



Annual, Progress & Final Reports

Part 1 - Summary Details

REPORTS

Please use your TAB key to complete part 1 & 2.

COTTON CRC Project Number: CRC21C

Annual Report: Due 29th May 2003
Progress Report: Due 22nd November 2003
Final Report: Due within 3 months of project completion

**Project Title: Cotton Production Systems for
Southern New South Wales
(CSIRO Milestones only)**

Project Commencement Date: **1/7/2000** Project Completion Date: **30/6/2003**

Research Program: 3. Sustainable farming Systems

Part 2 – Contact Details

Administrator: Mr Mark Hardwick
Organisation: CSIRO Entomology
Postal Address: GPO Box 1700. Canberra, ACT 2601
Ph: (02) 6246 4008 **Fx:** (02) 6246 4095 **E-mail:** mark.hardwick@.csiro.au

Principal Researcher: Dr Scott Hardwick
Organisation: CSIRO Entomology
Postal Address: CSIRO Entomology, PMB 3, Griffith NSW 2680
Ph: (02) 69 60 1547 **Fx:** (02) 69 60 1600 **E-mail:** scott.hardwick@.csiro.au

Supervisor : Dr Geoff Baker
Organisation: CSIRO Entomology
Postal Address: GPO Box 1700. Canberra, ACT 2601
Ph: (02) 6246 4401 **Fx:** (02) 6246 4000 **E-mail:** geoff.baker@.csiro.au

Other Staff & Collaborators – Please list

Signature of Research Provider Representative: _____

Part 6 – Final Report Format

1. Background

Field cropping systems in southern NSW have traditionally been associated with the production of grain crops. However since the 1998-1999 growing season there has been a rapid expansion in the area of cotton grown from approximately 1000 ha to a peak of 16000 ha in the 2001–2002 growing season. Due to the drought conditions experienced in the 2002–2003 season plantings of cotton declined due to water shortages. However, it is expected that dependant on the availability of water, the area of cotton production within the region will continue to rapidly increase in at least the short to medium term. The southern cotton growing region in eastern Australia faces production and environmental issues that differ from more northern areas. The main driver behind the differences is the short growing season experienced in the region. This means that production systems that have high inputs and have little tolerance to insect or pathogen damage. Furthermore production may be based on systems using ultra narrow row (UNR) and 15 inch row spacings and the strategic use of plant growth regulants in an effort to minimise the period from planting to harvest, (i.e. maximise earliness).

While the cotton production systems outlined above can and do result in acceptable yields and fibre quality, existing cotton producers believed that it was important to develop IPM strategies that were suited to a short growing season. This was considered particularly important to enable the sustainability of high input systems such as UNR where *Helicoverpa* thresholds were set at less than half those in conventional cotton based on one meter row spacings. Furthermore producers believed that it was important that any increase in the amount of cotton produced within southern NSW and northern Victoria was undertaken with the minimum impact on crops that are traditionally grown within the regions production systems. Other crops within the region traditionally receive low insecticide inputs and use IPM techniques to control pests such as aphids and mites. Integrated pest management techniques to help control *Helicoverpa* species by retaining beneficial insects were also developed for crops such as maize and soybean prior to the commencement of the current study. Early season insecticide use on properties producing cotton using high input systems has the potential to disrupt IPM systems, particularly those that utilise beneficial species, on adjacent properties. Cotton producers also expressed concerns that the lack of refuge areas within the cotton producing areas of southern NSW may have limited the potential to sustain adequate numbers of beneficial insects within production systems that used IPM. Therefore cotton producers wanted recommendations to help develop management systems that encourage the build up and retention of beneficial insects in cotton producing areas of New South Wales. It was envisioned that these systems would include recommendations on crop sequencing, refuge crops and the use of Area Wide Management (AWM) strategies.

One problem that exists in all production systems where *H. armigera* is a pest, which is largely controlled through the use of insecticide, is resistance to insecticidal control measures. Monitoring which has been undertaken as part of GRDC research programmes has revealed high levels of insecticide resistance to insecticides

(particularly synthetic pyrethroids) amongst *H. armigera* populations. This insecticide resistance is carried over between growing seasons by diapausing pupae. As cotton is a crop which receives numerous insecticide applications and is likely to be the least attractive crop within the region it is imperative that the appropriate insecticide resistance management strategies are practiced in conjunction with control of diapausing *H. armigera* through pupae busting. For this to occur successfully it is important that any strategies used to delay or prevent the onset of insecticide resistance to new or existing groups of insecticides be matched to the ecology of the pest within the southern cotton growing region. Further as there is an existing IRM strategy for grains crops within the region it is important that any strategy applied to cotton matches that for grain.

The third major area of concern for cotton growers in southern NSW and northern Victoria is the effect that changes in the balance of the diverse number of crops grown within the region may have on the dynamics of *Helicoverpa* and the implication that this may have for the implementation of Area Wide Management (AWM). Any IPM strategies developed for cotton need to be able to be incorporated into AWM strategies that are appropriate for other local industries.

The aim of the current project and the allied GRDC project CSE 163 (the regional management of *Helicoverpa* spp. in southern NSW and northern Victoria) was therefore to gather ecological data on *Helicoverpa* spp and other beneficial and pest invertebrates to help formulate;

- 1: An integrated pest management (IPM) system for southern NSW that incorporated suitable insect thresholds and was based on a better understanding of the ecology of pest and beneficial insects, and their interactions with refuge and host crops,
- 2: An area wide management strategy (AWM) that incorporated the various crops grown within the region and,
- 3: An insecticide resistance management strategy that incorporated the various crops within the region.

2. List the project objectives and the extent to which these have been achieved.

2.1: An integrated pest management (IPM) system for southern NSW that incorporated suitable insect thresholds and was based on a better understanding of the ecology of pest and beneficial insects, and their interactions with refuge and host crops.

This objective was successfully completed

Studies were undertaken by CSIRO staff to investigate the ecology of *Helicoverpa* species in a range of cropping species in the southern cotton growing region of NSW. This work also measured the abundance of other pest and beneficial invertebrates in various crops, waste areas and bush remnants. From these results recommendations on the use of early and late season trap crops, refuge crops of lucerne and the role of waste areas and bush remnants in IPM systems have been made. Research on the use of *Trichogramma pretiosum* in maize crops to reduce the build up of *Helicoverpa* spp. was also undertaken.

2.2: An area wide management strategy (AWM) that incorporated the various crops grown within the region.

This project objective was successfully completed.

The draft Area Wide Management (AWM) strategy for the control of *Helicoverpa* spp. was mailed to 334 individuals or organisations in October 2002, of these 225 received one copy while the other 109 received 5–20 copies. The AWM plan was also presented to grower groups industry groups and other researchers at field days and meetings. After taking into account comments made by relevant parties a number of minor changes were made to the strategy. The current version of the strategy has now been distributed and presentations have been made at a number of grower meetings. Articles on the AWM strategy have been accepted for publication in the Australian Cotton Grower and Australian Grain.

2.3: An insecticide resistance management (IRM) strategy that incorporated the various crops within the region.

This project objective was successfully completed.

In each year of the research project egg collections were made from crops within the region. Changes have been made to the Cotton IRM strategy in response to concerns raised by the results of this testing. Furthermore the Grains IRM strategy was amended each year to ensure that all industries were using IRM strategies that were

compatible with each other. One area of concern raised during the study is the time taken for *Helicoverpa* to complete their development during the late December-early February. Data generated from the HEAPs (*HElicoverpa Armigera* and *Punctigera* Simulation) model using temperature data from the Hillston region indicate that time to complete development from adult to adult may be as low as 30 days in some cases. This is a significant observation as IRMS windows are calculated on a 42-day basis. If the data is an accurate reflection of what is occurring in the field and early analysis of observational data suggests that it may be, then it is likely that there may be an increased risk of an increased rate in the development of insecticide resistance amongst *H. armigera* populations in the southern cotton growing region.

3. Detail the methodology and justify the methodology used.

3.1 Invertebrate monitoring

Ecological studies were conducted in order to better understand the ecology of *Helicoverpa*, other pests and beneficial invertebrates within cotton growing regions of southern NSW. Monitoring sites were established throughout the area in trap crops (chickpeas, pigeon peas) crops (chickpeas, cotton and maize) beneficial refuges (lucerne) and waste areas consisting of grassland and bush remnants. The number of crops sampled and sampling methods used during the study period is outlined in Table 1. The trap crops, crops and beneficial refuges were sampled for the presence of *Helicoverpa* and other pest and beneficial invertebrates throughout the growing season at 7–14 day intervals. All sampling carried out during the study used techniques that have previously been proven to provide suitably accurate data when used to sample *Helicoverpa* and associated invertebrates in field crops. Techniques used include surface searches, absolute sampling, beat sheet sampling and sweep netting (Table 1). Immature *Helicoverpa* life stages collected during the monitoring were returned to the laboratory and reared using proven techniques through to either adulthood or death to assess the levels of disease and parasitism within *Helicoverpa* populations. To monitor adult *Helicoverpa* activity a network of grower run pheromone traps that was set up in the GRDC project CSE111 was expanded into the Hillston region. Surveys of diapausing *Helicoverpa* populations were also undertaken in the Hillston region.

For each of the years of the study, results from the ecological data were compared with data generated from the *H. armigera* spring emergence and autumn diapause induction models and the HEAPs model.

3.2 *Trichogramma pretiosum* releases into maize

T. pretiosum releases were undertaken in four maize crops throughout the southern NSW cotton producing region. At each trial site, a randomised complete block experimental design was used to assess the ability of *T. pretiosum* releases into silking maize to reduce the number of *H. armigera* produced by maize plantings in southern cotton producing regions. Commercially produced *T. pretiosum* were released into treated plots at a rate of 180, 000 wasps ha⁻¹. Control plots remained untreated. At each site treatments were replicated 3 times. Immature stages of *H. armigera* were

measured prior to and post *T. pretiosum* release. At the end of the experimental period the number of *H. armigera* pupae under each plot was assessed by pupae counts.

3.3 Insecticide Resistance Monitoring

Helicoverpa egg samples were collected from maize, cotton, and pigeon pea trap crops whenever possible and sent to NSW Agriculture in Narrabri for insecticide resistance testing. The data generated from the testing was used to update the region’s Insecticide Resistance Management strategy (IRMs). Data gained from egg collections made in this project and the allied GRDC project CSE 163 were also used to update the grain industries IRMs on a yearly basis. This helped to ensure that both industries used IRMs that were compatible with each other.

The methods used above generated sufficient data to gain a better understanding of the ecology of *Helicoverpa* and beneficials within the cotton growing region of southern NSW. Furthermore it allowed for the development of IPM and AWM guidelines for both cotton and grain crops within the region

Table 1: Types of samples taken from crops during each growing season.

Year	Crop	Number of crops sampled	Sampling method ¹	Number of sampling sites per crop
2000–2001	Lucerne	3	ABS/Swe	6
	Chick pea	5	ABS	6
	Cotton-conventional	8	ABS/Beat	6
	Cotton-Ingard [®]	8	ABS/Beat	6
	Pigeon Pea	4	ABS	6
2000–2001	Lucerne	3	ABS/Swe/Suc	6
	Chick pea	4	ABS/Swe/Suc	12
	Cotton-conventional	8	ABS/Beat	6
	Cotton-Ingard [®]	8	ABS/Beat	6
	Pigeon Pea	4	ABS/Beat	6
2002–2003	Lucerne	3	ABS/Swe/Suc	6
	Chick pea	4	ABS/SW	12
	Cotton-conventional	8	ABS/Beat	6
	Cotton-Ingard [®]	8	ABS/Beat	6
	Pigeon Pea	2	ABS/Beat	6

¹ ABS=absolute sample (plants removed from 1 m of row and taken to laboratory where *Helicoverpa* and other invertebrates counted), Swe= Sweep net sample (20 sweeps), Suc=suction sample (10 m long), Beat=Beat sheet sampling (1 m of row.).

4. Detail results including the statistical analysis of results.

4.1 Crop monitoring

4.1 A Trap crops

Chickpeas

Figure 1 shows *Helicoverpa* egg and larval densities, the time that the first 5th instar larva was observed in trap crops within the district, the recommended starting date for destruction of trap crops and proportion of the *Helicoverpa* population that was *H. armigera*. The general pattern for *H. punctigera* population development in chickpea trap crops was that the first eggs were laid in late August early September as moths migrated into the Hillston region. Observations and modelling using the HEAPs model suggest that eggs hatching from the initial egg laying activity gave rise to first observed 5th instar larvae in mid to late October (Fig. 1). This generally would lead to the recommendation of destruction of trap crops in late October–mid November in each year. However, in years with warmer than average temperatures at the start of the season or earlier than normal movement of *H. punctigera* into the region, there is the possibility that trap crops would have to be destroyed as early as mid-October as was the case in the 2002–3 growing season (Fig. 1).

In the Hillston region *H. armigera* do not start emerging from diapause until late September–early October in each year. Adults continue to emerge from diapausing pupae until mid December with 50% and 75% of individuals having emerged by mid November and early December respectively. This pattern of emergence may mean that very few of the founding *H. armigera* moths have a chance to lay eggs into chick pea trap crops that would normally be destroyed in late October after the observation of the first 5th instar *Helicoverpa* larvae. The results shown in Fig. 1 reflect this with *H. armigera* only making up 0 and 20 % of the population at the time of destruction of the trap crops in the 2001–02 and 2002–3 growing seasons.

If the producers in the region are using trap crops to reduce *Helicoverpa* build up in the early to mid-season period then they can be considered a useful tool when following the current recommendations. However, if a producer is intent on attracting a large proportion of the *H. armigera* population, which is emerging from diapause, then trap cropping using current recommendations may be considered less than fully successful in the southern cotton production region. It may be possible to overcome the observed mistiming of trap cropping using chick peas by either manipulating the crop to delay flowering e.g. by slashing (however, some eggs are being laid before flowering) or by manipulating the *Helicoverpa* population by applying an insecticide such as NPV which has few if any detrimental effects to beneficial invertebrates within the region. Commercial chickpea crops show patterns of infestation similar to those outlined in Fig. 1. It is therefore probable that they act as sinks for *H. armigera* within the region providing that control is carried out in an efficacious manner.

As found in previous studies very few if any beneficial invertebrates were found in chickpea crops that were monitored. It therefore is concluded that they are of little importance as refuges for these species within the cotton producing areas of southern NSW.

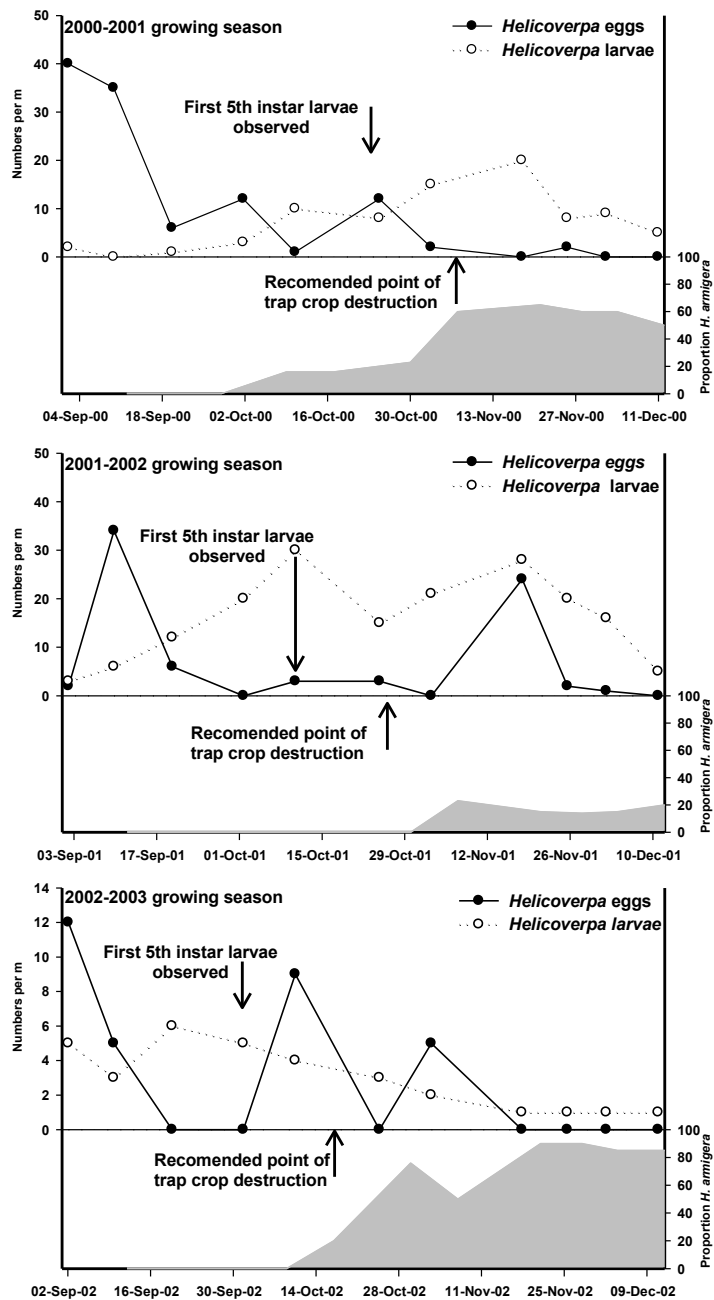


Figure 1: *Helicoverpa* egg and larval density, the time that the first 5th instar larvae was observed, the recommended starting date for destruction of trap crops and proportion of the *Helicoverpa* population made up by *H. armigera* in the 2000–01, 2001–2002 and 2002–2003 growing seasons in the Hillston region of Southern NSW

Pigeon peas

Helicoverpa

Monitoring of late season trap crops of pigeon pea in the Hillston and Coleambally regions of southern NSW revealed that *Helicoverpa* oviposition started in mid to late December in each of the study years. Substantial egg lays were then recorded in all pigeon pea crops in the late January–early February period. In the 2000–2001 growing season when crops were destroyed later than expected low levels of *Helicoverpa* oviposition continued through to late April. A second late season peak in *Helicoverpa* oviposition was also observed in the 2001–2002 growing season in April. This did not occur in the 2002–2003 season. *Helicoverpa* larvae were observed in pigeon pea trap crops from late December onwards in each of the years of monitoring. Larval densities were at their highest in early March (Fig. 2). Modelling of diapause induction predicts that *H. armigera* pupae arising from eggs laid after mid January have a 50% probability of entering diapause while those arising from eggs laid after late February will almost certainly enter diapause (Fig. 2). This gives rise to the probability that a small number of late season *Helicoverpa* adults would be generated by trap crops of pigeon pea. It is possible that growers would tolerate these individuals in seasons when the temperatures are average to above average, as they would emerge at a time that cotton crops are starting to become less sensitive to *Helicoverpa* damage. However, if the season is cooler than average (e.g. 2001–2002) there would be an increased chance that larvae arising from escapees would cause damage to the late cotton maturing crop. In seasons such as this it may be possible to manipulate larvae survival in pigeon pea trap crops through the use of NPV.

Pupal surveys showed that the late season pigeon pea trap crops had the potential to generate significant numbers of diapausing *H. armigera* pupae. Data from surveys revealed that diapausing *H. armigera* densities under trap crops ranged from 47000–192000, 6000–172000 and 56000–138000 ha⁻¹ in the 2000–2001, 2001–2002 and 2002–2003 growing seasons respectively.

Beneficial invertebrates

A wide range of beneficial invertebrates was found during beat sheeting and surface searches of pigeon pea trap crops. In the 2000–2001 and 2001–2002 growing seasons, densities of beneficial invertebrates peaked at approximately 15–20 m⁻¹. However, in the 2002–2003 growing season numbers peaked at 35 m⁻¹ in early February 2003 before declining to levels similar to previous years (Fig. 2). Examination of the data revealed that the elevated levels of beneficial invertebrates at this time were due to an influx of *Oeochalia schellenbergii* adults.

Rearing of *Helicoverpa* larvae collected from pigeon pea trap crops revealed the presence of at least six species of parasitoids (Table 2). Overall rates of parasitism in *Helicoverpa* larvae during the three growing seasons between 2000–2003 were in the range of 11–19%. *Microplitis demolitor* was the most common parasitoid encountered, followed by *Chaetophthalmus* spp., *Exorista* spp. and *Heteropelma scaposum*. *Netelia producta* and *Carcelia* spp. were encountered the least during the rearing of *Helicoverpa* larvae (Table 2).

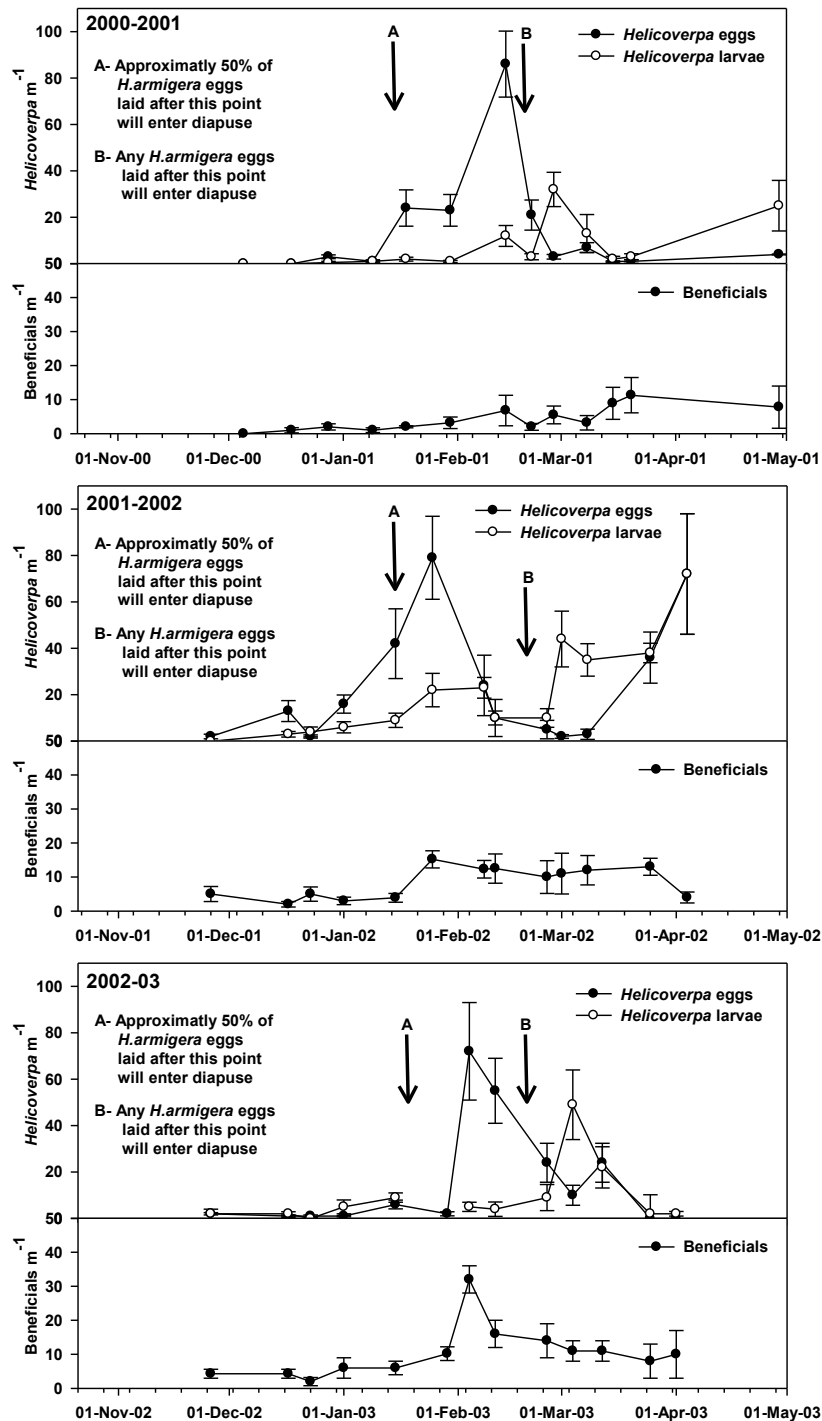


Figure 2: Mean Densities of *Helicoverpa* eggs and larvae, and beneficial invertebrates on pigeon pea trap crops (n=3) in the Hillston region during the 2000–2001, 2001–2002 and 2002–2003 growing seasons as measured by surface searches (Bar=SEM).

Table 2: Percentage parasitism of *Helicoverpa* larvae collected from pigeon pea trap crops in the Hillston region during the 2000–2001, 2001–2002 and 2002–2003 growing seasons.

Parasitoid	2000–2001	2001–2002	2002–2003	Mean
<i>Microplitis demolitor</i>	11.5	1	12	8.1
<i>Heteropelma scaposum</i>	1.5	1.5	3.5	2.1
<i>Netelia producta</i>	0.0	0.0	0.5	0.15
<i>Carcelia spp.</i>	0.5	0.0	0.0	0.15
<i>Chaetophthalmus spp</i>	3.0	7.0	2.0	3.0
<i>Exorista spp.</i>	0.5	1.5	1.5	1.15

4.1 B Cotton crops

Helicoverpa

Due to the influence that differences in crop cultivar and management practices can have on the density of *Helicoverpa* larvae only the egg-lay data from the data set collected is presented in Fig. 3. The results of *Helicoverpa* monitoring showed that there were two periods of increased egg pressure or, oviposition activity, in each of the three growing seasons (Fig. 3). This generally occurred in the periods of December–early January and from the second week of February–mid-March. Results from the HEAPs model and observational data suggest the earlier peak corresponds with the period when the first generation of local *H. punctigera* (arising from eggs deposited in September) move out of winter and spring crops such as chickpeas which are becoming less attractive and hay off. Any *H. armigera* eggs being deposited during the early to mid season are likely to have come from two sources, 1) adults that have emerged directly from diapausing pupae, and, 2) adults arising from the first generation of larvae. Lepton® tests and the rearing of collected eggs showed that approximately 75 % of *Helicoverpa* eggs laid during the early–mid-season peak in *Helicoverpa* oviposition are *H. punctigera*. This supports the theory that the bulk of the eggs laid arise from the first generation of *H. punctigera* that have developed on spring hosts such as chickpea, canola and faba bean.

Observational data such as the presence of fifth instar larvae in late January and early February (Fig. 3) and HEAPs modelling suggests that the second peak in *Helicoverpa* egg pressure during the late season period (February–mid-March) is likely to be due to oviposition by newly emerged second generation of *Helicoverpa* adults. Lepton® test data and rearing of collected eggs showed that 80-90% of the eggs laid during this late season period are *H. armigera*. *H. armigera* adults which laid the observed eggs could have potentially arisen from two sources, 1) escapees from cotton crops (i.e. larvae that have not been controlled by the insecticide regime used on cotton crops) and 2) maize crops within the region that are normally haying off during this period. The generation of *H. armigera* larvae arising from eggs deposited in March onwards

will not complete their development but result in pupae which enter diapause over the winter period.

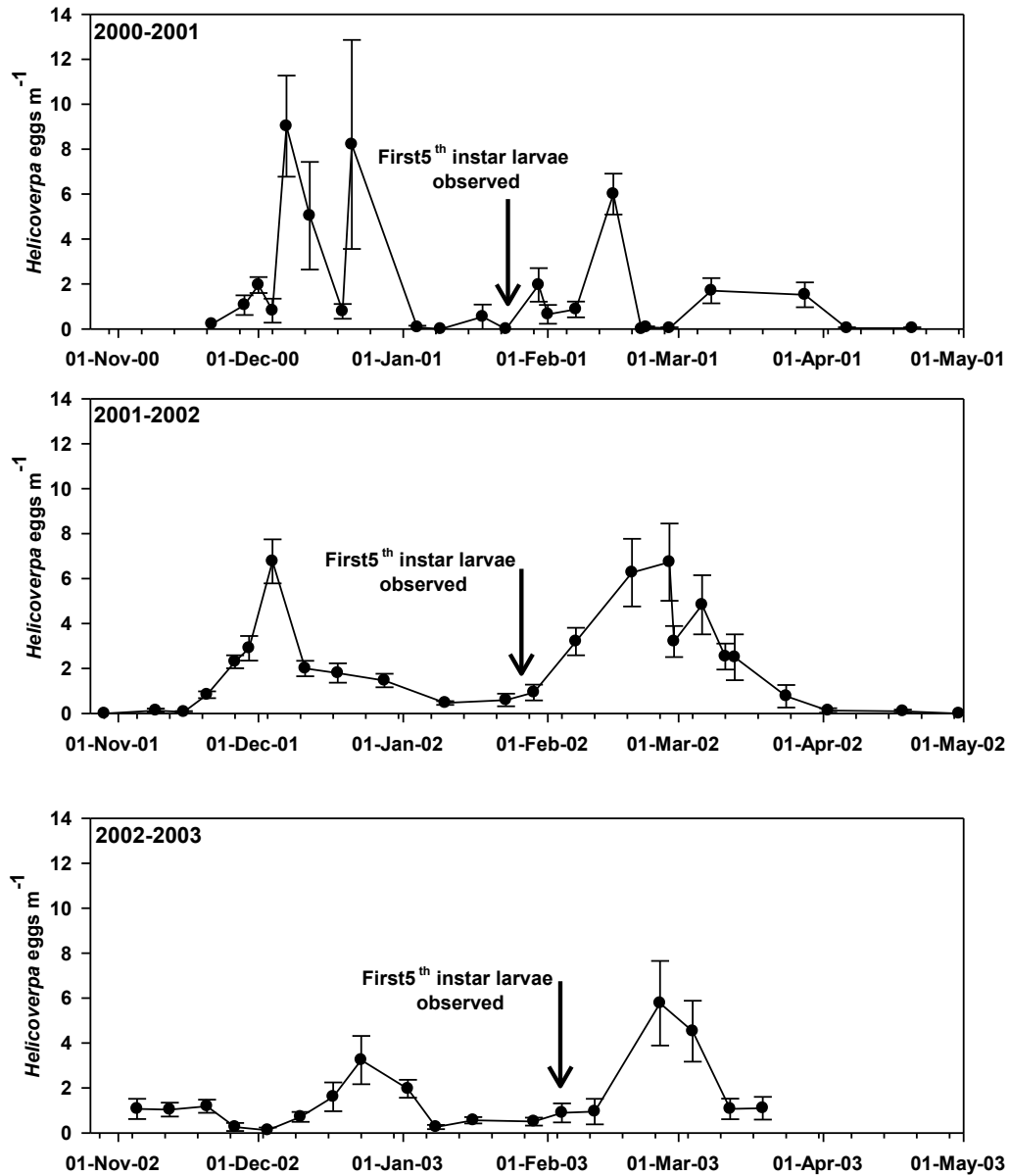


Figure 3: Mean egg counts and time of first 5th instar larvae from cotton (n=12) in the Hillston region during the 2000–2001, 2001–2002 and 2002–2003 growing seasons (Bars =SEM)

Beneficial invertebrates

The mean number of beneficial insects in monitored cotton crops is shown in Fig. 4. The data shows that generally speaking numbers of beneficial insects were low in all three years of sampling. In all years the numbers of beneficial invertebrates trended upwards in the first half of the growing season and then declined rapidly within the first two weeks of January. This rapid decline is thought to be associated with the opening of the synthetic pyrethroid application window, which occurred on January 1 in each season. Results also showed that there was a trend for greater densities of beneficial invertebrates to be present in Ingard® crops during the first half of the season. This is likely due to the reduced insecticide inputs needed to control *Helicoverpa* species that occur in Ingard® crops during the first 100 days of the season. In the 2000–2001 growing season two spikes in the abundance of beneficial insects in February and March were observed (Fig. 4.). Closer examination of the results revealed that these were due to sudden increases in the number of red and blue beetle in crops on 2 of the three properties when samples were taken. The sudden declines in abundance that followed these peaks are likely due to the heavy use of disruptive insecticides during the later part of the season.

A wide range of beneficial invertebrates was collected from cotton crops within the region. Spiders were the most commonly found predator group, with 27–52 % of the total number of predators captured (Fig. 5). The next most common groups of invertebrate predators were insects: ladybird beetles, damsel bugs, red and blue beetles, lacewings. Big-eyed bugs and predatory shield bugs were the least commonly found invertebrate predators in cotton crops grown in the Hillston region (Fig. 5).

Rearing of *Helicoverpa* larvae collected from cotton crops revealed the presence of at least five species of parasitoids, *M. demolitor*, *H. scaposum*, *N. producta*, *Chaetophthalmus* spp. and a *Exorista* spp. (Table 3). The mean rate of parasitism was low with 7–18 % of larvae being parasitised over the period of the study. *M. demolitor* was the most common parasitoid encountered, followed by *Chaetophthalmus* spp., and *H. scaposum*. *Netelia producta* and *Exorista* spp. were encountered the least during the rearing of *Helicoverpa* larvae (Table 3).

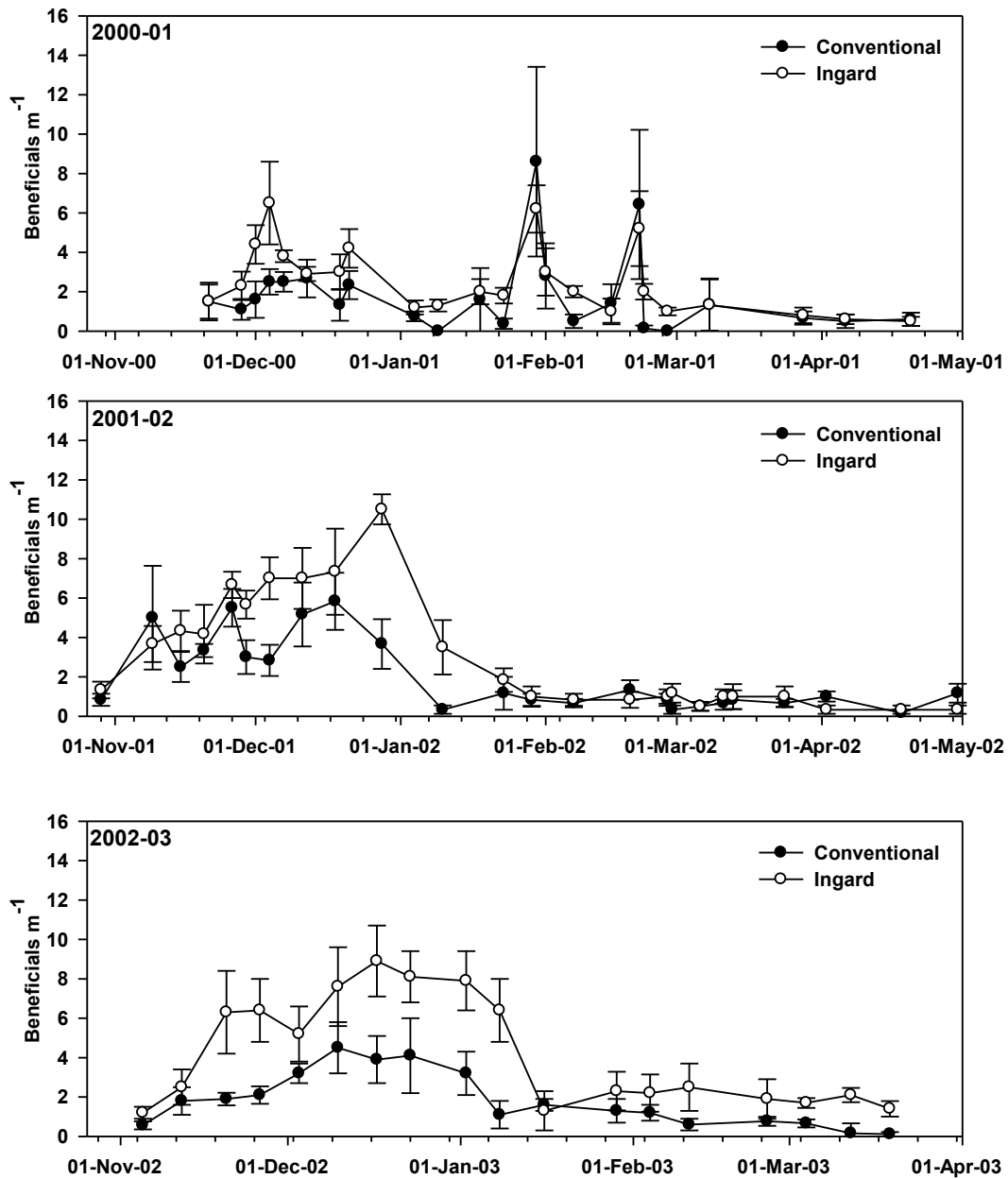
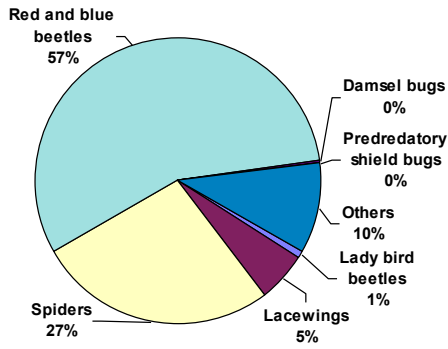
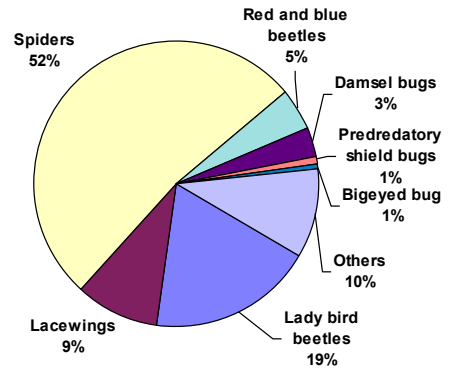


Figure 4: Mean density of beneficial insects in conventional (n=6) and Ingard® (n=6) cotton crops in the Hillston region during the 2000–2001, 2001–2002 and 2002–2003 growing seasons (Bars =SEM).

2000-2001



2001-2002



2002-2003

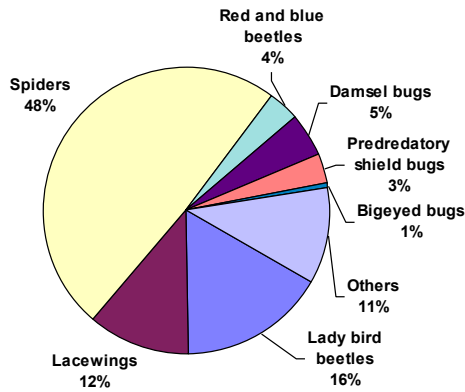


Figure 5: Proportion of predator groups in samples taken from cotton crops over three growing seasons over two growing seasons.

Table 3: Percentage parasitism of *Helicoverpa* larvae collected from cotton crops (n=12) in the Hillston region and parasitoid species responsible.

Year	Total % parasitism	<i>Microplitis demolitor.</i>	<i>Chaetophthalmus spp.</i>	<i>Exorista spp.</i>	<i>Heteropelma scaposum</i>	<i>Netelia producta</i>
2000-01	7.0	4.0	1.0	0.5	0.5	0.5
2001-02	18.0	12.0	4.0	0.0	2.5	0.0
2002-03	8.0	7.0	1.0	0.0	0.5	0.0
Mean	11.0	7.5	2.0	0.16	1.0	0.16

4.1 C Beneficial refuge crops

Beneficial refuges of lucerne grown as stand-alone blocks or as strips within the lucerne crops were monitored for the presence of *Helicoverpa* spp, and other pest and beneficial invertebrates. In all years, sampling showed that that plantings of lucerne in the form of a block beside crops or as strips within the cotton crop contained large numbers of beneficial invertebrates throughout the season. Figure 6 shows data collected from the 2001–2002 growing season. When the lucerne is managed to keep it attractive to mobile prey species such as *Helicoverpa*, aphids and mirids, as occurred in the Merrowie strips and CSIRO block, beneficial invertebrate densities were at their lowest during the winter. Densities then rose through the spring to a peak in mid summer before they declined slowly to previously measured winter lows (Fig. 6). However, if lucerne was not managed to keep it attractive to prey species such as occurred in the Laurie block, the density of beneficial invertebrates fell away rapidly in from early January and to levels similar to those occurring during the winter period (Fig. 6).

Spiders and ladybird beetles were the most commonly found invertebrate predator groups at both types of site making up to 30–40 % of the total number of predators captured (Fig. 7). The spider group contains a wide range of species, all of which have different functions within the agro-ecosystem. Many of the spiders found in the samples belong to families known to occur in cotton crops in large numbers. The next most common groups of invertebrate predators were lacewings, damsel bugs and red and blue beetles. Predatory shield bugs, and other insects such as big eyed bugs, carabid beetles and earwigs were least commonly found (Fig. 7).

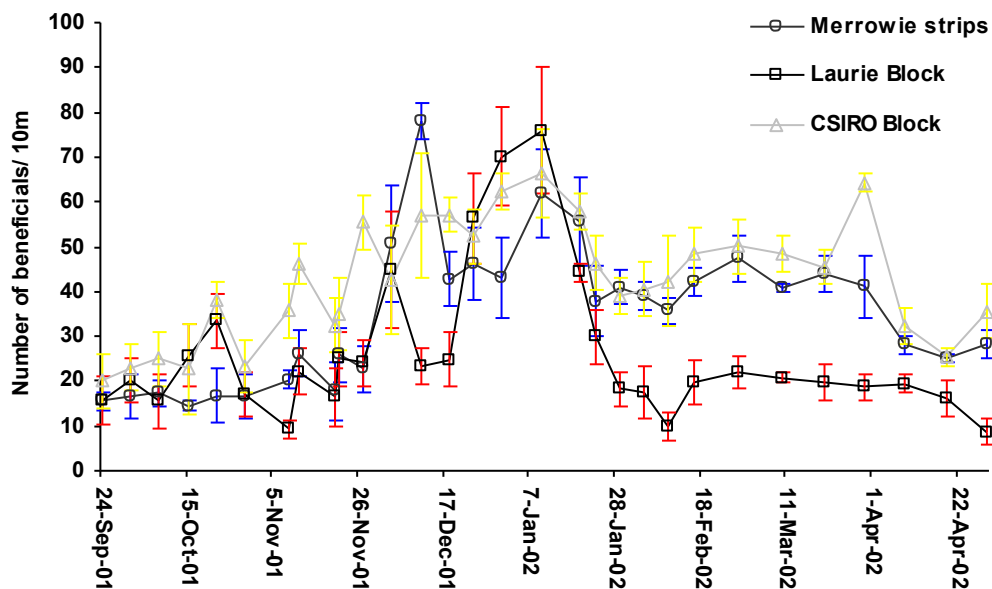


Figure 6: The mean number of beneficial insects in 10 m suction samples taken from beneficial refuges of lucerne in the 2001–2002 growing season (Bars = SEM).

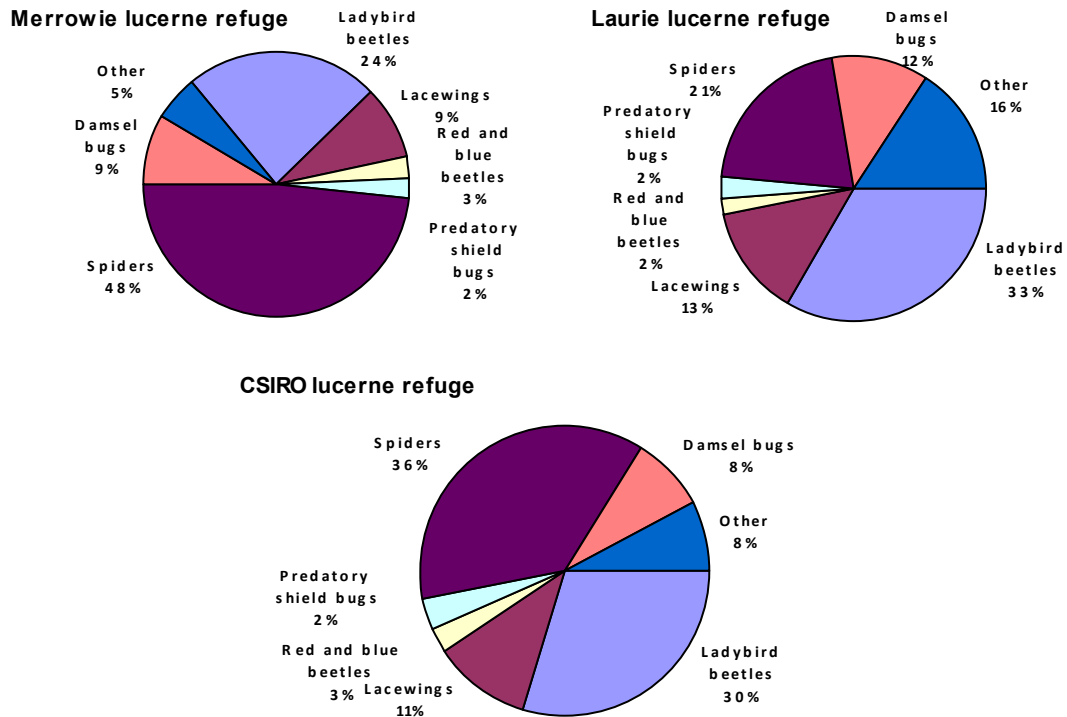


Figure 7: Proportion of predator groups in samples taken from beneficial refuges of lucerne.

4.1 D Bush remnant monitoring

In 2001-02 and 2002-03, data from the suction samples taken from the waste areas and bush remnants showed that the highest numbers of predators were present in spring and winter while numbers were lowest during the middle of the growing season (Fig. 8.). The number of predatory insects in samples taken from the bush remnants during spring and winter was higher than in corresponding samples taken from waste areas dominated by grasses and weeds (Fig. 8.). In the 2002–2003 samples, the numbers of predators in the waste areas sampled remained low throughout the cropping season. This may have been due to the drought causing a lack of prey species or ground cover and so reducing the ability of these areas to support populations of predators.

Spiders were the most commonly found predator group at both types of site - up to 30–40 % of the total number of predators captured (Fig. 9). Again, while the spider group contains a wide range of species, all of which have different functions within the agroecosystem, many of the spiders found in the samples belong to families known to occur in cotton crops in large numbers. The next most common groups of the invertebrate predators were insects: ladybirds, damsel bugs, red and blue beetles, lacewings and predatory shield bugs. Big-eyed bugs and carabid beetles and earwigs were least commonly found.

Closer examination of the results revealed a number of differences in the proportion of different types of predators at each type of site. Lacewings, in particular brown lacewings, big eyed bugs and damsel bugs made up a greater proportion of predators found in samples taken from grass dominated waste areas than those taken from native vegetation remnants. Predatory shield bugs, red and blue beetles, earwigs and carabid beetles were more likely to be found in samples taken from native vegetation (Fig. 9). The observation that different types of vegetation support different species of predators is important. It indicates that, within an agroecosystem, any effort to conserve or manage areas as reservoirs of predators must involve a range of vegetation types to maximise the potential benefit.

These results show that wastelands and remnant vegetation are important sources of predators, particularly at times when there is no other vegetation available. This means there are source populations of beneficial invertebrates available when crops are planted. Research now needs to be done on the movement of predators out of these areas and into developing crops and what means could be used to encourage it.

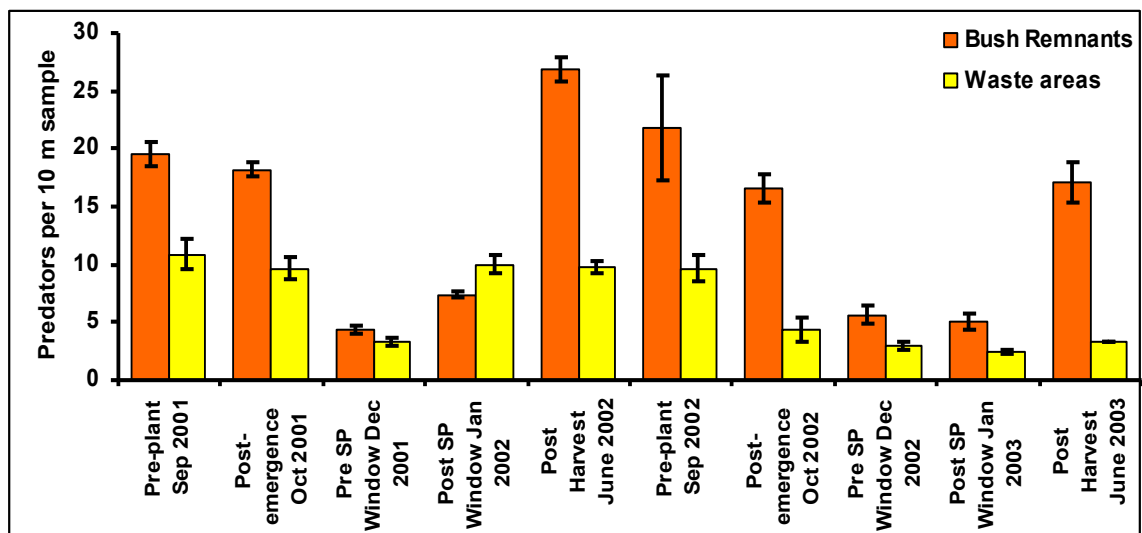


Figure 8: Numbers of predators found in 10 m suction samples taken from bush remnants and grass dominated waste areas over the 2001–02 and 2002–3 growing seasons.

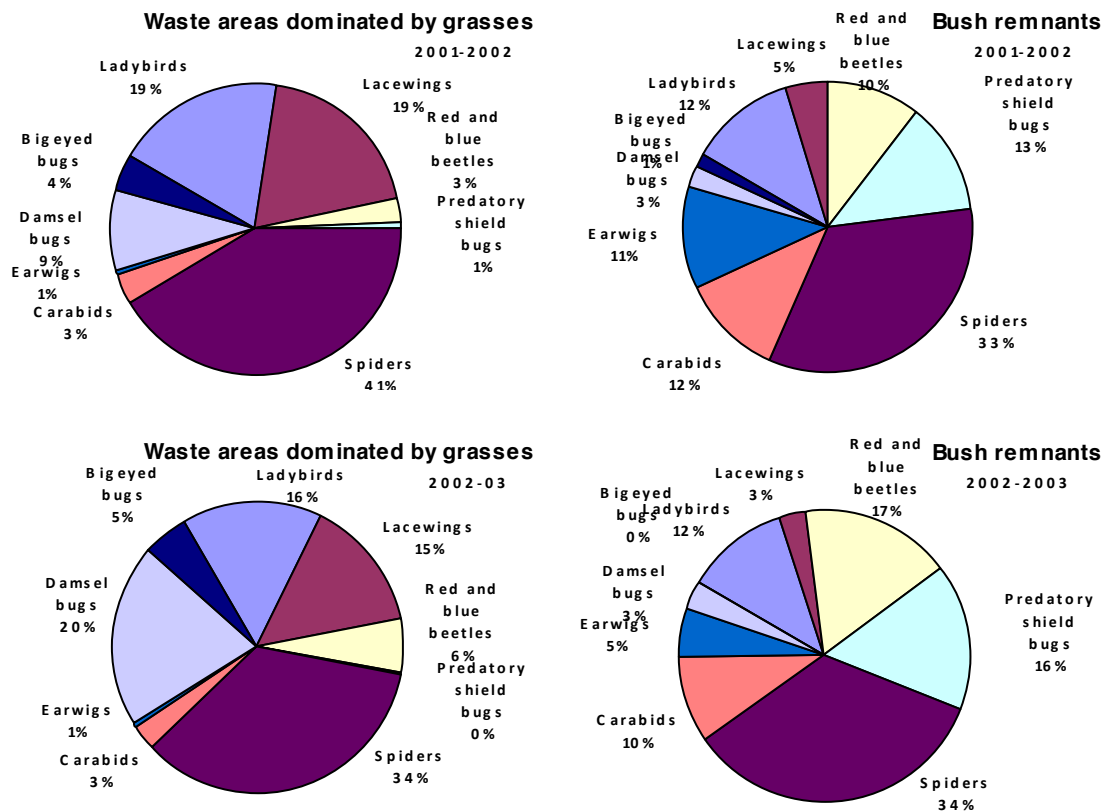


Figure 9: Proportion of predator groups in samples taken from waste areas dominated by grasses and native vegetation remnants over two growing seasons.

4.1E Overview of Chickpea-Cotton-Pigeon pea system using monitoring data and modelling

Figures 10, 11 and 12 show *Helicoverpa* egg populations and periods of peak 5th instar abundance in chickpea trap crops (circles), cotton crops (squares) and pigeon pea trap crops (triangles) overlaying the outputs of the *H. armigera* spring emergence and diapause induction models and the HEAPs model for each of the three growing seasons over the period of the research project.

2000–2001

The results of HEAPS, diapause induction and spring emergence modelling, and, *Helicoverpa* monitoring in chickpea, cotton and pigeon pea for the 2000–2002 growing season are shown in Fig 10. Results from the HEAPs, and spring emergence models predicted that the first *H. armigera* larvae would be present in chickpea trap crops in early October 2000 (Fig. 10). Results from the chickpea monitoring confirmed this prediction (Fig. 1). Given that the 2000–2001 season was relatively warm which in turn resulted in a potentially short generational period during January and February and the confirmation of the presence of early populations of *H. armigera* in chickpea crops it is likely that a portion of the regional *H. armigera* population could complete 4 generations. In this scenario diapausing *H. armigera* pupal populations in this season would likely be made up of a combination of 3rd and 4th generation individuals.

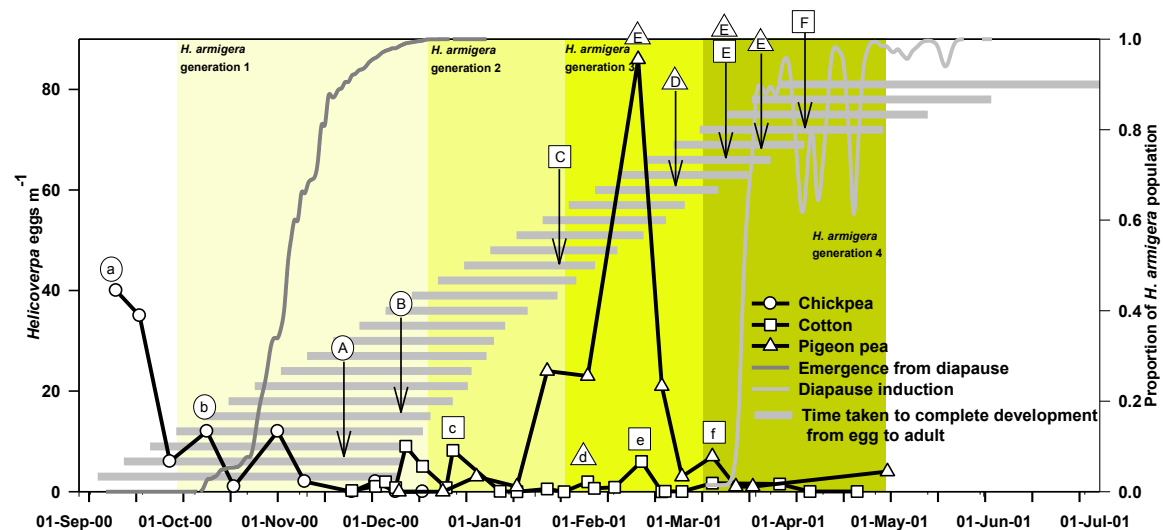


Figure 10: Results from HEAPS, diapause induction and spring emergence modelling, and *Helicoverpa* monitoring in chickpea, cotton and pigeon pea for the 2000–2001 growing season (Lower case letters in symbols represent peaks in oviposition activity in crops while the upper case letters indicate observations of possible associated peaks in 5th instar larval numbers).

2001–2002

The results of HEAPS, diapause induction and spring emergence modelling, and, *Helicoverpa* monitoring in chickpea, cotton and pigeon pea for the 2001–2002 growing season are shown in Fig 11. Results from the HEAPs, and spring emergence

models predicted that the first *H. armigera* larvae would be present in chickpea trap crops in early October 2001 (Fig. 11). However results from the monitoring of chickpea crops indicated that significant regional populations of *H. armigera* larvae were only present from mid-October onwards (Fig. 11). The non-detection of *H. armigera* larvae in crops during early October may have been due to the low numbers present in combination with the effects of a relatively limited sampling regime. Given that the 2001–2002 season was cool and resulted in slightly longer generational periods during January and February and the conformation of the presence of early populations of *H. armigera* in chickpea crops it is unlikely that few if any *H. armigera* within the regional population would have completed 4 generations. In this scenario diapausing *H. armigera* pupal populations in this season would solely be made up of 3rd generation individuals.

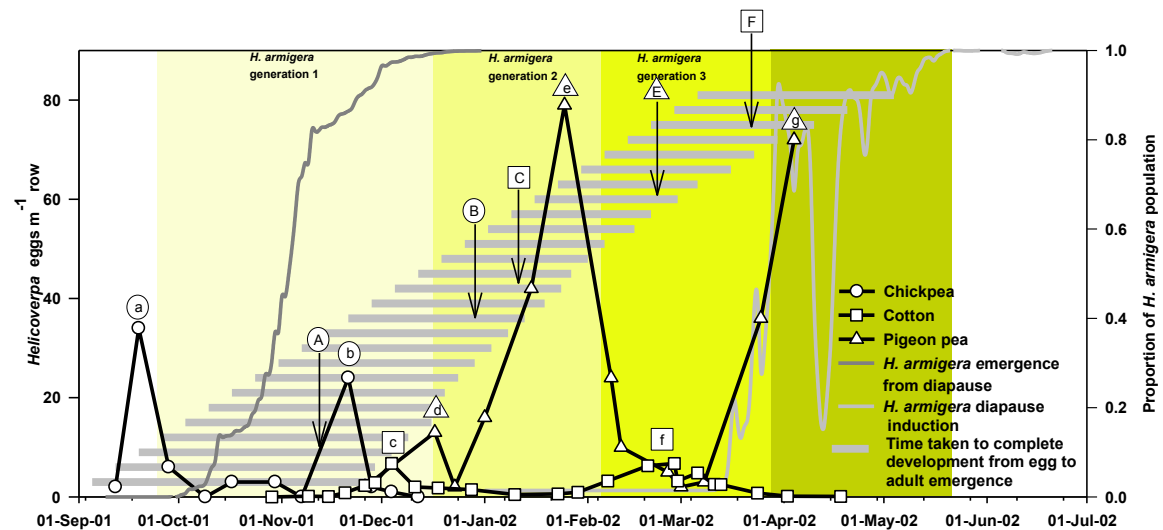


Figure 11: Results from HEAPS, diapause induction and spring emergence modelling, and *Helicoverpa* monitoring in chickpea, cotton and pigeon pea for the 2001–2002 growing season (Lower case letters in symbols represent peaks in oviposition activity in crops while the upper case letters indicate observations of associated peaks in 5th instar larval numbers).

2002–2003

The results of HEAPS, diapause induction and spring emergence modelling, and *Helicoverpa* monitoring in chickpea, cotton and pigeon pea for the 2002–2003 growing season are shown in Fig 12. Results from the HEAPs, and spring emergence models predicted that the first *H. armigera* larvae would be present in chickpea trap crops in early October 2002 (Fig. 12). Results from the monitoring of chickpea crops indicated that significant regional populations of *H. armigera* larvae were present from mid October onwards (Fig. 12). Given that the 2002–2003 season was warmer than average in turn resulted in a potentially short generational period during January and February and the conformation of the presence of early populations of *H. armigera* in chickpea crops it is likely that a portion of the regional *H. armigera* population could complete 4 generations. In this way, the 2002–2003 growing season was similar to the 2000–2001 growing season. It may therefore be probable that the diapausing *H. armigera* pupal populations in this season would likely be made up of a combination of 3rd and 4th generation individuals.

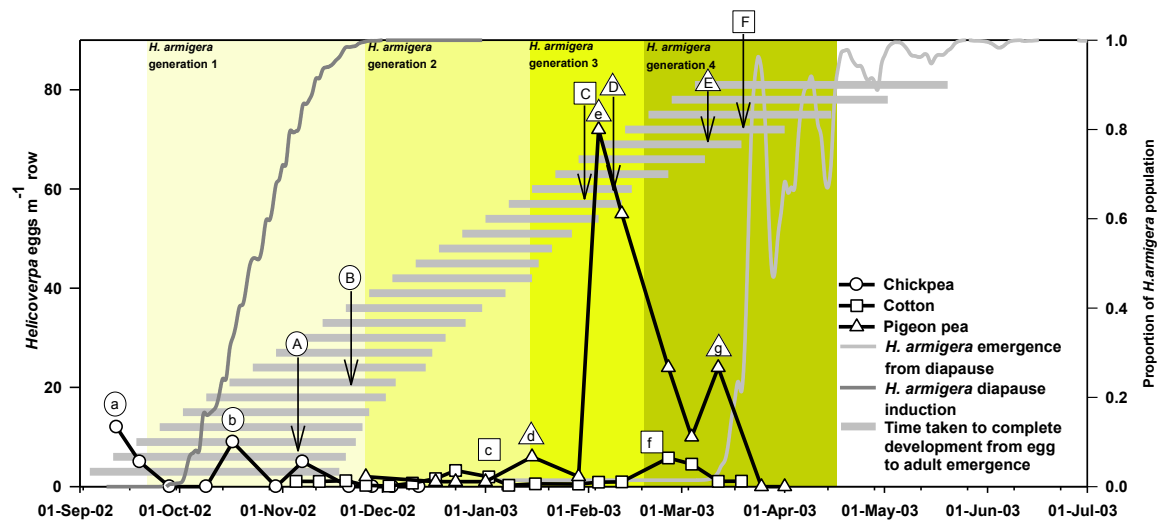


Figure 12: Results from HEAPS, diapause induction and spring emergence modelling, and *Helicoverpa* monitoring in chickpea, cotton and pigeon pea for the 2002–2003 growing season (Lower case letters in symbols represent peaks in oviposition activity in crops while the upper case letters indicate observations of associated peaks in 5th instar larval numbers).

Overview

The results of the modelling indicate that in years with average to above average temperature that a portion of the *H. armigera* and *H. punctigera* population can potentially complete four generations (Figs 10 & 12). However, for this to occur there would have to be a number of criteria satisfied, including, suitable host material being present throughout the growing season, uncontrolled movement from early-mid-late season crops, and a suitable moisture regime and host material that is present through to at least early May to enable the fourth and final generation to complete its development and enter pupal diapause. In well managed cropping systems this scenario is unlikely but still possible. However, if cropping systems are managed poorly and for instance there are escapes from early season trap crops, re-growth is allowed in harvested crop residues, suitable weed hosts are available throughout the growing season, late planted/maturing cotton crops are present and late season trap crops are poorly managed then it becomes more likely that a greater number of *Helicoverpa* will complete four generations within the southern cotton growing region of NSW.

4.2 *Trichogramma pretiosum* releases into maize to reduce the within season build up of *H. armigera* in southern cotton producing regions.

Four releases of *T. pretiosum* into maize crops within the southern NSW cotton production region were undertaken during the 2001–2002 growing season. The

rationale behind these releases is that reducing *H. armigera* egg survival would result in decreased larval and pupal densities. This in turn would result in fewer *H. armigera* adults being produced by the maize crop. Reducing the number of adult *H. armigera* produced by maize crops may help reduce the pressure on late season crops such as cotton and soybean, thereby helping to increase the profitability of the crops by minimise costs of controlling end of season *H. armigera*.

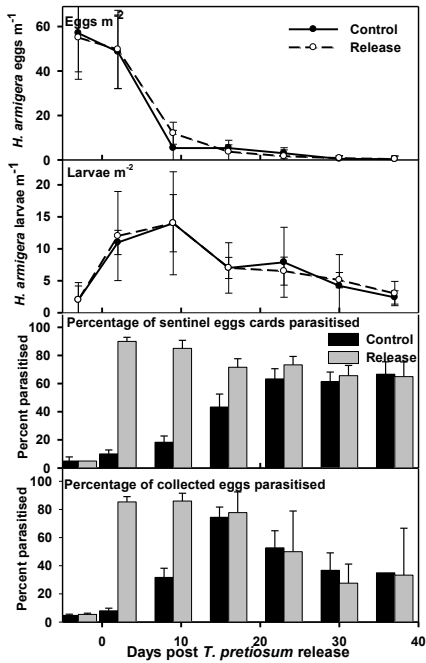
Pre-release monitoring of the maize crops using sentinel egg cards and by rearing of collected *H. armigera* eggs showed that there were low levels of egg parasite activity in three of the four sites monitored (Fig. 13 A, B, D). At the fourth site, up to 20% of sentinel egg cards and 40% of collected eggs were parasitised (Fig. 13 C). Egg parasitoids collected at sites during pre-release monitoring included *Telenomus* spp. and *Trichogramma* spp.

Post *T. pretiosum* release monitoring revealed that three days post release 70–95% of sentinel egg cards in release plots had at least 1 egg parasitised compared with 10–20% of cards in control plots ($P < 0.05$) (Fig. 13 AD). Parasitism of collected *H. armigera* eggs in release plots was 60–80% compared to 10–20 % in control plots at sites 1 and 2 (Fig. 13 A & B). Percentage parasitism of sentinel egg cards in control plots increased with time to such an extent that by 15 days post *T. pretiosum* release the levels of parasitism in control and release sites were not significantly different (Fig 13 A–D). By 20 days post *T. pretiosum* release there was no significant difference ($P > 0.05$) in the level of parasitism of collected eggs in the control and release plots at all sites (Fig. 13 A–D).

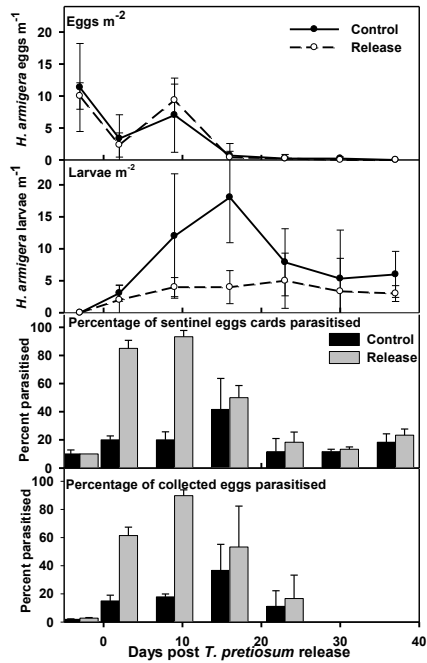
Results of the pupae searches carried out at each site 40 days post *T. pretiosum* release are shown in Fig. 14. The results mirrored the *H. armigera* larval count data in Fig. 13 A–D with significant reductions in pupal densities only occurring at site 2 (Fig. 14), where the density of *H. armigera* pupae in the release plots was $45\,000 \pm 8\,000\text{ ha}^{-1}$ compared with $121\,000 \pm 16\,000\text{ ha}^{-1}$ in the control plots ($P < 0.05$).

The results suggest that although *T. pretiosum* had the ability to parasitise a high proportion of *H. armigera* eggs laid on silking maize they do not appear to be able to reliably reduce the larval densities and hence the over all resulting pupal population under the crop. Therefore at this stage it cannot be recommended that *T. pretiosum*, be released into maize crops to help reduce the seasonal build-up of *H. armigera*.

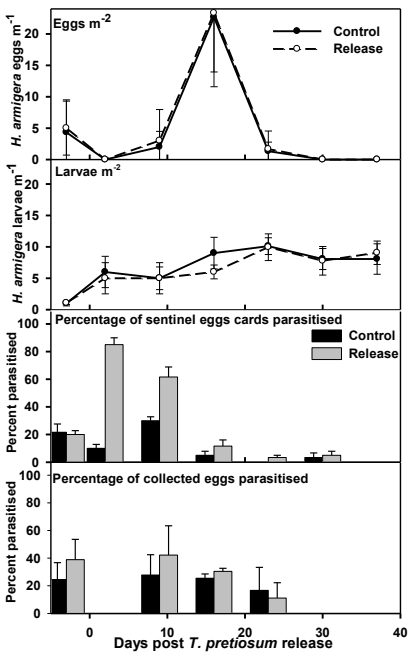
A



B



C



I

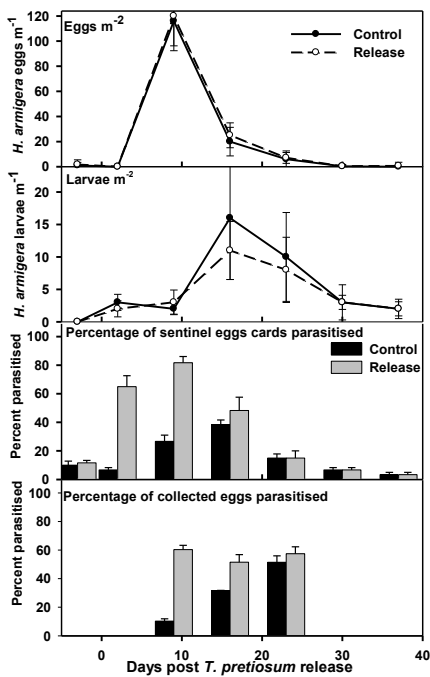


Figure 13: The number of *H. armigera* eggs and larvae and the percentage of egg cards and collected eggs parasitised on each sampling date during four trials carried out in the 2001-2002 growing season (Error Bars in plots of egg and larval densities represent 95% confidence interval, error bars in plots of % egg parasitism represent SEM).

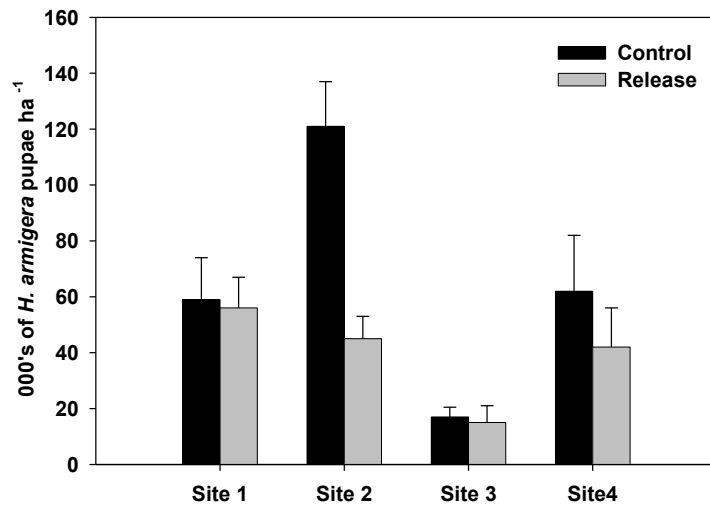


Figure 14: Density of *H. armigera* pupae under maize crops at four sites in southern NSW where *T. pretiosum* was released. (Bars=SEM)

4.3 Pheromone trapping

A network of 14 pheromone trap pairs was set up within the cotton growing area in the Hillston region. The results of this monitoring are shown in Fig. 15. The general pattern for pheromone trap catches of *H. armigera* and *H. punctigera* are similar in the Hillston region if not the same as those reported in the GRDC project CSE 111 undertaken in the CIA/MIA. In each year of monitoring, peak *H. punctigera* flight activity was observed in mid-September–mid-November period (Fig. 15). Activity then tailed off through the growing season so that by mid February *H. punctigera* catches were negligible (Fig. 15). *H. armigera* activity follows the opposite trend with the first moths being caught in traps in low numbers in late September–early October with increasing catches as the season progresses (Fig. 15). *H. armigera* trap catches reach a maximum in the March–April period of each year before declining to nothing by May (Fig. 15). *H. punctigera* catches during the September period of the 2003–2004 growing season have revealed high levels of moth activity with captures being as high as 1000 moths trap⁻¹ week⁻¹ over a wide area in the southern NSW cotton growing region.

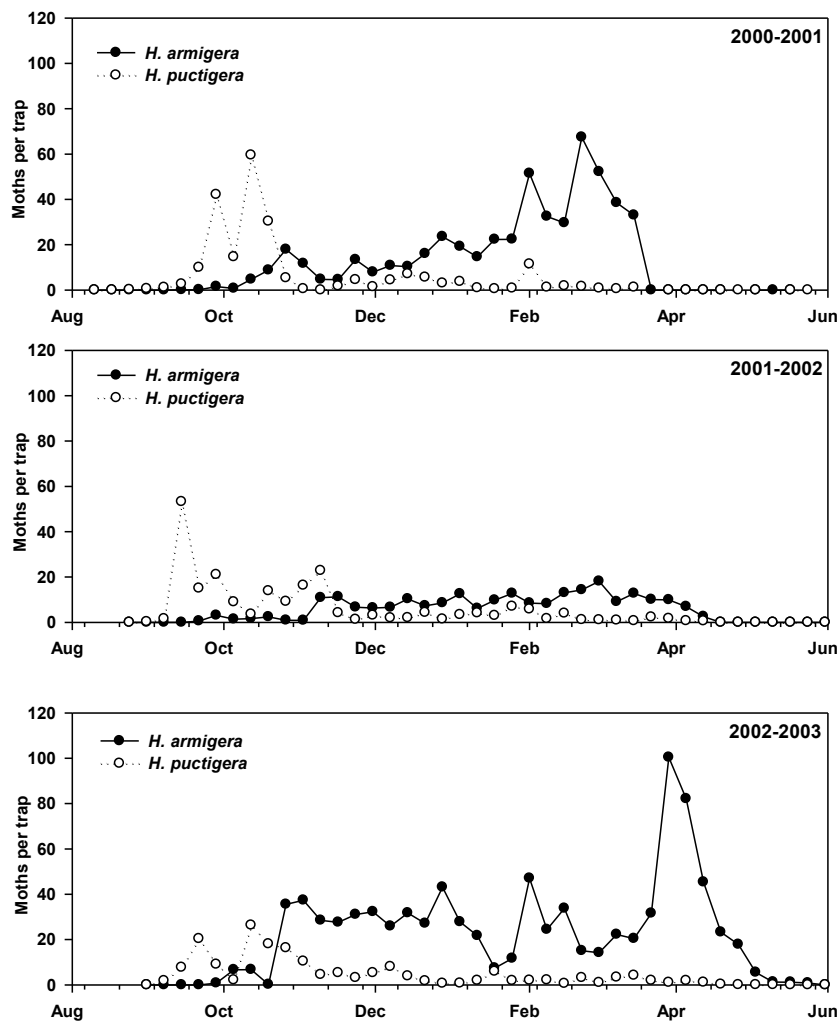


Figure 15: Mean weekly *H. armigera* and *H. punctigera* pheromone trap catches (n=14) in the Hillston region of southern NSW in during the 2000–2001, 2001–2002 and 2002–2003 growing seasons.

4.4 Surveys of diapausing *H. armigera*

Pupal surveys were carried out in all three years of the research project carried out in cotton growing regions of southern NSW (Table 4). In each of the three years of the study, results indicated that the main producer of diapausing pupae within the cotton growing region of southern NSW was cotton (Table 4). Sampling estimated that the cotton crops within the region could potentially be contributing 77–95 % of the total diapausing pupae within the Hillston region of southern NSW (Table 4). Although the highest pupal densities were measured under late maize crops in 2001 and 2003 they only contributed 3–22 % of the diapausing pupae within the region (Table 4). Early planted maize crops contributed very few diapausing pupae to the overall population in 2001 and 2003. However cool climatic conditions in the 2001–2002 growing season meant that early season crops contributed as many diapausing *H. armigera* pupae to the regional population as late maize crops (Table 4)

4.5 Insecticide Resistance monitoring

During the three-year period of the project, 60 egg collections were sent to NSW Ag for insecticide resistance monitoring. Insecticide resistance testing data from these collections that have been generated by NSW Agric. have been used to generate yearly updates of the southern Cotton IRM strategy. Although this process has been relatively successful there have however, been a number of problems associated with egg collections that have affected the usefulness of samples sent from the southern region (see further comment below).

To ensure that IRM strategies used by the cotton and grain industries comply with each other the Southern Insecticide Resistance Management Group has met annually to update the Grains IRM strategy for southern NSW and Northern Victoria (see below).

The development rates of *Helicoverpa* were modelled using the HEAPS model and temperature data from the Hillston region (Table 5). Results from modelling using the long term mean data suggest that the time taken for *Helicoverpa* to complete egg to moth development is less than 42 days for the period of early December–early February (Table 5). When data for warmer growing seasons such as the 2000–2001 and 2002–2003 seasons are used to predict development time, the results of the modelling suggests that the period of time taken for *Helicoverpa* to complete egg to moth development in less than 42 days begins in mid November and carries on through to late January–early February. In these warm years, it is possible that the time taken for *Helicoverpa* to complete egg to moth development may be as low as 30 days (Table 5). However, in growing seasons that are cooler than average such as occurred in 2001–2002 modelling predicts that 42 days is the shortest development time to occur (Table 5).

The HEAPS results suggest that the current 42 day length of the IRMs stage window may have to be revisited as, if the data is an accurate reflection of what is occurring in the field and early analysis of observational data suggests that it may be, then it is likely that there may be an increased risk of an increased rate of insecticide resistance amongst *H. armigera* in southern cotton growing region.