | 8% |
| Intrepid | 50 | 0.18 | 3.5% | | | 100% |
| Canopy oil / Biopest | 32 | 0.12 | 2.2% | 38% | 9% | 53% |
| Larvin | 30 | 0.11 | 2.1% | | | 100% |
| Amitraz | 14 | 0.05 | 1.0% | | 29% | 71% |
| Predator | 5 | 0.02 | 0.4% | | | 100% |
| Prodigy | 4 | 0.01 | 0.3% | 100% | | |
| Agrimec | 1 | 0.004 | 0.1% | | 100% | |

The insecticide usage for farms participating in the second season of the trial (2003/04) is presented in Table 10. Spray data for farms that dropped out of the trial (because they reverted to disruptive insecticides outside the windows permitted in the trial IRMS) is presented in Table 11. The 03/04 season was subject to intense early season pest pressure. In general the sprays are still dominated by soft and non-disruptive options, but there is also significant usage of medium to high disruptive sprays. The average Beneficial Disruptive Index (BDI) per field for farms participating in the trial in this season was 37, with an average of 13.9 sprays per field. For the farms that dropped out of the trial the average BDI was 48, with an average of 13.3 spray applications per field. Although the average number of spray applications is similar, fields that dropped out of the trial tended to use a greater proportion of disruptive insecticides.

Table 10. Average Spray Applications for farms **IN** the trial - 2003/2004

| Product | Active | Total # | Sprays / field |
|-----------------------|---------------------|----------------|-----------------------|
| Canopy Oil or Biopest | Petroleum Oil | 322 | 3.07 |
| Dipel | Bt | 195 | 1.86 |
| Steward | Indoxacarb | 172 | 1.64 |
| Regent | Fipronil | 120 | 1.14 |
| Tracer | Spinosad | 116 | 1.10 |
| Affirm | Emamectin benzoate | 77 | 0.73 |
| Pegasus | Diafenthiuron | 72 | 0.69 |
| Predator or Lorsban | Chlorpyrifos | 71 | 0.68 |
| Methyl Parathion | Parathion | 59 | 0.56 |
| Rogor | Dimethoate | 50 | 0.48 |
| Intrepid | Chlorfenapyr | 45 | 0.43 |
| Larvin | Thiodicarb | 38 | 0.36 |
| Ovasyn or Armitraz | Amitraz | 25 | 0.24 |
| Curacron | Profenofos | 24 | 0.23 |
| Vivus or Gemstar | NPV virus | 17 | 0.16 |
| Pyrethroids | Pyrethroids | 13 | 0.12 |
| Food spray | Food spray | 13 | 0.12 |
| Endosulfan | Endosulfan | 8 | 0.08 |
| Pirimor | Pirimicarb | 6 | 0.06 |
| Intruder | Acetamiprid | 5 | 0.05 |
| PBO | Synergist | 4 | 0.04 |
| Comite | Propargite | 3 | 0.03 |
| Nudrin or Lannate | Methomyl | 1 | 0.01 |
| Prodigy | Methoxyfenozide | 1 | 0.01 |
| Rescue | Chlorpyrifos-methyl | 0 | 0 |
| Folimat | Omethoate | 0 | 0 |
| | TOTALS | 1457 | 13.9 |

Table 11. Average Spray Applications for farms **OUT OF** the Trial - 2003/2004

| Product | Active | Total # | Sprays / field |
|-----------------------|---------------------|----------------|-----------------------|
| Predator or Lorsban | Chlorpyrifos | 27 | 1.42 |
| Regent | Fipronil | 26 | 1.37 |
| Ovasyn or Armitraz | Amitraz | 25 | 1.32 |
| Steward | Indoxacarb | 22 | 1.16 |
| Canopy Oil or Biopest | Petroleum Oil | 19 | 1.00 |
| Vivus or Gemstar | NPV virus | 19 | 1.00 |
| Tracer | Spinosad | 18 | 0.95 |
| Pyrethroids | Pyrethroids | 18 | 0.95 |
| Methyl Parathion | Parathion | 13 | 0.68 |
| Affirm | Emamectin benzoate | 12 | 0.63 |
| Dipel SC | Bt | 10 | 0.53 |
| Endosulfan | Endosulfan | 7 | 0.37 |
| Nudrin or Lannate | Methomyl | 7 | 0.37 |
| Intruder | Acetamiprid | 6 | 0.32 |
| Food spray | | 5 | 0.26 |
| Larvin | Thiodicarb | 4 | 0.21 |
| Rescue | Chlorpyrifos-methyl | 4 | 0.21 |
| PBO | Synergist | 3 | 0.16 |
| Intrepid | Chlorfenapyr | 2 | 0.11 |
| Curacron | Profenofos | 2 | 0.11 |
| Folimat | Omethoate | 2 | 0.11 |
| Pegasus | Diafenthiuron | 1 | 0.05 |
| Rogor | Dimethoate | 1 | 0.05 |
| Pirimor | Pirimicarb | 0 | 0 |
| Comite | Propargite | 0 | 0 |
| Prodigy | Methoxyfenozide | 0 | 0 |
| | TOTALS | 253 | 13.3 |

Consultant beat sheet data

In the first season of the trial (2002/03) consultants provided beat sheet data from 312 cotton fields. A summary of the average density of total predators per metre, as well as the proportion of predators in each of the major taxonomic groups is presented in 0. There is a slight trend of increasing abundance of predators as the season progresses, reaching a maximum average density of over 5 total predators per metre by the end of the season.

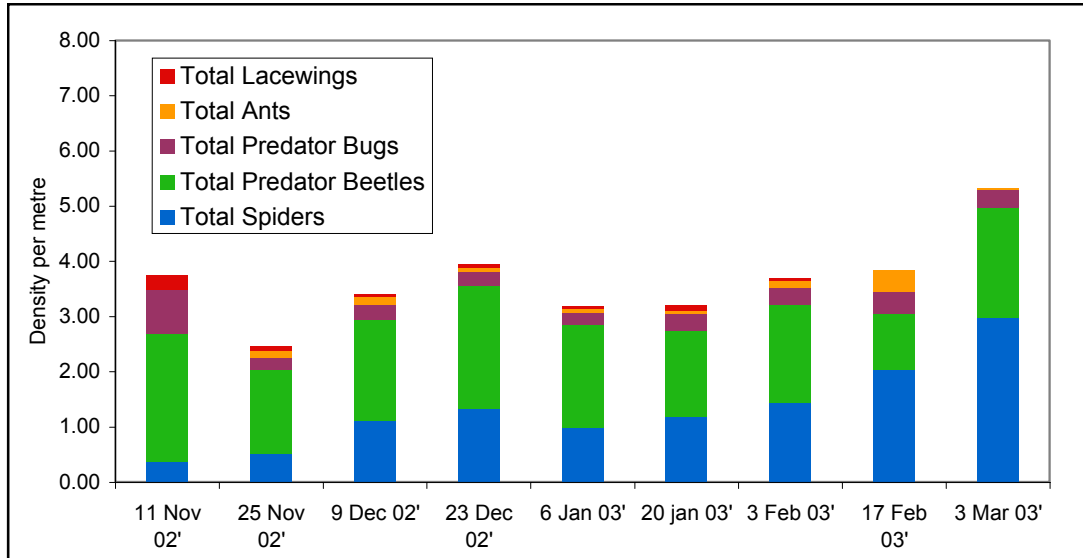


Figure 40. The 2002/03 average abundance and composition of predators counted by Consultant Beat Sheet checks throughout the Macintyre Valley. Data represents 1412 checks on 312 cotton fields (Average 4.5 check dates per field).

The consultant beat sheet data showed a significant difference between the average density of beneficial predators in conventional cotton compared with Bt cotton. On average throughout the 02/03 season conventional fields had a mean density of 2.94 predators per metre (se 0.185, n=309). Ingard fields had a much higher average density of predators: 5.32 predators per metre (se 0.397, n=278).

CSIRO data collected from commercial cotton fields in the Macintyre and Namoi valleys during this period consistently showed that the Macintyre fields harboured a higher density of predators per metre (Figure 41).

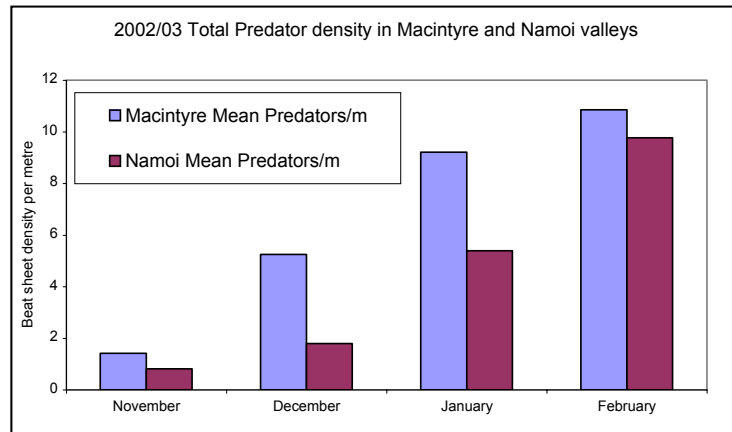


Figure 41. Comparison of average predator densities in commercial cotton fields in Macintyre and Namoi Valleys 2002/03. Data represents fortnightly beat sheet samples (each 12 metres) in 12 fields.

In the second season of the trial (2003/04) the consultant beat sheet data shows a substantially lower average density of predators per metre (Figure 42).

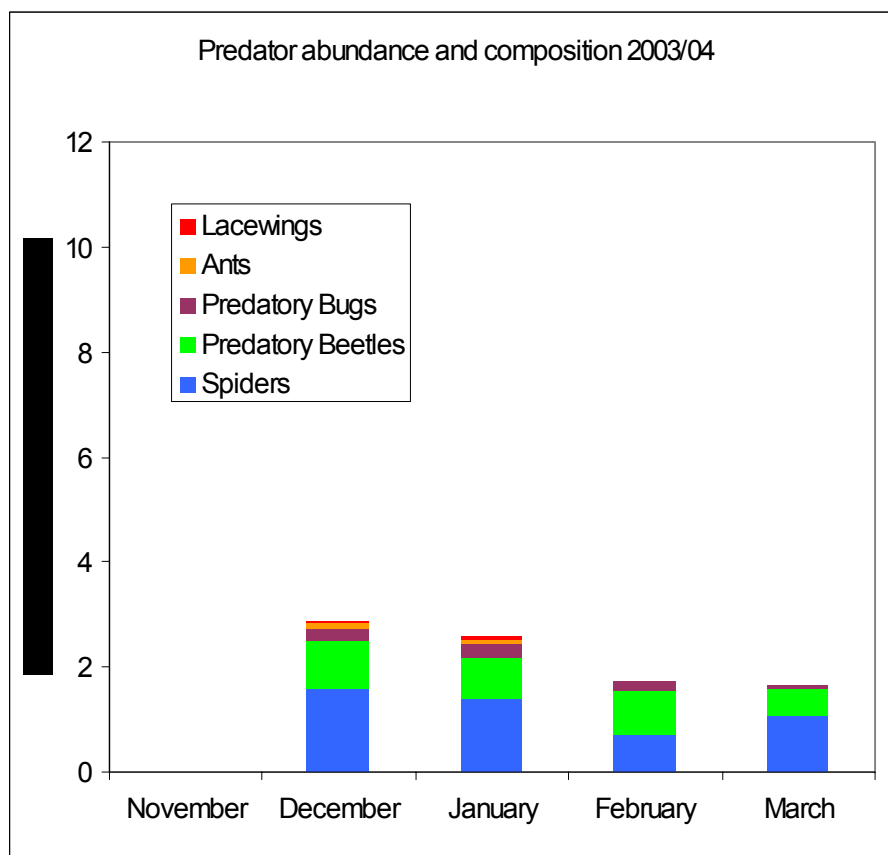


Figure 42. Summary of consultant beat sheet data showing the abundance (density per metre) and taxonomic composition of predators in cotton fields in the 2003/04 Macintyre IRMS trial.

Resistance testing

Results from the *Helicoverpa* resistance testing program undertaken concurrently during the Macintyre IRMS trial are presented in detail in Dr Louise Rossitor's final report to CRDC (Rossitor 2005). As well as routine resistance monitoring, particular emphasis was placed on testing for resistance to Steward, Affirm, Tracer and Intrepid. Despite the low pressure season, over 2000 *Helicoverpa* eggs were collected in the Macintyre for testing against these four insecticides. The sample sizes in the Macintyre were second only to the Namoi valley, and provide a robust basis upon which to evaluate and make comparisons. For each of the four insecticide products, the levels of resistance were so low that there is no evidence to conclusively show that any valley has higher levels or risks of resistance than any other valley. Overall there was no evidence to suggest that the Macintyre valley IRMS trial in 2002/03 or 2003/04 resulted in any changes to resistance levels in *H. armigera* to any insecticides (either soft or hard).

3.4.4 Discussion

Historically, the average number of spray applications applied to cotton fields in the Macintyre valley used to be similar to the average for the Gwydir valley. Following the intense pest seasons of 1997/98 and 1998/99, a strong areawide management approach focussing on minimising the use of disruptive insecticides developed in the Boggabilla landcare group, and in the following seasons in most other parts of the Macintyre Valley.

This approach appears to have led to a reduction in the average number of sprays applied to both ingard and conventional cotton fields in the Macintyre Valley relative to other valleys, particularly the Gwydir. For example, Doyle et al (2002) present comparative data for the 2001/2002 season (Figure 43). In that season the Macintyre had the lowest average total sprays in conventional cotton out of all the valleys (6.1 sprays per field), and the average sprays applied to ingard fields was amongst the lowest (2.7 sprays).

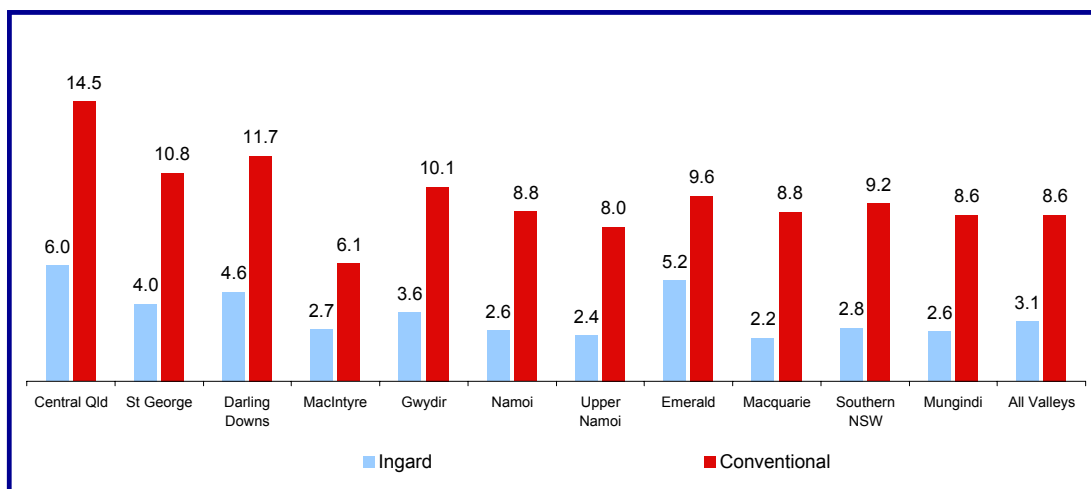


Figure 43. Average number of insecticide sprays in each cotton growing valley. Source: Doyle, Reeve & Bock (2002). The performance of Ingard Cotton in Australia during the 2001/2002 season.

The chart showing the average density and taxonomic composition of beneficial insects and spiders sampled by beat sheet as part of the Macintyre trial IRMS strategy is shown in 0. This is a robust set of data representing counts from 312 cotton fields. In general relatively high densities of beneficials were maintained throughout the 2002/03 season, reflecting the generally low numbers of sprays applied, and the generally low level of disruption (i.e. low BDI). Figure 41 shows an independent comparison of beneficial densities in 12 cotton fields in the Macintyre and Namoi valleys collected by CSIRO. Throughout the season, the subset of fields in the Macintyre valley maintained consistently higher densities of beneficials than the subset of fields in the Namoi. All fields in the comparison were from farms implementing IPM.

In the second season of the trial pest pressure was higher, particularly early in the season. The subsequent increased intensity and disruptiveness of spray applications during 2003/04 is likely to be directly responsible for the lower average abundance of predators (Figure 42).

4. Conclusions and 'take home messages'

Over the course of the project addressing the four objectives detailed above a number of definitive conclusions and take home messages have been derived.

This study has demonstrated that the Beneficial Disruption Index (BDI) is a valid tool for assessing the relative impact of a cotton fields spray regime on the abundance and diversity of natural enemies present in the field. Cotton fields subject to spray regimes that had a high proportion of disruptive sprays and therefore had high BDI scores, had lower density and diversity of beneficial arthropods.

The project clearly demonstrated that beat sheet sampling is an efficient and accurate method for sampling beneficial insects and spiders, and green mirids, but is not suitable for sampling *Helicoverpa* (any life stage), or mites, aphids, whitefly or thrips. The beat sheet is a valuable tool for cotton managers wishing to track and utilise the abundance of natural enemies in their crops.

Beat sheets detect between two and three times as many beneficial insects and spiders, and three times as many mirids as visual counts. This difference in efficiency must be taken into account when making management decisions based on beat sheet counts.

The study presents strong evidence that within an areawide management group committed to minimising the use of disruptive insecticides, fields with relatively soft spray regimes (low BDI) can be at least as profitable as fields with hard spray regimes (high BDI) in most seasons.

The project shows that such a soft approach results in greater survival of natural enemies within the field and its surrounds, and by reducing the total number of spray applications, a soft approach is also likely to reduce the rate at which pests develop resistance to insecticides.

There was no evidence that the Macintyre Valley IPM IRMS trial had any impact on resistance levels on any insecticides.

The study documents the impact that Bt cotton has on arthropods. It showed Bt fields supported significantly less *Helicoverpa* and predatory Damsel (Nabis) bugs than conventional fields. It showed Bt fields supported significantly more big eyed bugs, yellow night stalker spiders and lynx spiders than conventional fields, as well as significantly more arthropods in general.

5. Economic, Environmental and Social outputs of this research

This research project directly addressed CRDC's triple bottom line outputs. The philosophy of areawide management within the Australian cotton industry centres on achieving sustainable cotton production systems that are profitable, that minimise environmental impacts and disruption and that empower people by giving them the information and confidence to change practices.

This project has demonstrated that pest management approaches that minimise disruption to natural enemies in cotton fields can be economically profitable, at least within committed AWM groups.

The project demonstrates that fields managed softly (with a low BDI) had higher numbers and more types of natural enemies than fields managed with more disruptive insecticides – a clear indication of the environmental benefits of a soft approach. The project results also clearly demonstrate that Bt fields are subject to lower numbers of insecticide applications than conventional fields, and the sprays applied to Bt fields tend to have a lower level of disruption, resulting in an overall higher abundance and diversity of natural enemies in Bt fields.

By quantifying the relative severity and the impacts of different paddock level pest management practices on non-target beneficial arthropods, and by disseminating project findings to growers, consultants, extension staff, researchers and the community at large, this project has allowed the cotton growing community and industry to gain a better understanding and confidence to continue progressing further along the sustainability and IPM continuum.

The research completed during this project underpins progress towards an increased adoption of IPM approaches, and a reduction in cotton growers' dependence on chemical insecticides.

6. Summary of project outcomes

a) Technical Advances

A major technical result to arise from this work has been a validation of the Beneficial Disruption Index (BDI) as a measure of the relative disruptiveness of the spray regimes applied to cotton fields.

The study provides a clear demonstration that the severity or level of disruptiveness of insecticide spray regimes applied to cotton fields have a direct impact on the abundance and diversity of beneficial predators present.

The study presents strong evidence that within an areawide management group committed to minimising the use of disruptive insecticides, fields with relatively soft spray regimes can be at least as profitable as fields with hard spray regimes in most seasons.

The project also clearly demonstrated that beat sheet sampling is an efficient and accurate method for sampling beneficial insects and spiders, and green mirids, but is not suitable for sampling *Helicoverpa* (any life stage), or mites, aphids, whitefly or thrips.

The study provides an important large scale and multi-year data set on the faunal assemblages present in commercial Bt and conventional cotton fields.

These findings have been incorporated into extension material and IPM guidelines for Australian cotton growers.

b) Other Information Developed

Sustainability : Through recognition of the dynamics of insect pests and beneficial invertebrates in response to varying management practices (eg transgenic cotton, different pesticides), this research project has provided information for growers of the advantages to be gained by utilising the benefits (ecosystem services) provided by natural enemies, and the need to reduce and soften insecticide use and limit the possibilities of insecticide resistance whilst controlling insect pests.

c) Changes to the Intellectual Property Register

None required. There were no commercially significant innovations achieved during this project.

7. Future plans

a) Further Development of Project Technology

Apart from completing the manuscripts detailed in section 8.9 below, there are no plans to further develop any of the technology addressed in this study.

b) Presentation and Dissemination of Project Outcomes

Project results have been extensively presented to growers, consultants and scientists. See section 8 below for a complete listing. Future planned scientific manuscripts are also listed in section 8.9 below.

c) Future Research

It would be ideal if future research could focus on the Beneficial Disruption Index (BDI). Although the BDI is a simple and easy to use measure of the severity or relative disruptiveness of both individual insecticides and of overall spray regimes applied to cotton fields, it has some imperfections. For example a field with many applications of a soft insecticide (eg NPV or Bt) may accrue a high overall BDI even though the degree of disruption to natural enemies may be virtually zero. The BDI also relies on the “overall” impact of an insecticide across groups of taxa as outlined by Wilson et al (2002). In many cases, individual beneficial taxa may be much more severely impacted by a given insecticide than other taxa are (e.g. fipronil is moderately soft, but is extremely toxic to bees, wasps and ants). Further work should be undertaken on refining the BDI to improve its utility as a measure of the impact of a cotton fields spray regime.

Different sampling methods detect certain arthropod taxa better than others. Further research needs to be undertaken on assessing the effectiveness of different sampling methods, and particularly on converting sampling results to visual equivalents for use in management decisions. For example sweep nets for mired sampling showed signs of being an efficient and effective.

With the broad-scale uptake of Bollgard II cotton, there remains a need to determine how the diversity and abundance of beneficial invertebrates, “secondary” (sucking) pests and *Helicoverpa* are affected by changing field level insecticide management strategies and resulting BDIs as they accompany the advent of Bollgard II in commercial cotton fields and associated Bt refuges within AWM regions.

Finally I believe it is crucial that research providers continue to give direct and on-ground assistance to regional AWM group trials, in particular the Macintyre IPM / IRMS Trial through assistance with objective data analysis and support provision of additional invertebrate abundance data. Through the development of robust IPM strategies that are environmentally healthy (optimal use of “soft” pesticides, capture of ecosystem services from beneficial species) whilst satisfying resistance management needs, large scale trials like this one have the potential to really change grower practices and increase awareness of the benefits of IPM.

8. Communication and Publications

Research results from this project have been broadly disseminated to all levels of the industry and the community at large in a variety of ways:

8.1 Industry Talks, Education and Training

Project results have been broadly communicated through participation in areawide management group meetings, farm walks, field days, trial books, seminars, conferences, lectures to participants of the IPM short course and UNE Cotton Production course, industry magazine and media articles, and scientific publications.

Over the course of the project advice on area wide management, the use of selective sprays and sampling has been given to cotton Industry Development Officers, Areawide Management groups, and numerous individual cotton growers. Martin Dillon was a member of the Trouble Shooting Committee for the Macintyre Valley Insecticide Resistance Management Strategy (IRMS) Trial from July 2002 to December 2004.

Mr Dillon gave the following presentations to industry meetings:

2002/2003 season 3 x lectures and 1 x field practical presented to IPM Short Course for cotton growers. “Know Your Beneficials” and “IPM: Putting it all together” Moree (14 Nov 2002, 14 Jan 2003), Goondiwindi (12 Aug 2003), and Trangie (5 sep 2003).

12 September 2002. A research overview seminar was presented at a Certification & Up-skilling Workshop for Cotton Consultants of Australia Inc., Wee Waa, NSW.

10 December 2002, “Beneficial Insect and Spider Identification Workshops” for cotton growers and bug-checkers, Boggabilla, NSW and Goondiwindi, Qld.

14 June 2003 Macintyre Valley End of 02/03 season review: “Sampling and AWM”. Goondiwindi.

25-26 June 2003, Synopsis of research presented at QDPI Farming Systems IPM Forum, Toowoomba.

23-24 July 2003, Synopsis of research presented at Australian Cotton CRC Annual Review, Armidale.

19 August 2003, 2 x lectures presented to UNE Cotton Production Course Residential students, Narrabri, “Trap cropping” and “Economic evaluation of IPM”.

26-27 August 2003, “IPM on an Areawide Scale in the Macintyre Valley” presented at the Cotton Production Seminar (Cotton Consultants Australia Inc.), Narrabri.

10 September 2003, Research Update: “Macintyre Valley Trial IPM/IRMS” Macintyre Valley Review Meeting, Goondiwindi.

2003/2004 season 2 x lectures and 2 x field practicals presented to IPM Short Course for cotton growers. “Know Your Beneficials” and “IPM: Putting it all together” Goondiwindi (26 Nov 2003, 18 Feb 2004), and Trangie (18 DeC 2003, 16 Feb 2004).

24 Feb 2004 AWM meeting for Upper Namoi groups at Ban Baa, NSW.

11 March 2004, Presentation titled: “IPM and IRMS in the Australian Cotton Industry” for visiting Brazilian Cotton growers.

3 May 2004, Talk to Calrossi Girls High school Year 12 students (Tamworth) “Insects and cotton”.

3 May 2004, Meeting with NSW Beekeepers Association to discuss ways to minimise impact of cotton pest management practices on hives near cotton crops.

5 May 2004, Coordinated a workshop titled “Draw an Insect” at St Francis Xavier’s Primary School, Narrabri.

6 June 2004, Talk titled “Economic Outcomes / Beneficial Disruption Index” at the CRC 5th Year Review.

3 August 2004, Research Update: “Macintyre Valley Trial IPM/IRMS” Macintyre Valley End of Season Review Meeting, Goondiwindi.

31 August 2004, 2 x lectures presented to UNE Cotton Production Course Residential students, Narrabri, “Trap cropping” and “Economic evaluation of IPM”.

8.2 Media

M.Dillon’s research featured in the following media items during the term of this project:

19 September 2002, Article in The Land newspaper: ‘Trap crops for heliothis?’

25 September 2002, Feature story for ‘Cotton Magazine’ newspaper – ‘Bats: New weapon in biocontrol of Heliothis?’

9 October 2002, Interviewed and Videotaped for CSD ‘Web on Wednesday’ internet resource ‘Helicoverpa population dynamics’.

21 October 2002, Article in ‘North-west Magazine’ newspaper titled ‘Bats to join the IPM army?’

November 2002, Article in ‘Heliothis Stateline’ newsletter titled ‘Moth munching bats!’

8 June 2003, Australian Cotton CRC media release ‘Importance of pupae busting highlighted’

30 September 2003, Australian Cotton CRC media release ‘World first spray guide for beneficial cotton insects’

2 October 2003, Interviewed for 2WEB Bourke Outback radio on the “Impact of insecticides on beneficials” guide for cotton.

22 March 2004, Interviewed and Videotaped for CSD ‘Web on Wednesday’ internet resource ‘Honeybees and NPV’.

31 March 2004, Australian Cotton CRC media release ‘Honeybees give Heliothis hell’

31 March 2004, Interviewed by Neil Lyon for The Land newspaper for background info on bats in cotton.

1 April 2004, Interviewed on Radio 2WEB (Bourke) re Honeybees and NPV.

2 April 2004, Interviewed on Radio 2VN (Moree) by Ken Birch for Cotton Show re Honeybees and NPV.

26 May 2004, Featured in CSD Web on Wednesday on the ‘Importance of Pupae busting’.

31 May 2004, Article in ‘North West Magazine’ newspaper titled “CSIRO Scientist Highlights Importance of Pupae busting”.

8.3 Photo Credits

“Green Tree Frog in cotton” photo featured in numerous publications and posters, including: Front cover of the 2000/01 Australian Cotton CRC Annual Report, CRDC Annual Report 2003, CRDC Snapshot competition promotion 2004, UNE Biodiversity in Cotton Report 2002, Australian Cotton CRC “Cotton and the Environment” Poster 2003

Numerous photos taken by Martin Dillon are used throughout the Second edition of the ‘Integrated Pest Management Guidelines for cotton production systems in Australia’.

8.4 Industry Guidelines

Wilson, L.J., Mensah R., Dillon M., Wade M., Scholz B., Murray D.A., Heimoana V., and Lloyd R. (2002) *Impact of insecticides and miticides on predators in cotton: October 2002 update*. Support Document 1 in: Mensah, R. and Wilson, L.J. (Editors): *Integrated Pest Management Guidelines for Australian Cotton*. Australian Cotton Cooperative Research Centre, Narrabri, NSW <http://cotton.pi.csiro.au/Publicat/Pest/> [See Attachment 1]

Hickman M, Larsen D and Dillon ML. 2002. *Guidelines for assessing pupae risk for dryland cotton growers*. Cotton Information Sheet July 2002. Australian Cotton Cooperative Research Centre, Narrabri. [See Attachment 2]

8.5 Conference and Seminar Presentations

Mansfield S, Dillon ML and Whitehouse MEA. 2002. Do beneficials pay their way? Poster presentation at the second joint conference of the *Ecological Society of Australia* and the *New Zealand Ecological Society*, Cairns Qld. 2-6 December 2002.

Hoque Z, Dillon ML and Farquharson R. 2002. Three seasons of IPM in an Areawide Management Group – a comparative analysis of field level profitability. Pages 749-755 in *Proceedings of the 11th Australian Cotton Conference*, Brisbane, Qld. 13-15 August 2002.

Dillon ML, MacKinnon L, Long R and Richards G. 2002. Little moth-munching bats scare the proverbial out of *Helicoverpa* moths in cotton fields. Poster Presentation at The *11th Australian Cotton Conference*, Brisbane, Qld. 13-15 August 2002.

Dillon ML, Hoque Z and Farquharson RJ. 2003. The Beneficial Disruption Index: A tool for comparing insecticide regimes applied to crop fields. Paper presentation at the *World Cotton research Conference - 3*, Capetown, South Africa. 8-12 March 2003

Dillon ML. 2003. Trap crops for managing *Helicoverpa* (Lepidoptera: Noctuidae) in Australian cotton farming systems. Paper presentation at the *World Cotton research Conference - 3*, Capetown, South Africa. 8-12 March 2003

Dillon ML. 2003. Research Overview presented at “DPI Farming Systems IPM Meeting” Toowoomba, 25/26 June 2003.

Dillon ML. 2003. Understanding the components of successful areawide management. Presentation to Cotton CRC Annual Review, Armidale, 23-24 July 2003.

Dillon M. 2003. IPM on an Areawide Scale in the Macintyre Valley. *Proceedings of the Cotton Production Seminar (Cotton Consultants Australia Inc.)*, Narrabri 26-27 August 2003.

McKinnon C, Deutscher S, Dillon M, Mansfield S and Staines T. 2003. Comparison of the beat sheet technique with established methods for sampling pest and predator abundance in cotton. Namoi Field Day, October 2003.

Staines T, Dillon ML and Halloway P. 2003. Silent but deadly: Bats as predators over cotton crops. Paper presentation at the *2003 Ecology Conference, Ecological Society of Australia*, Armidale NSW. 8-11 December 2003

Dillon M. 2004. Evaluation of Areawide Management Strategies. Presentation at the *National Helicoverpa Workshop*, Toowoomba, 21-22 June 2004.

Dillon M. 2004. Trap crops for managing *Helicoverpa armigera* in Australian cotton. Presentation at the *XXI International Congress of Entomology*, Brisbane (15-21 Aug 2004).

T.L. Staines, M.L. Dillon and T.Murphy. A tractor mounted device for collecting live arthropods in cotton crops. Poster presented at the *XXI International Congress of Entomology*, Brisbane (15-21 Aug 2004).

8.6 Industry Publications

Wilson, L.J., Mensah R., Dillon M., Wade M., Scholz B., Murray D.A., Heimoana V., and Lloyd R. 2002 Impact of insecticides and miticides on predators in cotton: October 2002 update. Support Document 1 in: Mensah, R. and Wilson, L.J. (Editors): *Integrated Pest Management Guidelines for Australian Cotton*. Australian Cotton CRC.

Dillon M. 2003. IPM on an Areawide Scale in the Macintyre Valley. Macintyre Valley 2002/03 Trial Book.

Tann C., Dillon ML and Baker, G. 2002. Entomological Research Update: *Helicoverpa* Cotton Season 2001-2002. Pages 102-103 in Cotton Seed Distributors 2002 Variety Trial Results & Grower Information. CSD, Wee Waa.

Hickman M, Larsen D and Dillon ML. 2002. *Guidelines for assessing pupae risk for dryland cotton growers*. Cotton Information Sheet July 2002. Australian Cotton Cooperative Research Centre, Narrabri.

Tann C, Baker G, Dillon M, Mansfield S and Whitehouse M. 2003. Entomology update. Pages 101-102 in Cotton Seed Distributors 2003 Variety Trial Results & Grower Information. CSD, Wee Waa.

Dillon ML and Scholz B. 2003. Fire ants: An invader we don't want in cotton. *The Australian Cottongrower* 24(7): 16-17. [See Attachment 3]

Deutscher S, Dillon ML, McKinnon C, Mansfield S, Staines T. and Lawrence L. 2003. Giving insects a good beating. *The Australian Cottongrower* 24(3): 24-27. [See Attachment 4]

McKinnon C, Deutscher S, Dillon M, Mansfield S and Staines T. 2003. Comparison of the beat sheet technique with established methods for sampling pest and predator abundance in cotton. Macintyre Valley Field Trial Book 2003.

McKinnon C, Deutscher S, Dillon M, Mansfield S and Staines T. 2003. Comparison of the beat sheet technique with established methods for sampling pest and predator abundance in cotton. Lower Namoi Valley Cotton Field Day Booklet.

Dillon ML. 2003. Final Report CSE95C: Honey bee dissemination of *Heliothis* NPV onto cotton flowers. A final report prepared for the Cotton Research and Development Corporation. CSIRO Entomology, Narrabri NSW.

Lawrence L and Dillon M. 2004. Honey bee crop dusters plug a gap in Bt cotton defences. *The Australian Cottongrower* 25(2): 14-15.

Lawrence L and Dillon M. 2004. Targetting cotton flowers: Using Honey bees to plug a gap in Bt in cotton plants. *Outlooks on Pest Management*, April 2004 (UK), 83-84. [See Attachment 5]

Dillon ML. 2004. Final Report CSE86C: Quantifying behavioural responses of *Helicoverpa* moths to trap crops for areawide management. A final report prepared for the Cotton Research and Development Corporation. CSIRO Entomology, Narrabri NSW.

Wilson L, Dillon M and Roth G. 2004. 'Impact of insecticides on beneficial arthropods' submission to the National CRC Association Innovation Award program.

Martin Dillon contributed to the revision of the 2nd edition of the IPM Guidelines for Australian Cotton.

Martin Dillon contributed to the revision of the 2004/2005 "Cotton Pest Management Guide 2004/05".

Martin Dillon in collaboration with Lewis Wilson and John Rhodes, developed a table of insecticide impacts for honeybees in cotton for inclusion in the 2004/2005 Cotton Pest Management Guide and the 2nd edition of the IPM Guidelines.

8.7 Simulation Modelling

During the period of this project Martin Dillon continued to run the *Helicoverpa armigera* and *Punctigera* Simulation (HEAPS) model from time to time in response to requests from other researchers and extension staff. For example a comprehensive set of simulations were undertaken for Dr Scott Hardwick (CSIRO Entomology, CRC21C). The model was used to predict Griffith and Hillston diapause autumn induction and spring emergence over an historical 14 year period, and also to predict generation times (days required for *Helicoverpa* to develop from egg to adult moth) for weekly egg lays for three recent growing seasons and also for long term average temperatures at Griffith and Hillston. These simulations were also an important component of the analysis presented in Scott *et al.* (2005) (Attachment 8).

HEAPS diapause induction and emergence simulations for the 2002/03 and 2003/04 seasons were undertaken for Julie O'Halloran (Gwydir IDO) for publication in the Cottontales newsletter.

8.8 Scientific Manuscripts published

Duffield SJ and Dillon, ML. 2005. The emergence and control of overwintering *Helicoverpa armigera* in southern NSW. *Australian Journal of Entomology* 44: 316-320 [Attachment 6]

Mansfield S, Dillon ML and Whitehouse MEA. (2005, submitted). Are arthropod communities in cotton really disrupted? An assessment of insecticide regimes and evaluation of the Beneficial Disruption Index. *Agriculture, Ecosystems and Environment*. [Attachment 7]

Scott LJ, Lawrence N, Lange CL, Graham GC, Hardwick S, Rossiter L, Dillon ML, and Scott KD. (2005, submitted). Population dynamics and gene flow of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) on Cotton and Grain crops in the Murrumbidgee Valley, Australia. *Journal of Economic Entomology*. [Attachment 8]

8.9 Scientific Manuscripts in Preparation

Planned manuscript 1.

“A comparison of beneficial arthropod faunas in conventional and Bt cotton fields in Australia”. Dillon ML, Whitehouse MEA, Harden S, Boland C, Deutscher S, McKinnon C, and Staines TL. (2006 In preparation). This paper will present data from beat sheet sampling of sets of paired Bt and conventional cotton fields. The data was collected from large scale commercial fields in the Macintyre and Namoi valleys and spans 3 seasons. Consistent trends were detected showing some arthropod taxa were significantly more abundant in either Bt or in Conventional cotton crops. The full paper will be submitted for internal review by April 2006 and will be targeted at the international journal “Environmental Entomology”.

Planned manuscript 2.

M. L. Dillon, M. E. A. Whitehouse, and S. Harden. (2006 In preparation). The effect of sample size on beat sheet estimates of arthropod abundance in Australian cotton crops. This paper will analyse existing data to determine the minimum number of beat sheet samples required to adequately estimate densities of specific beneficial arthropod taxa. The full paper will be submitted for internal review by June 2006 and will be targeted at the “Australian Journal of Entomology”.

Planned manuscript 3.

M. L. Dillon, S. Deutscher, C. Threlfall, M.E.A. Whitehouse, and T. Staines. (2006 In preparation). Estimating green mirid (*Creontiades dilutus*) densities using different sampling techniques in Australian cotton crops. This manuscript deals with the topic of converting green mirid counts from beat sheets or other sampling methods to visual equivalents.

Planned manuscript 4.

Dillon, ML., Hoque, Z., Farquharson, R. and Harden S. (2006, In preparation). Insecticide spray strategies and cotton field profitability. The paper will be targeted at the international journal “Economic Entomology”. It will present the definitive analysis of over 6 years of commercial paddock-level data from the Boggabilla landcare group.

Planned manuscript 5.

M.A.Merritt, K.S.Wilkinson, K.D.Scott, M.Dillon, L.J.Scott, C.L.Lange, M.K.Schutze, J.K.Kent, D.J.Merritt And G.C.Graham. (2006, in preparation.) Gene flow in two consecutive collections of the Lepidopteran pest, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) from the Narrabri region, New South Wales. Australian Journal of Agricultural Research. This paper is undergoing a second revision prior to re-submission.

9. Impact of project Results and Conclusions for the Cotton Industry

A list of specific conclusions and take home messages arising from this project is given in section 4 and section 6 above.

The findings of this project suggest that an IPM and AWM based approach to managing insect pests and natural enemies in cotton is at least as profitable as more conventional approaches, but has added environmental benefits of increased biodiversity and less risk of insecticide resistance.

By reducing farmers' dependence on chemical insecticides, AWM may help to slow the evolution of resistance, and may help to reduce potential adverse environmental effects of disruptive sprays.

The project results have been widely disseminated throughout the Australian cotton industry, and have provided the basis for increased confidence that IPM and AWM can be effective and profitable methods of protecting cotton from insect pests that minimise environmental impacts.

10. Acknowledgements

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A very sincere thanks is extended to all of the growers and consultants of the Boggabilla Landcare Group and the Two Rivers Areawide Management group who generously provided hospitality, data, allowed us to undertake research in their commercial cotton fields, and were continually questioning and encouraging. I'd like to particularly thank Iain Macpherson for his passionate advocacy of sustainable area-wide based IPM and his significant input into this project. Thanks to the farm staff of CSIRO and NSW DPI at the Australian Cotton Research Institute for assisting with cotton trials. Lastly, thanks to Dr Simon Lott and E.A. Systems Pty Limited for allowing me to use company resources to complete this final report.

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12. Final Report Checklist

| Requirement | Section |
|---|---------------------------------------|
| Outline the background to the project | Section 1 |
| List the project objectives and the extent to which these have been achieved | Section 2 |
| Detail the methodology and justify the methodology used | Section 3 |
| Detail and discuss the results including the statistical analysis of results | Section 3 |
| Provide a conclusion as to research outcomes compared with objectives. What are the “take home messages”? | Section 4 |
| Detail how your research has addressed the Corporation’s three Outputs - Economic, Environmental and Social? | Section 5 |
| Provide a summary of the project ensuring the following areas are addressed: <ul style="list-style-type: none"> a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.) b) other information developed from research (eg discoveries in methodology, equipment design, etc.) c) are changes to the Intellectual Property register required? | Section 6 |
| Detail a plan for the activities or other steps that may be taken: <ul style="list-style-type: none"> (a) to further develop or to exploit the project technology. (b) for the future presentation and dissemination of the project outcomes. (c) for future research. | Section 7 Section 7 Section 8.9 |
| List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s) | Section 8 and Attachments 1 to 8 |
| Have you developed any online resources and what is the website address? | N/A |
| Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community | Section 9 |

13. Appendices

| | | |
|---------------|---|----|
| Appendix A. | Statistical details of the comparison of arthropod faunas in paired Bt and conventional cotton fields | 75 |
| Attachment 1. | Wilson LJ, Mensah R, Dillon M, Wade M, Scholz B, Murray DA, Heimoana V and Lloyd R. 2002. Impact of insecticides and miticides on predators in cotton: October 2002 update. Support Document 1 in: Mensah, R. and Wilson, LJ. (Editors): Integrated Pest Management Guidelines for Australian Cotton. Australian Cotton Cooperative Research Centre, Narrabri, NSW. http://cotton.pi.csiro.au/Publicat/Pest/ | 84 |
| Attachment 2. | Hickman M, Larsen D and Dillon ML. 2002. <i>Guidelines for assessing pupae risk for dryland cotton growers</i> . Cotton Information Sheet July 2002. Australian Cotton Cooperative Research Centre, Narrabri | 87 |
| Attachment 3. | Dillon ML and Scholz B. 2003. Fire ants: An invader we don't want in cotton. <i>The Australian Cottongrower</i> 24(7): 16-17 | 88 |
| Attachment 4. | Deutscher S, Dillon ML, McKinnon C, Mansfield S, Staines T. and Lawrence L. 2003. Giving insects a good beating. <i>The Australian Cottongrower</i> 24(3): 24-27 | 89 |
| Attachment 5. | Lawrence L and Dillon M. 2004. Targetting cotton flowers: Using Honey bees to plug a gap in Bt in cotton plants. <i>Outlooks on Pest Management</i> , April 2004 (UK), 83-84 | 90 |
| Attachment 6. | Duffield SJ and Dillon, ML. 2005. The emergence and control of overwintering <i>Helicoverpa armigera</i> in southern NSW. <i>Australian Journal of Entomology</i> 44: 316-320 | 91 |
| Attachment 7. | Mansfield S, Dillon ML and Whitehouse MEA. (2005, submitted). Are arthropod communities in cotton really disrupted? An assessment of insecticide regimes and evaluation of the Beneficial Disruption Index. <i>Agriculture, Ecosystems and Environment</i> | 92 |
| Attachment 8. | Scott LJ, Lawrence N, Lange CL, Graham GC, Hardwick S, Rossiter L, Dillon ML, and Scott KD. (2005, submitted). Population dynamics and gene flow of <i>Helicoverpa armigera</i> (Hübner) (Lepidoptera: Noctuidae) on Cotton and Grain crops in the Murrumbidgee Valley, Australia. <i>Journal of Economic Entomology</i> | 93 |

Appendix A. Statistical details of the comparison of arthropod faunas in paired Bt and conventional cotton fields

Table 12. Difference in total number of insects sampled on beat sheets between conventional and Bt cotton crops across four field seasons. Figures denote mean \pm SE (n)

| Year | Conventional | Bt |
|-------------|----------------------|----------------------|
| 1 (01/02) | 11.8 \pm 1.3 (309) | 15.2 \pm 1.5 (278) |
| 2 (02/03) | 25.9 \pm 1.2 (384) | 34.5 \pm 1.6 (252) |
| 3 (03/04) | 10.1 \pm 1.4 (266) | 20.2 \pm 1.5 (277) |
| 4 (04/05) | 20.8 \pm 1.4 (266) | 20.1 \pm 1.5 (265) |

Table 13. Comparison of lepidopteran abundance sampled on beat sheets between conventional and Bt cotton crops. Data are pooled from four field seasons

| Heli Stage | Conventional | Bt | Conv : Bt | X²₁= | P= |
|-------------------|---------------------|------------------|------------------|-----------------------------------|-----------|
| Eggs | 0.021 \pm 0.04 | 0.055 \pm 0.04 | - | 0.81 | 0.40 |
| Tiny larvae | 0.070 \pm 0.02 | 0.017 \pm 0.02 | 4.1 : 1 | 8.42 | 0.004 |
| Small larvae | 0.193 \pm 0.04 | 0.027 \pm 0.04 | 7.2 : 1 | 15.37 | < 0.001 |
| Medium larvae | 0.090 \pm 0.03 | 0.016 \pm 0.03 | 5.6 : 1 | 5.75 | 0.02 |
| Large larvae | 0.047 \pm 0.01 | 0.011 \pm 0.01 | 4.3 : 1 | 6.40 | 0.01 |
| All larvae | 0.399 \pm 0.09 | 0.071 \pm 0.09 | 5.6 : 1 | 12.10 | < 0.001 |

| Taxa | Conventional | Bt | Conv : Bt | X²₁= | P= |
|------------------|---------------------|------------------|------------------|-----------------------------------|-----------|
| Non-Heli larvae | 0.071 \pm 0.02 | 0.030 \pm 0.02 | | 3.16 | 0.08 |
| All caterpillars | 0.472 \pm 0.10 | 0.097 \pm 0.10 | | 13.90 | < 0.001 |

Table 14. Comparison of minor pest abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| Taxa | Conventional | <i>Bt</i> | Conv : <i>Bt</i> | X²₁= | P= |
|-----------------------------|---------------------|------------------|-------------------------|-----------------------------------|-----------|
| Green mirids – adults | 0.116 ± 0.05 | 0.135 | | 0.14 | 0.71 |
| Green mirids – nymphs | 0.405 ± 0.18 | 0.613 | | 1.40 | 0.24 |
| Total green mirids | 0.522 ± 0.216 | 0.758 | | 1.19 | 0.28 |
| Brown mirids – adults | 0.006 ± 0.003 | 0.004 | | 0.32 | 0.57 |
| Brown mirids – nymphs | 0.010 ± 0.004 | 0.008 | | 0.25 | 0.62 |
| Total brown mirids | 0.016 ± 0.006 | 0.013 | | 0.18 | 0.70 |
| Total mirids | 0.538 ± 0.218 | 0.774 | | 1.17 | 0.28 |
| GVB | 0.026 ± 0.012 | 0.015 | | 0.88 | 0.35 |
| Jassids** | 6.706 ± 2.593 | 11.226 | | 3.04 | 0.08 |
| Rutherglen | 0.177 ± 0.087 | 0.191 | | 0.03 | 0.87 |
| Cot. Seed Bug | 0.388 ± 0.140 | 0.540 | | 1.18 | 0.28 |
| Flea Beetle | 0.332 ± 0.196 | 0.370 | | 0.04 | 0.85 |
| Total minor pests** | 7.77 ± 2.675 | 12.62 | | 3.28 | 0.07 |
| Total minor pests - jassids | 1.166 ± 0.263 | 1.516 | | 1.77 | 0.18 |
| TOTAL PESTS** | 8.21 ± 2.694 | 12.67 | | 2.74 | 0.10 |

Table 15. Comparison of predatory bug abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| Taxa | Conventional | <i>Bt</i> | Conv : <i>Bt</i> | X²₁= | P= |
|--------------------------------------|---------------------|------------------|-------------------------|-----------------------------------|-----------|
| ADB | 0.187 ± 0.062 | 0.264 | | 1.54 | 0.21 |
| BEB** | 0.139 ± 0.069 | 0.307 | | 5.86 | 0.02 |
| Nabis-* | 0.260 ± 0.052 | 0.093 | | 10.40 | < 0.001 |
| Glossy Shield | 0.006 ± 0.004 | 0.002 | | 0.32 | 1.00 |
| Predatory shield | 0.011 ± 0.007 | 0.005 | | 0.74 | 0.39 |
| Assassin | 0.014 ± 0.011 | 0.000 | | 2.06 | 0.15 |
| Pirate | 0.059 ± 0.032 | 0.089 | | 0.90 | 0.34 |
| Brown smudge | 0.029 ± 0.012 | 0.014 | | 1.53 | 0.22 |
| Total predatory bugs – nabis** | 0.382 ± 0.113 | 0.600 | | 3.72 | 0.05 |
| Total non-significant predatory bugs | 0.308 ± 0.087 | 0.380 | | 0.69 | 0.41 |
| Total predatory bugs | 0.733 ± 0.162 | 0.735 | | 0.00 | 0.99 |

Table 16. Comparison of predatory beetle abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| Taxa | Conventional | <i>Bt</i> | Conv : <i>Bt</i> | X²₁= | P= |
|---------------------------|---------------------|------------------|-------------------------|-----------------------------------|-----------|
| Three-banded | 0.031 ± 0.012 | 0.025 | | 0.26 | 0.61 |
| Common spotted | 0.002 ± 0.001 | 0.002 | | 0.01 | 0.93 |
| Variable | 0.004 ± 0.003 | 0.003 | | 0.08 | 0.78 |
| Transverse | 0.073 ± 0.020 | 0.055 | | 0.83 | 0.36 |
| Striped | 0.001 ± 0.002 | 0.004 | | 2.22 | 0.14 |
| Total lady beetles | 0.122 ± 0.032 | 0.126 | | 0.02 | 0.90 |
| Lady beetle larvae-* | 0.010 ± 0.016 | 0.037 | | 2.96 | 0.09 |
| Hippo | 0.094 ± 0.026 | 0.097 | | 0.02 | 0.89 |
| Diomus | 0.026 ± 0.011 | 0.026 | | 0.00 | 0.96 |
| Red/Blue | 1.052 ± 0.210 | 1.314 | | 1.56 | 0.21 |
| Total predatory beetles** | 1.114 ± 0.174 | 1.400 | | 2.70 | 0.10 |

Table 17. Comparison of spider abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| Taxa | Conventional | <i>Bt</i> | Conv : <i>Bt</i> | X²₁= | P= |
|-------------------------------|---------------------|------------------|-------------------------|-----------------------------------|-----------|
| Yellow night stalker** | 0.272 ± 0.118 | 0.534 | | 4.98 | 0.03 |
| Orb weaver | 0.057 ± 0.033 | 0.068 | | 0.12 | 0.73 |
| Jumping spider | 0.136 ± 0.070 | 0.217 | | 1.31 | 0.25 |
| Lynx spider** | 0.419 ± 0.103 | 0.646 | | 4.84 | 0.03 |
| Flower/crab spider | 0.134 ± 0.060 | 0.038 | | 3.01 | 0.08 |
| Wolf spider | 0.072 ± 0.045 | 0.065 | | 0.02 | 0.88 |
| Tangle web spider | 0.362 ± 0.173 | 0.578 | | 1.56 | 0.21 |
| Other spiders** | 0.815 ± 0.257 | 1.296 | | 3.51 | 0.06 |
| Total spiders** | 2.203 ± 0.449 | 3.362 | | 6.67 | 0.01 |
| Total non-significant spiders | 1.524 ± 0.347 | 2.189 | | 3.67 | 0.06 |

Table 18. Comparison of 'other predator' abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| Taxa | Conventional | <i>Bt</i> | Conv : <i>Bt</i> | X²₁= | P= |
|-------------|---------------------|------------------|-------------------------|-----------------------------------|-----------|
| Small ants | 0.048 ± 0.016 | 0.050 | | 0.01 | 0.93 |
| Big Ants | 0.024 ± 0.012 | 0.033 | | 0.60 | 0.44 |
| Total Ants | 0.070 ± 0.019 | 0.080 | | 0.23 | 0.63 |

Table 19. Comparison of 'neutral taxa' abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| Taxa | Conventional | <i>Bt</i> | Conv : <i>Bt</i> | X²₁= | P= |
|----------------------|---------------------|------------------|-------------------------|-----------------------------------|-----------|
| Red banded | 0.000 ± 0.001 | 0.001 | | 1.12 | 0.29 |
| Diptera | 0.750 ± 0.184 | 0.585 | | 0.81 | 0.37 |
| Other Hymenoptera | 0.151 ± 0.053 | 0.154 | | 0.00 | 0.95 |
| Other bugs | 1.200 ± 0.324 | 1.494 | | 0.83 | 0.36 |
| Other insects | 0.021 ± 0.016 | 0.000 | | 1.81 | 0.18 |

Table 20. Comparison of total predators, total major pests, total minor pests, and total arthropod abundance sampled on beat sheets between conventional and *Bt* cotton crops. Data are pooled from four field seasons

| | | | | | |
|--------------------------------|---------------|--------------|--|-------|---------|
| Total Predators** | 4.048 ± 0.559 | 5.555 | | 7.26 | 0.007 |
| Total Helicoverpa | 0.399 ± 0.09 | 0.071 ± 0.09 | | 12.10 | < 0.001 |
| Total minor pests | 7.77 ± 2.675 | 12.62 | | 3.28 | 0.07 |
| Total non-heli arthropods** | 12.47 ± 2.90 | 19.44 | | 5.78 | 0.02 |

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