

June 98



**CSIRO Entomology  
Cotton Research Unit  
and  
CRC for Sustainable Cotton Production**

**FINAL REPORT**

**Project title:** The dynamics of beneficial insect communities in cotton agroecosystems and the role of alternative crops in producing natural enemies for cotton

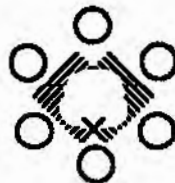
**Project code:** CSE51C

**Research organisation:** CSIRO Entomology

**Principal researcher:** Dr Paul Walker - 100%  
CSIRO Entomology  
PO Box 59  
Narrabri 2390

**Supervisors:** Dr Gary Fitt  
CSIRO Entomology  
PO Box 59  
Narrabri 2390 (Phone 0267 991514)

Dr Robert Mensah  
NSW Agriculture  
PO Box 59  
Narrabri 2390 (Phone 0267 991525)



*A final report prepared for the Cotton Research and Development Corporation*

The information, advice and/or procedures contained in this publication are provided for the sole purpose of disseminating information relating to scientific and technical matters in accordance with the functions of CSIRO under the Science and Industry Act 1949. To the extent permitted by law CSIRO shall not be held liable in relation to any loss or damage incurred by the use/or reliance upon any information advice and/or procedures contained in this publication.

**Project CSE51C: The dynamics of beneficial insect communities in cotton agroecosystems and the role of alternative crops in producing natural enemies for cotton**

**SUMMARY**

***Seasonal phenology and abundance of cotton beneficials in crop and non-crop habitats in the Namoi Valley agroecosystem***

The seasonal phenology and abundance of cotton beneficials was determined in over 20 crop and non-crop habitats in the Namoi Valley agroecosystem between 1995 and 1998. Irrigated lucerne crops supported the most diverse and abundant cotton beneficial community. The presence of lucerne throughout the year, abundant prey, constant irrigation and long flowering period provided beneficials with a stable habitat in which they could feed and reproduce. Other crops, particularly grain sorghum, often supported high numbers of cotton beneficials but only for a short period of time compared to lucerne. Grain legume crops were poor sources of cotton beneficials but good trap crops for *Helicoverpa* spp.

Of the non-crop habitats sampled, burr medic (*Medicago* spp.) was found to support the largest populations of cotton beneficials, particularly brown lacewings and hoverflies. However, the ability of all non-crop habitats to support cotton beneficials was severely limited by rainfall which was highly variable in the study area.

***Nursery crops for producing beneficial insects of cotton***

Small plot trials, conducted during the first two years of study, confirmed the value of lucerne as a nursery crop for cotton beneficials. After lucerne, grain sorghum consistently had the highest populations of beneficials, while grain legume crops had the lowest. In the final year of study, the value of Ingard refuge crops as sources of cotton beneficials was compared. Grain sorghum supported a more diverse and abundant community of beneficials than cotton, pigeon pea, corn or lab lab.

***Parasitism of *Helicoverpa* larvae and pupae***

Analysis of a large database, containing records of *Helicoverpa* larvae and pupae collected from a variety of crop and non-crop habitats over a nine year period, showed that larval parasitism was highest in native Asteraceae and lowest in chickpeas. Pupal parasitism was highest in grain sorghum and lowest in maize. The majority of larvae collected from lucerne failed to pupate and it is suspected that this crop may act as an important reservoir of *Helicoverpa* disease, particularly NPV virus.

***Parasitism of *Helicoverpa* eggs in the Namoi Valley***

Over 138,000 *Helicoverpa* eggs were placed in various crop and non-crop habitats in the Namoi Valley to compare rates of parasitism. Less than 2.0% of eggs were parasitised and levels were too low to compare habitats. Reasons for the low level of egg parasitism in the Namoi Valley are discussed and are worthy of further investigation.

***Recommendations for Best Management Practices***

1. Cotton farms should maintain permanent areas of irrigated lucerne, away from sprayed fields, to provide a stable habitat for cotton beneficials.
2. Where feasible, areas of burr medic and Asteraceae should be preserved and set aside from grazing to promote the establishment of beneficials during the spring.
3. Sorghum should be utilised as an Ingard refuge crop in order to increase cotton predator and parasitoid numbers as well as provide sufficient moths to act as an effective refuge.

**Project CSE51C      The dynamics of beneficial insect communities in cotton agroecosystems and the role of alternative crops in producing natural enemies for cotton**

### **Objectives**

- To quantify the seasonal phenology and abundance of key beneficials of cotton pests in other parts of the agroecosystem, including uncultivated habitats.
- To evaluate the potential of a range of nursery crops for beneficials, some of which may also be effective trap crops for *Helicoverpa*, and explore methods of integrating them into cotton production systems.

### **Research project summary**

Beneficial insects are not widely utilised in cotton pest management because their efficacy is poorly understood and their abundance is highly variable. IPM systems are now being developed for cotton that place greater emphasis on the role of beneficials in the management of key pests. These systems aim to conserve beneficials by using selective insecticides or supplementary foods, or may be augmented by mass releases. Within the cotton agroecosystem there is also scope to use other crops as nurseries and/or refuges for beneficials, and/or as trap crops for *Helicoverpa* and other pests. There is also considerable interest in raingrown production and the emerging organic systems for the use of other crops sown in strips through cotton fields/ This approach could also have application in irrigated systems. However, the advantages and disadvantages of various crops have not been investigated under Australian conditions. In addition, the dynamics of major beneficials outside the cotton-growing season is poorly understood. To complement work now underway to encourage beneficials and quantify their effects in cotton we need to better understand the origin and dynamics of the beneficial populations available to colonise cotton crops or the nursery crop we propose to study.

The two parts of this project will improve understanding of the abundance and phenology of beneficials in cotton cropping systems and experimentally evaluate the potential of a range of crops as nurseries for beneficials from where they be utilised in cotton IPM, and/or as trap crops for pest species.

### **Industry significance**

A major focus of the cotton industry is to reduce dependence on insecticides. This can be achieved by developing IPM programs which place greater reliance on natural enemies. The research proposed here will provide data on the patterns of abundance of beneficial species within the agroecosystem and indicate the most suitable crops to incorporate with cotton for the maintenance of these populations leading to more sustainable cotton production systems.

### **Methodology**

#### ***Seasonal phenology and abundance of beneficials in the Namoi Valley cotton agroecosystems***

Beneficials were sampled in crop and non-crop habitats in the Namoi Valley using suction samplers (modified Homelite HB180V Blower Vac) exclusively throughout the project. Four fixed study sites were chosen to represent contrasting cropping areas. Site 1, located around the Australian Cotton Research Institute at Myall Vale, was a typical intensively farmed cotton growing area interspersed by grazing land. A variety of summer crops was grown in this area including sorghum and various grain legumes. Site 2 was located near Wee Waa and was centred on a group of farms where crops atypical to the region were

grown with minimal insecticide usage. This area was surrounded by cotton farms and bisected by a small tract of native forest. The principal summer crops grown included peanuts, maize, mung beans and forage sorghum. Site 3 was located in the Maules Creek/Harparary area and was initially chosen for a large area of lucerne grown on adjacent farms. However, in the final year of study the area of lucerne grown significantly decreased as one operator changed to cotton production. Other summer crops present in this area included sorghum and various grain legumes. Site 4 was located in the Bellata - Edgeroi region and represented a typical dryland farming area interspersed with large areas of grazing land. Crop diversity was the lowest at this site with sunflowers and sorghum being the principal summer crops. In all four study areas wheat was the main winter crop while faba beans were also present at Sites 1 and 2. Other crops present in the study areas during winter included oats, field peas, potatoes, chickpeas and lucerne.

In all four study areas, the uncultivated areas of vegetation were highly disturbed through grazing or other agricultural practices. Often introduced weeds dominated and these represent the bulk of the d-vac samples from uncultivated areas. Unlike irrigated crops, the growth and seasonal phenology of non-crop vegetation was highly variable according to rainfall and was often in too poor a condition to sample. Dominant species along roadsides and field margins included Paterson's curse (*Echium plantagineum*), wild parsnip (*Trachymere glaucifolia*) and turnip weed (*Rapistrum rugosum*). In grazing areas burr medic (*Medicago* spp.), often in association with turnip weed, predominated during winter and spring months while yellow vine (*Tribulus terrestris*) was common during summer months in some areas. Various other species of native and introduced plants were sampled opportunistically when present in the study area.

Sampling was conducted by taking three (1995/96 season) or five (1996/97 and 1997/98 seasons) 10m long d-vac samples. The vegetation was sampled at approximately fortnightly intervals from the seedling stage until senescence or harvest or, as in the case of many weeds, during the time of peak flowering and fruiting. Key taxa of cotton beneficials (Table 1) were identified and counted. All spiders caught were grouped together but in the 1997/98 season they were separated into major families (Table 1). During the final two seasons, numbers of potential prey (thrips, aphids, leafhoppers, mites and whitefly) were also counted in all samples.

Predator abundance in each habitat was compared by giving each taxa a score of 0 (not present), 1 ( $\leq 0.09$  predators/m), 2 (0.1 - 0.99 predators/m), 3 (1.0-1.99 predators/m), 4 (2.0 - 2.99 predators/m) or 5 ( $> 3.0$  predators/m). Scores for all taxa were totalled to give a predator abundance rating for each habitat sampled.

The Shannon-Weaver diversity index ( $H'$ ) was calculated for each habitat using the formula:

$$H' = -\sum p_i * \ln p_i$$

where  $p_i$  is the proportion of the  $i$ th species in the total sample. This diversity index combines information on the abundance and diversity of predators found in each habitat. Habitats which have a low diversity or are dominated by a few predatory species will have values of  $H'$  approaching 0. Habitats with a large number of predatory species, present in equal abundance, will have higher values of  $H'$ . As the total number of predator taxa considered in this study was 18, the maximum value of  $H'$  would be 2.890 if all species were present in the habitat in equal proportion.

#### ***Nursery crops for producing beneficial insects of cotton***

Small plot trials to evaluate potential nursery crops for producing beneficials of cotton were conducted near Narrabri and Dalby during the first two years of the project. In the final year of study, it was decided to make use of two large-scale Ingard refuge trial sites where various crops were being compared as an option for the Bt cotton resistance management strategy. These trial sites were used as it may be feasible to select an Ingard refuge crop

which is not only good for producing large numbers of *H. armigera* but is also good for producing predators and parasitoids of cotton pests (see Discussion). The crops compared in each trial are listed in the Results section. Sampling for cotton beneficials was conducted using d-vacs as described above. *Helicoverpa* larvae and pupae were collected from each crop type at irregular intervals to assess rates of parasitism.

Two-way analysis of variance was performed to compare the abundance and diversity of predators caught in each crop. All data was transformed to  $\ln n + 1$  before analysis. The Shannon-Weaver diversity index was calculated for each crop type as described above. In trials where the number of potential prey was counted, correlation coefficients were calculated to determine any predator-prey relationships.

Table 1. Key predatory taxa counted in d-vac samples.

Order	Family	Species	Common name	
Hemiptera	Nabidae	<i>Nabis capsiformis</i>	Damsel bug	
	Lygaeidae	<i>Geocoris lubra</i>	Big-eyed bug	
	Anthocoridae	<i>Orius</i> spp.	Pirate bug	
	Pentatomidae		<i>Oechelia schellenbergii</i>	Predatory shield bug
			<i>Cermatulus nasalis</i>	Glossy shield bug
	Miridae	<i>Deraecoris signatus</i>	Brown smudge bug	
Coleoptera	Melyridae	<i>Dicranolaius bellulus</i>	Red and blue beetle	
	Coccinellidae		<i>Coccinella transversalis</i>	Transverse ladybird
			<i>Harmonia octomaculata</i>	Three-banded ladybird
			<i>Micraspis frenata</i>	Striped ladybird
			<i>Diomus notescens</i>	Two-spotted ladybird
			<i>Stethorus</i> spp.	Mite eating ladybird
	Anthicidae	<i>Anthicus</i> spp.	Anthicus beetle	
Neuroptera	Chrysopidae	<i>Mallada</i> spp.	Green lacewing	
	Hemerobidae	<i>Micromus tasmaniae</i>	Brown lacewing	
Diptera	Syrphidae	Various spp.	Hover flies	
Araneidae	Thomisidae	Various spp.	Crab spiders	
	Theridiidae	Various spp.	Tangle web spiders	
	Salticidae	Various spp.	Jumping spiders	
	Oxyopidae	Various spp.	Lynx spiders	

#### ***Analysis of Helicoverpa larval and pupal parasitism records***

The suction sampler used in this study was ideal for sampling predators and potential prey as most species were relatively sedentary and could be caught before they had chance to avoid the sampling device. However, d-vacs are not good for sampling highly mobile insects such as the parasitoids of *Helicoverpa* larvae and pupae. Consequently, in order to obtain information on the seasonal phenology and abundance of *Helicoverpa* parasitoids in the cotton agroecosystem, use was made of a large database containing parasitism records for larvae and pupae collected over a nine year period by Dr Gary Fitt. Parasitism records were sorted according to the host plant *Helicoverpa* larvae and pupae were collected from.

## *Parasitism of Helicoverpa eggs in the Namoi Valley agroecosystem*

*Helicoverpa* eggs, laid on paper towelling and stapled onto card ('egg cards'), were placed in various crop and non-crop habitats to detect the presence of egg parasitoids. Egg cards were also placed in the nursery crop trials conducted near Narrabri at irregular intervals depending on the availability of eggs at the time. Cards were stapled onto the leaves of plants near the top of the canopy. After two days, the cards were retrieved from the field and the number of eggs remaining was counted. Eggs were incubated at 25° C until the emergence of a larva or parasitoid.

## **Results**

### *Seasonal phenology and abundance of beneficials in the Namoi Valley cotton agroecosystems*

Over 20 crop and non-crop habitats were sampled in the Namoi Valley, between December 1995 and April 1997, on 775 sampling occasions. Fig.1 shows the seasonal phenology of the key cotton predators considered (Table 1) for all habitats sampled and across all years of study. Predator abundance and diversity peaked in the autumn with a smaller secondary peak in late spring. Predatory bugs, predatory beetles and spiders were most abundant in April and May while lacewings and hoverflies peaked in October. Peaks in the abundance of predators coincided with peaks in numbers of potential prey (Fig. 2). Significant correlations ( $p < 0.05$ ) were found between the number of many predators and potential prey with the highest values of  $r$  for associations between spiders and leafhoppers (Table 2). However, these correlations do not take into account the time lag in the response of predator populations to available prey. Often predator populations build-up slowly over time due to the delay in colonisation of habitats and prolonged life-cycles. This may be why the correlation between numbers of predators and aphids was relatively poor and often not significant (Table 2).

Seasonal changes in the taxonomic composition of major predator groups for all habitats sampled are shown in Fig. 3. Overall, spiders dominated representing on average *ca* 50% of all predators caught. The lacewing/hoverfly predator group increased in numbers during September and October being principally composed of brown lacewings (Fig. 3). Green lacewings and hoverflies (Syrphidae) were comparatively rare in all habitats sampled. Brown lacewing and hoverfly numbers peaked during the time when aphids were most abundant in the spring (Fig. 2). Predatory beetles were dominated by Coccinellids with the species composition changing markedly throughout the year (Fig. 3). High numbers of predatory beetles were caught in April (Fig. 1) and were dominated by mite-eating ladybirds (*Stethorus* spp.) (Fig. 3) which peaked following a marked increase in two-spotted mite populations on many summer crops (Fig. 2). Other common species of predatory beetles included red and blue beetles, transverse ladybird, three banded ladybird and two-spotted ladybird. Few striped ladybirds, staphylinids or carabids were caught in the d-vac samples. Predatory hugs were dominated by pirate bugs during summer and early autumn while brown-smudge bugs increased during late autumn and early winter (Fig. 3). Damselfly bugs dominated during late winter and early spring at a time when very few predatory bugs were caught (Fig. 1). All other species of predatory bugs were rarely encountered in the habitats sampled.

Lucerne had the highest predator abundance rating and greatest diversity closely followed by grain sorghum, corn and sunflowers (Fig. 4). In general, all grain legumes had low predator abundance ratings and very low predator diversity with chickpeas being the worst crop. Predator abundance ratings for the non-crop habitats sampled were generally lower than many of the crop habitats (Fig. 5). A riparian site, consisting of a mix of annual forbs and grasses, had the highest score followed by burr medic.

The seasonal phenology of predators in each major crop and non-crop habitat sampled is shown in Fig 6. These graphs give an indication of the length of time each habitat was available in the agroecosystem. Lucerne was the only crop sampled which was present all year round. The abundance and diversity of predators found in lucerne was high throughout much of season (Fig. 6), peaking in April and November at a time when aphid numbers were also high (Fig. 2). Predator abundance and diversity was also high in grain sorghum and maize but only for a short period of time compared to lucerne. In grain sorghum, very high numbers of pirate bugs (*Orius* spp.) were found during flowering and grain maturation. Pirate bugs were also common in maize and forage sorghum. In some maize crops a large increase in predator numbers occurred during March and April due to the influx of *Stethorus* spp. and brown smudge bugs. High numbers of brown smudge bugs were also found in potato crops planted in the autumn. Peanuts and lab lab generally supported low numbers of cotton predators until April when large infestations of mites attracted *Stethorus* spp. and other mite feeding predators. Safflowers, and to a lesser extent sunflowers, supported high numbers of predators in the spring but only for a short period of time as these plants quickly senesced after flowering. Predator abundance and diversity in all winter crops sampled (wheat, faba beans and field peas) was low compared to lucerne, gradually increasing in the spring at the very end of the crops growing period.

Table 2. Correlation coefficients for mean number/sample ( $\log n + 1$ ) of predators vs potential prey for all d-vac samples from crop and non-crop habitats. N = number of sampling occasions. Bold numbers indicate a significant correlation at  $p < 0.05$ .

Taxa	Thrips (N = 549)	Aphids (N = 549)	Leafhoppers (N = 548)	Mites (N = 469)	Whitefly (N = 536)
Thrips					
Aphids	0.0434				
Leafhoppers	<b>0.4010</b>	-0.0390			
Mites	0.0082	0.1721	0.0208		
Whitefly	<b>0.2061</b>	-0.1836	<b>0.3499</b>	-0.0087	
Predatory shield bug	<b>0.2382</b>	0.0765	<b>0.2929</b>	0.1799	0.0155
Big eyed bug	0.1210	0.0229	<b>0.2165</b>	0.1577	0.1617
Germalus (Green BEB)	0.0633	-0.0444	0.0236	0.0011	0.0733
Orius (Pirate bug)	<b>0.2859</b>	<b>0.2444</b>	0.1484	0.1639	-0.0824
Glossy shield bug	0.0865	0.0303	0.1450	0.0988	-0.0534
Brown smudge bug	0.0283	0.0393	<b>0.3249</b>	<b>0.2184</b>	<b>0.2305</b>
Nabis	<b>0.2924</b>	0.1523	<b>0.4610</b>	0.0405	0.0492
Red & blue beetle	0.1388	-0.0199	<b>0.2774</b>	0.1114	0.1008
Transverse ladybird	<b>0.3756</b>	-0.0402	<b>0.3228</b>	-0.1330	<b>0.2798</b>
3 banded ladybird	-0.0036	<b>0.2113</b>	0.0417	0.1119	0.0592
Striped ladybird	0.1488	0.0273	0.1067	-0.0491	0.1360
2 spotted ladybird	<b>0.3868</b>	-0.1041	<b>0.3168</b>	-0.1714	<b>0.3881</b>
Anthicus sp.	0.1197	0.1672	<b>0.2218</b>	0.0337	0.0135
Staphylinid	0.1415	0.1037	0.1602	0.0295	-0.0022
Stethorus	0.0695	0.0684	<b>0.2197</b>	<b>0.4953</b>	0.0411
Green lacewing	<b>0.2376</b>	0.0293	0.1410	-0.0509	<b>0.2015</b>
Brown lacewing	<b>0.3601</b>	<b>0.3336</b>	<b>0.2710</b>	0.0038	-0.0851
Hover fly	<b>0.2234</b>	<b>0.2286</b>	0.0639	0.0510	-0.0298
All predatory bugs	<b>0.3234</b>	<b>0.2163</b>	<b>0.4092</b>	<b>0.2109</b>	0.0552
All predatory beetles	<b>0.3600</b>	0.1134	<b>0.4058</b>	0.1248	<b>0.2868</b>
All lacewings & hoverflies	<b>0.4032</b>	<b>0.3420</b>	<b>0.2833</b>	-0.0118	-0.0406
All spiders	<b>0.3935</b>	-0.0970	<b>0.5945</b>	0.1137	0.1735
All predators	<b>0.4935</b>	0.1257	<b>0.6193</b>	0.1555	0.1748
All predators (except spiders)	<b>0.4679</b>	<b>0.2717</b>	<b>0.4972</b>	0.1383	0.1597
No. of predatory taxa	<b>0.4342</b>	<b>0.2139</b>	<b>0.4729</b>	0.0542	<b>0.2168</b>
Shannon-Weaver index	<b>0.3206</b>	0.1419	<b>0.3779</b>	-0.0441	<b>0.2128</b>

Changes in the diversity of the predator community over time, as measured by the Shannon-Weaver diversity index ( $H'$ ), reflected changes in predator abundance (Fig. 7). Lucerne had relatively high levels of predator diversity ( $> 1.0$ ) throughout the year, peaking in April and November. Other crops had similar levels of diversity to lucerne at various times of the year, but only for short periods of time. Values of  $H'$  in Chickpeas was zero as only one predator was found in the crops sampled. The highest value of  $H'$  recorded (2.229) was for potatoes sampled in June.

Data on the seasonal phenology of predators in non-crop habitats is patchy and incomplete due to the poor condition of vegetation for most of sampling period. Burr medic and Paterson's curse were prevalent only during wet winter and spring months, becoming dormant in hot and/or dry conditions. The most important non-crop habitat found supporting cotton beneficials was burr medic. During the winter of 1996, dense swards of medic developed in grazing areas and along roadsides. The medic became heavily infested with aphids in August. Large populations of brown lacewings and hoverflies developed in these patches of medic, particularly where protected from grazing, until the plants senesced in late October (Fig. 8). In 1997, due to a very dry winter and early spring, no samples could be obtained from medic as the condition of the vegetation was too poor to sample. Other non-crop habitats sampled also varied markedly in condition according to the amount of rainfall received and were only sampled opportunistically whenever fresh growth was present. Paterson's curse supported relatively high numbers of predators during peak flowering (Fig. 8) but the plants rapidly dried out and became unattractive to beneficials with the onset of warm, dry weather. Although wild parsnip and wild sunflowers flowered for relatively long periods during summer, very few predators were found on these plants and diversity was low (Fig. 8). Values of  $H'$  for the non-crop habitats was also generally lower than that for crop habitats (Fig. 9). The highest value of  $H'$  recorded was for yellow vine sampled in November but diversity was much lower in samples taken between December and January.

### *Nursery crops for producing beneficial insects of cotton*

#### *1995/96 season cotton:*

At ACRI, Narrabri, the number of predators caught was generally low throughout the season, particularly in cotton. Predator numbers were highest in early summer but declined markedly after mid-January, coinciding with the application of pyrethroid sprays on nearby cotton crops. Some predators, with the exception of predatory beetles, increased in numbers again towards the end of the season. Of the early plant crops compared, more predators were consistently caught in sorghum than in other crops (Fig. 10) although the difference between sorghum and niger was not statistically significant ( $p > 0.05$ ). Spiders, lacewings and predatory bugs were particularly more abundant in early plant sorghum. The diversity of the predator complex was also significantly higher in early plant sorghum and niger. Similarly, more predators were consistently caught in late plant sorghum than in the other late plant crops compared (Fig. 10). Few predators were caught in adzuki beans, pigeon pea and cotton despite developing high *Helicoverpa* larval infestations. Sunflowers were a poor nursery crop for predators due to the short growing period of this crop. Similarly, while safflowers were also sown at the same time as other early plant crops, the plants had completely dried-off by late December and could not be sampled.

At Dalby Agricultural College, the difference in the number and diversity of predators caught between crops was less marked. Significantly more predators were caught in cotton and lucerne than in sunflowers, mung beans and pigeon pea ( $p < 0.05$ ) mainly due to differences in spider numbers. Significantly more predatory beetles were also caught in cotton and sorghum than in sunflowers and pigeon pea ( $p < 0.05$ ) being dominated by three-banded ladybirds. While more predatory bugs were caught in cotton, lucerne, sorghum and buckwheat than in other crops the difference was not significant ( $p > 0.05$ ) due to considerable variation in numbers over the sampling period. Pirate bugs were particularly

common in sorghum while damsel bugs and brown smudge bugs were only found in high numbers in lucerne. Few lacewings were caught in any crop except very early in the season in lucerne, sorghum and cotton.

The commonest parasitoid of *Helicoverpa* larvae collected from the Dalby plots was *Microplitis demolitor* but numbers were too low to compare crops. The highest cause of larval mortality was virus with ascovirus being more common than nuclear polyhedrosis virus (NPV). Of 163 small and medium *Helicoverpa* larvae recorded as killed by *M. demolitor* or by viruses, 59.5% were infected with ascovirus and 11.7% with NPV. Overall, 41.1% of small and medium larvae collected were killed by these three agents.

#### **1996/97 cotton season:**

At Auscott near Narrabri, the diversity and abundance of the predator complex was highest in November and December, tending to decrease over the remainder of the sampling period, except in lucerne where the number of species increased again in April. In general, lucerne, niger and sorghum supported the most abundant and diverse predator community in both the early and late plant plots (Fig. 11). Significantly more predators were caught in these crops than in cotton, buckwheat or pigeon pea ( $p < 0.05$ ). Early plant sorghum had significantly higher numbers of lacewings than all other crops ( $p < 0.05$ ) but very few were caught in the late the plant plots and the difference was not significant ( $p > 0.05$ ) (Fig. 11). Numbers of mirids and leafhoppers were highest in lucerne and niger, particularly early in the season. Aphid numbers were highest in early plant plots of sorghum and cotton, increasing in lucerne at the end of the sampling period. Thrip numbers fluctuated greatly throughout the season but were generally highest in lucerne plots. Thrips also increased in numbers in the late plant pigeon pea plots at the end of the sampling period. The correlation between potential prey and predators was highly significant for many comparisons (Table 3). The highest correlations obtained were between leafhoppers and all predatory groups except lacewings and hoverflies. Conversely, aphids were not significantly correlated with any predator group except lacewings and hoverflies. Thrips were significantly correlated with many predator groups but they were also highly correlated with numbers of leafhoppers. There were no significant correlations between whitefly and predator numbers. The number of mites in samples was not counted in this trial. Parasitism of *Helicoverpa* larvae collected from the trial site ( $N=893$ ) was 15.4% in lucerne, 14.4% in pigeon pea, 14.3% in sorghum, 3.9% in niger, 2.4% in cotton and 0% in buckwheat. Parasitoids were dominated by *M. demolitor* (47.2%) and *H. scaposum* (40.7%) while tachinids collectively comprised 12.0%.

At Dalby, due to the dry conditions and the poor condition of the crops sampled, the number of predators caught was too low for statistical analysis. The highest numbers of predators were collected in sorghum, particularly in February when numbers of pirate bugs and three banded ladybirds peaked. Buckwheat also supported high numbers of these beneficial species on this sampling date. Both of the lucerne crops sampled supported few beneficials with the exception of spiders which varied greatly in numbers throughout the sampling period. Similarly, low numbers of beneficials were collected from mung beans, maize and pigeon pea.

#### **1997/98 cotton season:**

At Milchengowrie near Boggabri, the highest number of predators were consistently caught in the early and late plant sorghum crops while the lowest numbers were caught in pigeon pea (Fig. 12). Numbers of coccinellid beetles was high in sorghum due to the large numbers of aphids found in both the early and late plantings. At the end of the sampling period numbers of mites increased greatly particularly in lab lab and late corn. In response, mite-eating ladybird (*Stethorus* spp.) also increased in abundance in these crops. Predatory bugs were dominated by pirate bugs particularly in sorghum and corn. Both the early and late plant plots of sorghum supported significantly higher numbers of predatory bugs and lacewings than all other refuge crops except cotton and late plant corn (Fig. 12). There was

no significant difference ( $p > 0.05$ ) in the number of predatory taxa found in each crop or in values of the Shannon-Weaver diversity index. The correlation between potential prey and predator groups was highly significant for many comparisons (Table 4). However, due to significant correlations between most of the potential prey categories it is difficult to interpret these results. Parasitism of *Helicoverpa* larvae ( $N=706$ ) collected from the trial site was 24.7% in sorghum, 14.0% in cotton, 10.3% in lab lab, 7.2% in pigeon pea and 0% in corn. The majority of parasitoids were *M. demolitor* (66.0%) while *H. scaposum* (12.6%) and tachinids (20.6%) comprised the rest.

As in 1996/97, the number of predators caught at sample sites on the Darling Downs was too low for statistical comparison. All of the crops sampled were surrounded by areas of cotton which received heavy insecticide applications. Consequently, the number of predators caught was very low in all crops, including lucerne, and the results for these trials are not reported.

Table 3. Correlation coefficients for mean number/sample ( $\log n + 1$ ) of predators vs potential prey for all d-vac samples ( $N=91$ ) from small plot trials at Auscott, Narrabri, during cotton season. Bold numbers indicate a significant correlation at  $p < 0.05$ .

Taxa	Thrips	Aphids	Leafhoppers	Whitefly
Thrips		<b>0.2794</b>	<b>0.6047</b>	0.1655
Aphids	<b>0.2794</b>		-0.0138	0.1976
Leafhoppers	<b>0.6047</b>	-0.0138		<b>0.3642</b>
Whitefly	0.1665	0.1976	0.1976	
All predatory bugs	<b>0.5457</b>	0.1536	<b>0.6713</b>	0.1312
All predatory beetles	<b>0.3404</b>	0.0109	<b>0.5857</b>	0.0831
All lacewings & hoverflies	0.1493	<b>0.2674</b>	0.1299	-0.0332
All spiders	<b>0.6255</b>	0.0254	<b>0.6835</b>	-0.0847
All predators	<b>0.6207</b>	0.1191	<b>0.7388</b>	0.1247
All predators excluding spiders	<b>0.5457</b>	0.1536	<b>0.6713</b>	0.1241
No. of predatory taxa	<b>0.5846</b>	0.1005	<b>0.7481</b>	<b>0.2372</b>
Shannon-Weaver diversity index	<b>0.4736</b>	0.1710	<b>0.6535</b>	<b>0.2919</b>

Table 4. Correlation coefficients for mean number/sample ( $\log n + 1$ ) of predators vs potential prey for all d-vac samples ( $N=46$ ) from Ingard refuge site at Milchengowrie, Boggabri, during the 1996/97 cotton season. Bold numbers indicate a significant correlation at  $p < 0.05$ .

Taxa	Thrips	Aphids	Leafhoppers	Whitefly
Thrips		0.0711	0.1382	<b>0.4776</b>
Aphids	0.0711		-0.0833	0.2473
Leafhoppers	0.1382	-0.0833		-0.0480
Whitefly	<b>0.4776</b>	0.2473	-0.0480	
Mites	<b>0.5651</b>	0.2498	<b>0.4018</b>	<b>0.3945</b>
All predatory bugs	0.2244	<b>0.5618</b>	<b>0.4653</b>	0.1570
All predatory beetles	0.2728	<b>0.5436</b>	<b>0.3944</b>	0.2182
All lacewings & hoverflies	0.0624	<b>0.4617</b>	<b>0.4722</b>	0.1187
All spiders	<b>0.5838</b>	0.0504	<b>0.5523</b>	0.5140
All predators	<b>0.4362</b>	<b>0.4629</b>	<b>0.5510</b>	<b>0.3297</b>
All predators excluding spiders	<b>0.3003</b>	<b>0.5680</b>	<b>0.4733</b>	0.1785
No. of predatory taxa	<b>0.3375</b>	<b>0.5144</b>	<b>0.3329</b>	<b>0.3778</b>
Shannon-Weaver diversity index	0.1085	<b>0.3015</b>	-0.0029	<b>0.3530</b>

### *Analysis of Helicoverpa larval and pupal parasitism records*

Parasitism records for 20,936 larvae and 9,909 pupae collected from 14 host plant taxa were extracted from the *Helicoverpa* database. A report summarising the findings is attached as Appendix 1. Levels of parasitism varied markedly between host plants (Fig. A1). Parasitism was highest in larvae collected from Asteraceae (11.8%), pigeon pea (11.2%), adzuki beans (10.7%) and sorghum (10.6%). Larval parasitism was lowest in chick pea (1.0%), maize (2.1%) and cotton (4.4%). Pupal parasitism was much higher than larval parasitism for all host plants but the rank order was similar (Fig. A1). Pupal parasitism was highest in sorghum (41.3%) and lowest in maize (7.8%). The species composition of the parasitoid complex varied markedly between seasons (Fig. A2) and host plants (Fig. A3).

### *Parasitism of Helicoverpa eggs*

Parasitism of *Helicoverpa* eggs placed in various crop and non-crop habitats during the period of study was very low (Table 5). A total of 138,553 *Helicoverpa* eggs were exposed during the period of study of which 77,638 (60.7%) were recovered after two days exposure in the field. The disappearance of eggs may give an indication of the level of egg predation occurring in each habitat. While some eggs may have disappeared due to dislodgment through the effects of wind and rain, exposure of eggs during adverse weather conditions was avoided. Of the eggs recovered only 914 (1.6%) were parasitised by Trichogrammatid wasps. Identification of the species found is in progress but the majority appear to be *Trichogramma* spp. with very few *Telenomus* or *Trichogrammatoidea* spp. present. Due to the very low levels of egg parasitism no statistical comparisons of habitats or nursery crops could be made.

Table 5. Total number of *Helicoverpa* eggs exposed in the Namoi Valley between 1996 and 1998, percentage of eggs recovered and percentage of eggs parasitised by Trichogrammatid wasps.

Cotton season	Total no. eggs exposed	Total no. eggs recovered	% of eggs recovered	Total no. eggs parasitised	% of eggs parasitised
1995/96	33261	21529	66.9	475	2.3
1996/97	24297	14887	62.1	114	1.1
1997/98	80995	41222	53.1	325	1.4
Total	138553	77638		914	
Mean			60.7		1.6

## **Discussion**

This project has confirmed the value of lucerne as a refuge or nursery crop for key beneficials of cotton. Lucerne is an ideal crop to use as a refuge for beneficials for the following reasons:

- It is a perennial crop available all year round often when other host plants are not present in the agroecosystem or are unsuitable for supporting populations of beneficials. Consequently, it offers a stable environment in which beneficials can establish and maintain populations within the agroecosystem throughout the year.
- Lucerne flowers throughout the growing period, therefore providing a constant source of nectar for beneficials. A source of nectar and/or pollen is essential for the successful reproduction of many beneficial insects, particularly parasitic wasps and flies.

- Lucerne supports a large and diverse community of potential prey for predators throughout its growth stages. Results from this study suggests that aphids and leafhoppers are important prey for many key cotton predators. Aphids and leafhoppers were particularly abundant on lucerne in the spring and autumn giving rise to large populations of coccinellid beetles, brown lacewings, hoverflies and spiders.
- While the density of *Helicoverpa* larvae in lucerne can sometimes be high, the majority are *H. punctigera* and few appear to reach maturity due very high levels of disease such as NPV. In the Namoi Valley, NPV loadings in the soil of lucerne crops are much higher than other crops (A. Richards, CSIRO Entomology, Canberra, pers. comm.). Therefore, lucerne is unlikely to act as a source of *H. armigera* and may in fact be useful as a reservoir of *Helicoverpa* larval diseases.
- The dense canopy of lucerne, particularly during the first year of production, may provide a suitable microclimate for beneficials during times of climatic extremes. The availability of shelter is probably of particular importance during the summer when temperatures are high and moisture is limiting.

However, there are also negative aspects to using lucerne as a nursery crop for beneficials that must be addressed. The high costs associated with the management of lucerne crops may be prohibitive unless financial returns can be made through the harvesting and sale of hay. The use of lucerne hay originating from cotton growing areas as fodder for cattle is unpopular due to the perceived risk of contaminating stock with pesticide residues. Lucerne is also a suitable host plant for the silverleaf whitefly (SLW) *Bemisia tabacai* B-biotype, a new exotic pest that is a threat to the Australian cotton industry. Unless lucerne acts as a reservoir for parasitoids and predators of SLW, increased production of this crop may worsen the SLW threat by providing areas in which populations can survive between cotton seasons (Lea and Franzmann 1998). Lucerne is not suitable for dryland farming systems unless drought tolerant varieties are used. More research is needed to determine which varieties of lucerne are best for producing cotton beneficials under different farming systems.

After lucerne, the next best nursery crop for beneficials was grain sorghum. However, the short growing period of this crop and its attractiveness to *Helicoverpa* spp. make it much less suitable as a refuge for beneficials than lucerne. Grain sorghum, an unsuitable host for SLW, may be the best choice as a nursery crop for cotton beneficials where lucerne production is not feasible or when choosing a crop as an Ingard refuge site. The Bt cotton resistance management strategy offers a unique opportunity to increase numbers of cotton beneficials on individual farms. Selection of a refuge crop that also favours predators and parasitoids may be advantageous if those beneficials can then be attracted into the cotton crops, particularly towards the end of the season when pests such as aphids and *H. armigera* increase in numbers (Appendix 1, Fitt and Tann 1996).

Grain legume crops are poor nursery crops for cotton beneficials but good trap crops for *Helicoverpa* spp. Chick pea was a particularly poor source of predators and parasitoids of *Helicoverpa*.

Of the non-crop hosts sampled, burr medic (*Medicago* spp.) was the most important source of cotton beneficials, particularly for brown lacewings and hoverflies. However, growth of vegetation in all non-crop habitats was severely affected by grazing and rainfall. Rainfall in the Namoi Valley is very unpredictable and highly variable between years. Consequently, reliance on natural habitats for the production of cotton beneficials will be dependant on the amount of rainfall received. By planting an irrigated perennial nursery crop such as lucerne, growers can ensure that a stable habitat for cotton beneficials exists throughout the year regardless of local weather conditions.

The very low levels of *Helicoverpa* egg parasitism in the Namoi Valley recorded in this study confirms previous findings by Fitt (pers. comm.). This contrasts markedly with other cropping systems in Australia particularly in the Ord River Irrigation Area (ORIA)

where parasitism of *Helicoverpa* eggs by *Trichogramma pretiosum* frequently reaches over 90% in many crops including cotton (Strickland and Lacey 1996). *T. pretiosum* was introduced into Western Australia from the USA during the 1970's and is probably absent in the Namoi Valley. Consequently, it may be worthwhile conducting inoculative releases of *T. pretiosum* to determine whether populations could be established in northern NSW.

### Recommendations for Best Practice IPM

From the results of this project and other related research (Hossain *et al.* 1997, Mensah 1998), the following recommendations are suggested for inclusion in the Cotton Best Practice Manual:

1. Maintain permanent areas of lucerne on cotton farms throughout the year to act as a stable refuge for beneficials. The lucerne crop must be frequently irrigated and cut to maintain the fresh growth necessary for potential prey of predators and to retain mirids. Cut only part of the area at a time to help conserve established populations of beneficials. Allow the lucerne to flower before cutting to provide beneficials with a constant source of nectar. The area of lucerne needed and the proximity to cotton crops is the subject of current research by Dr Robert Mensah.
2. If present, conserve areas of burr medic (*Medicago* spp.) and native Asteraceae on the farm by setting aside from grazing and/or production. In the Namoi Valley, burr medic was an important source of cotton beneficials during the spring, particularly brown lacewings and hoverflies. *Helicoverpa* larvae collected off native Asteraceae, during winter and spring months, were heavily parasitised by Dipteran and Hymenopteran parasitoids.
3. If growing a refuge crop, as part of the requirement for the Bt cotton resistance management strategy, select grain sorghum. After lucerne, grain sorghum was consistently the best crop for producing predators and parasitoids of cotton pests. At least two plantings are needed in order to ensure the availability of attractive plants over the entire cotton season. Establish sorghum crops early so that predator numbers build-up in November and December.

### Links with other CRDC and CRC projects

Collaboration with: Ian Rochester, CSIRO, Narrabri (rotation crops for cotton)  
Andy Richards, CSIRO, Canberra (environmental impact of genetically modified NPV)  
Mary-Louise Johnson, Marie Yee and Peter Gregg, UNE, Armidale (*Helicoverpa* predators)  
Lewis Wilson, CSIRO, Narrabri (over-wintering of mites)  
Robert Mensah, NSW Agriculture, Narrabri (lucerne strips in cotton)  
Gary Fitt and Colin Tann, CSIRO Narrabri (Ingard refuge crops)

## References

- Fitt, G. P. and Tann, C. (1996). Quantifying the value of refuges for resistance management of transgenic Bt cotton. In: Proceedings of the 8th Australian Cotton Conference, Gold Coast, August 1996, pp. 77-83.
- Hossain, Z., Gurr, G. M. and Wratten, S. D. (1997). Habitat manipulation for lucerne pests: temporal trends in pest and natural enemy populations. In: Proceedings of the 1997 Australian Entomological Society Conference, Melbourne, p.55.
- Lea and Franzmann, B. A. (1998). Development of the silverleaf whitefly on key host plants in the cotton agroecosystem. In: Proceedings of the 9th Australian Cotton Conference, Gold Coast, August 1998, pp. 465-469.
- Mensah, R. K. (1998). Habitat diversity: Implications for the conservation of and use of predatory insects of *Helicoverpa* spp. in cotton systems in Australia. International Journal of Pest Management (In press).
- Stickland, G. and Lacey, I. (1996). The seasonal abundance of *Trichogramma pretiosum* in cotton grown with different pest management strategies in the Ord River Irrigation Area (ORIA). In: Proceedings of the Eighth Australian Cotton Conference, Surfers Paradise, pp. 273-277.

## Publications arising from this project

- Gurr, G. M., Wratten, S. D., Irvin, N. A., Hossain, Z., Baggen, L. R., Mensah, R. K. and Walker, P. W. (1998). Habitat manipulation in Australasia: recent biological control progress and prospects for adoption. In: Proceedings of the Sixth Australasian Applied Entomological Research Conference (Ed: M. P. Zalucki, R. Drew and G. White), Brisbane, 29 September - 2 October 1998), Volume 2, p. 225.
- Walker, P. W. (1998). Tachinids: a little known group of heliothis parasitoids. The Australian Cottongrower, 19: (2) 44-46.
- Walker, P. W. (1997). Biology of *Chaetophthalmus dorsalis* (Malloch) (Diptera: Tachinidae) - a parasitoid of *Helicoverpa* spp. (Lepidoptera: Noctuidae) larvae. In: Proceedings of the 1997 Australian Entomological Society Conference, Melbourne, p. 57.
- Walker, P. W., Dillon, G. E. and Fitt, G. P. (1997). Occurrence of key beneficial insects of cotton in crop and non-crop habitats in the Namoi Valley. In: Proceedings of the 1997 Australian Entomological Society Conference, Melbourne, p. 97.
- Walker, P. W. and Lawrence, L. (1998) The secret life of a parasitic fly. The Helix, 61: p. 8.
- Walker, P. W., Fitt, G. P., Franzmann, B. A, Lloyd, R. J. and Mensah, R. K. (1996). Alternative crops for producing natural enemies of cotton pests. In: Proceedings of the Eight Australian Cotton Conference, Surfers Paradise.

## Publications in preparation

- Walker, P. W. and Fitt G. P. Parasitoids of *Helicoverpa* spp. in Australian cotton agroecosystems. To be submitted to Australian Journal of Entomology.

Walker, P. W. and Fitt, G. P. Distribution of cotton predators in the Namoi Valley. To be submitted to *The Australian Cottongrower*.

Walker, P. W. and Fitt, G. P. Occurrence and seasonal phenology of key predators of cotton in crop and non-crop habitats in the Namoi Valley cotton agroecosystem, NSW, Australia. To be submitted to *Bulletin of Entomological Research*.

Walker, P. W. and Fitt, G. P. Aspects of the biology of *Chaetophthalmus dorsalis* (Diptera: Tachinidae), a parasitoid of *Helicoverpa* spp. (Lepidoptera: Noctuidae) larvae in Australia. To be submitted to *Entomophaga*.

Fig. 1. Seasonal abundance (A, D-G) and diversity (B and C) of cotton predators in the Namoi Valley agroecosystem for crop and non-crop habitats combined. Monthly averages for samples taken between December 1995 and April 1998.

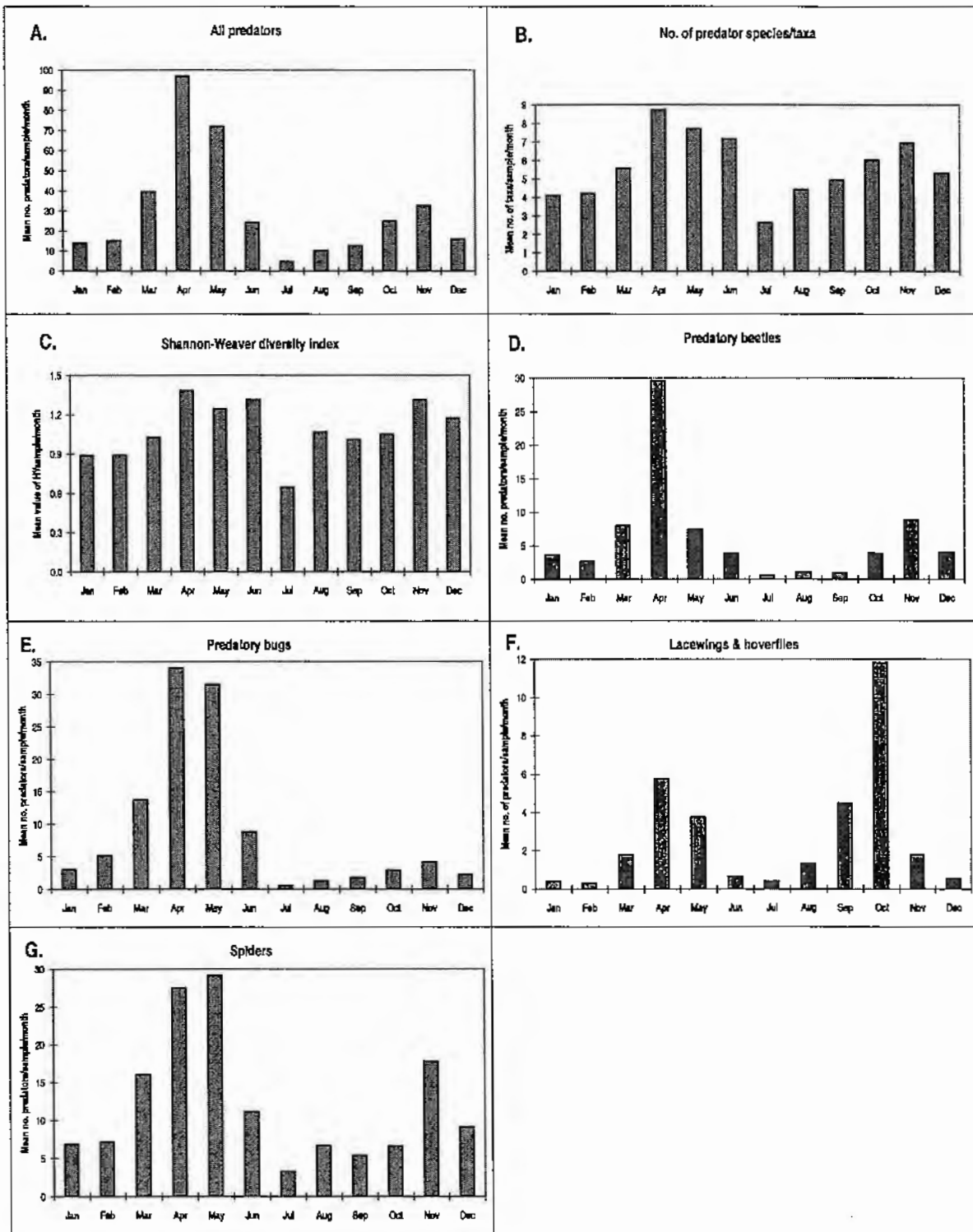


Fig. 2. Seasonal abundance of potential prey of cotton predators in the Namoi Valley agroecosystem for all crop and non-crop habitats combined. Monthly averages for samples taken between December 1995 and April 1998.

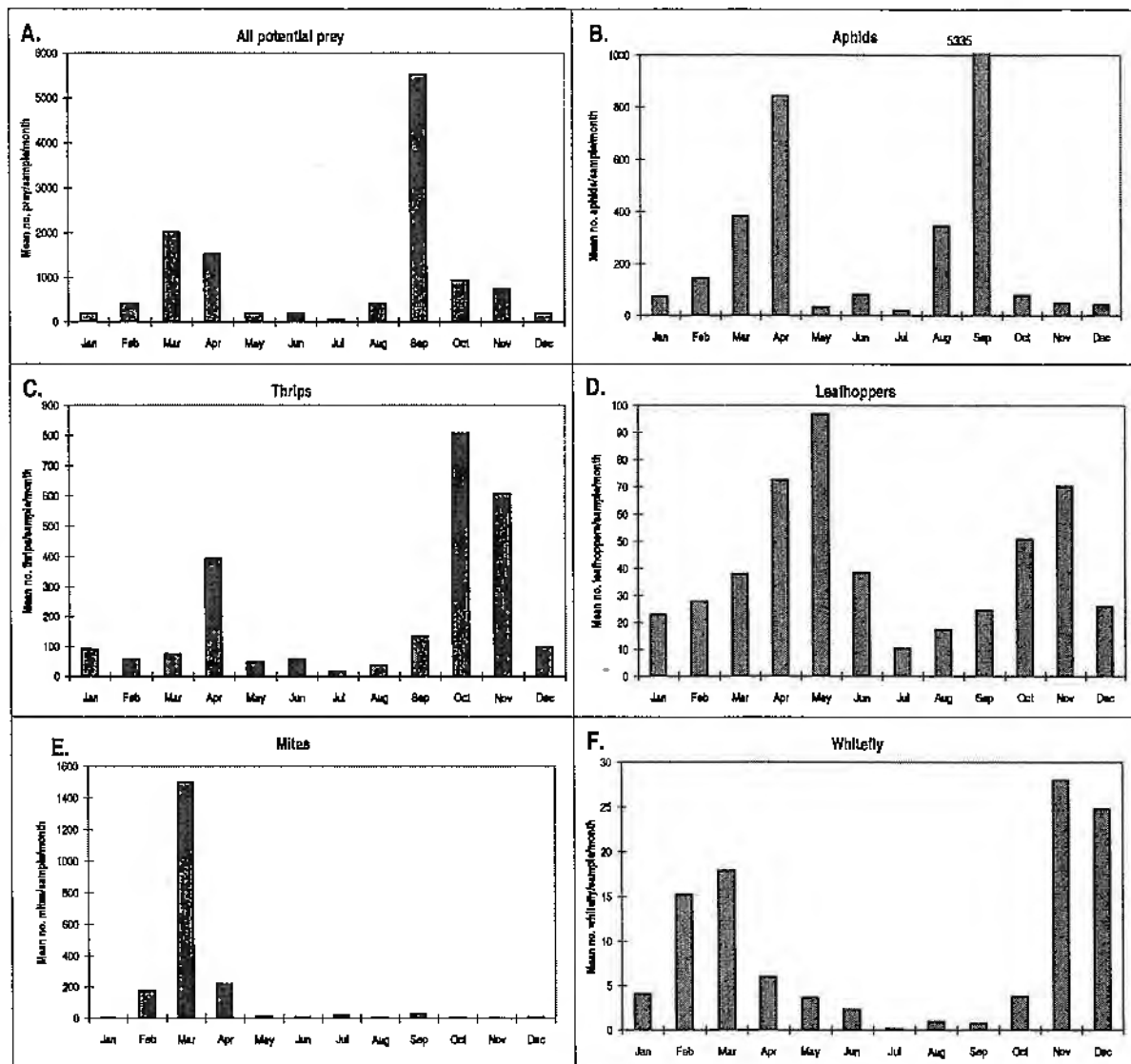


Fig. 3. Monthly changes in the composition of key cotton predator groups in the Namoi Valley agroecosystem for all crop and non-crop habitats combined.

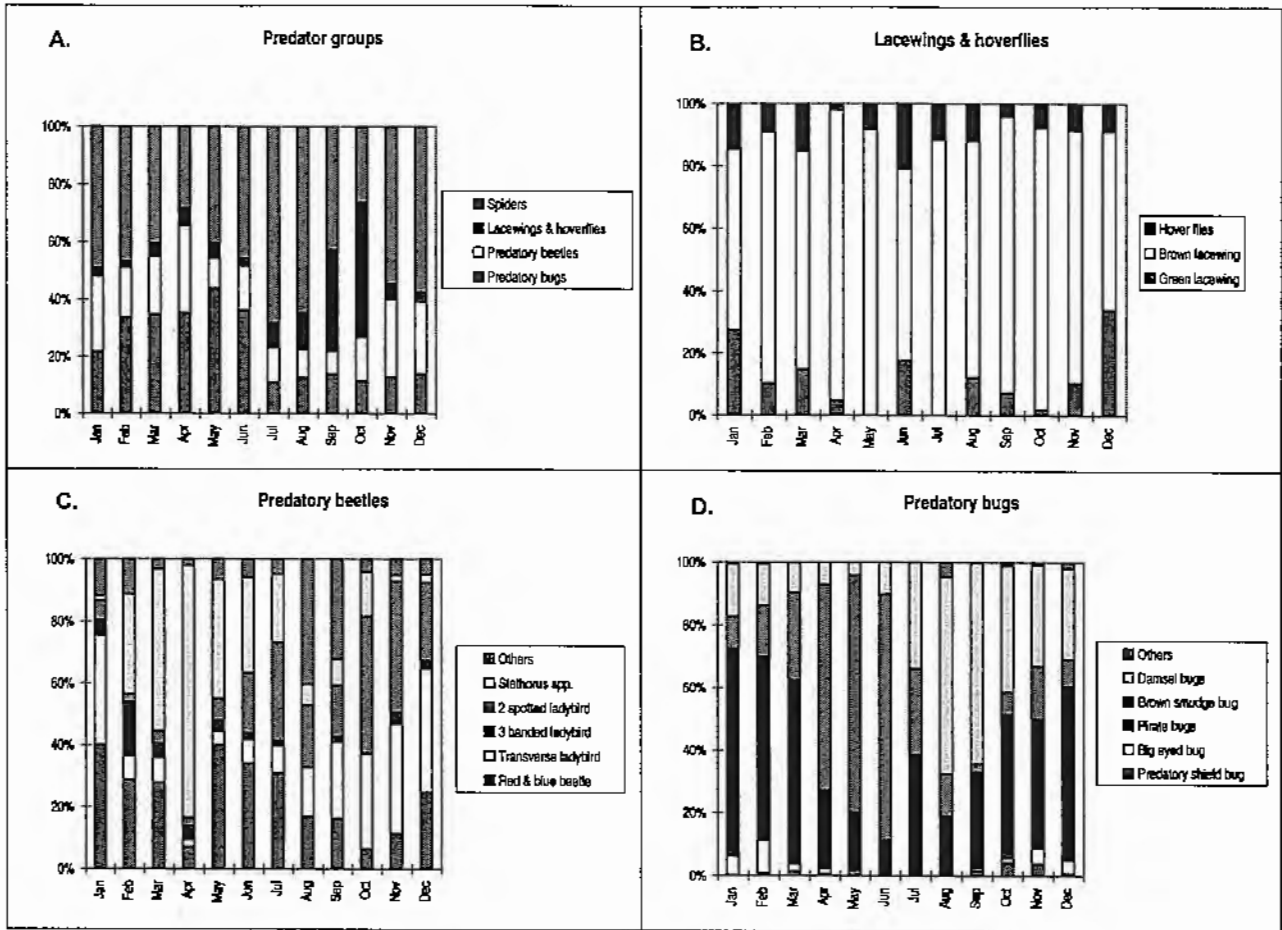


Fig. 4. Abundance ratings and number of cotton predatory taxa caught in d-vac samples from crop habitats in the Namoi Valley between December 1995 and April 1998.

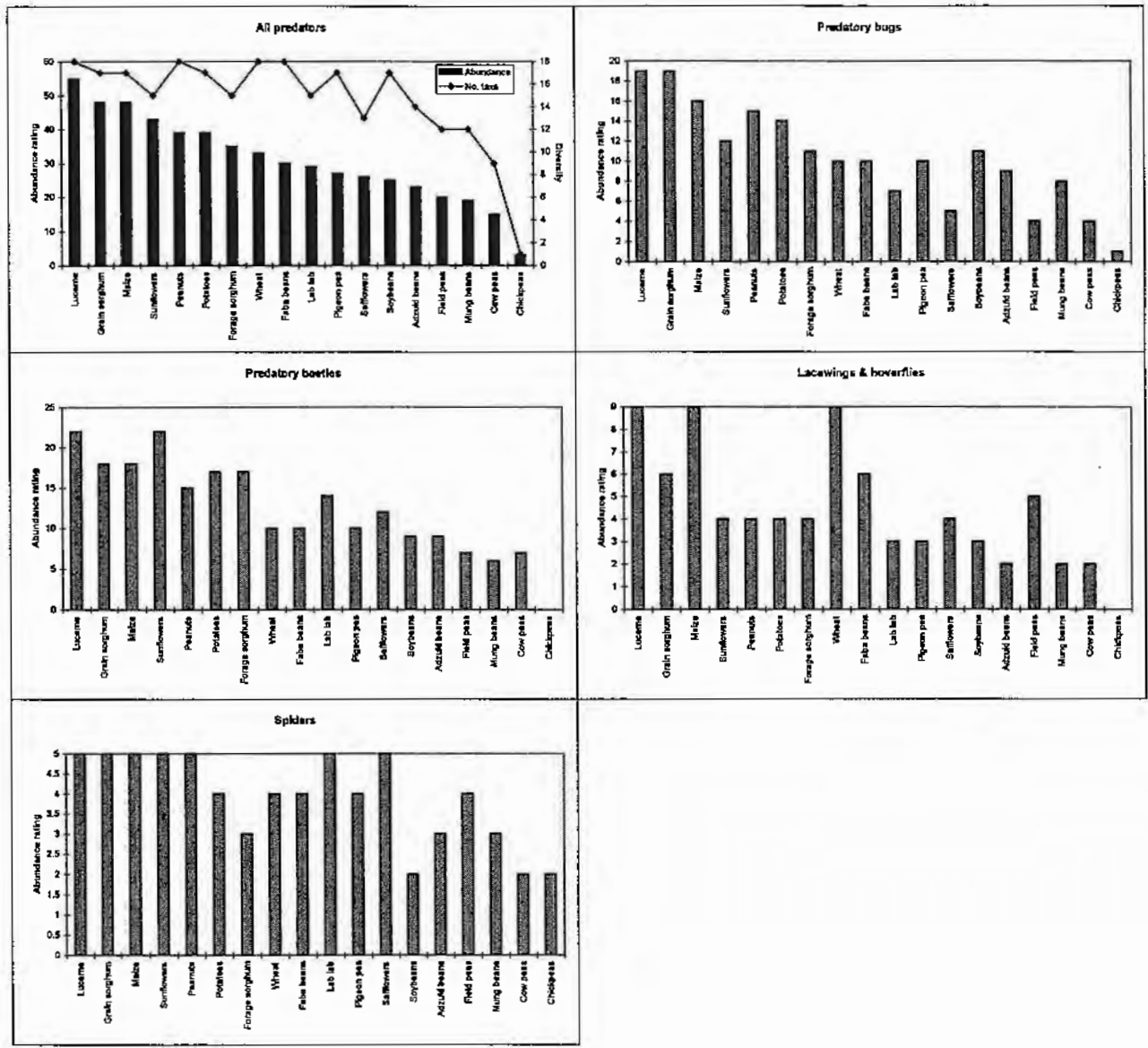


Fig. 5. Abundance ratings and number of cotton predatory taxa caught in d-vac samples from non-crop habitats in the Namoi Valley between December 1995 and April 1998.

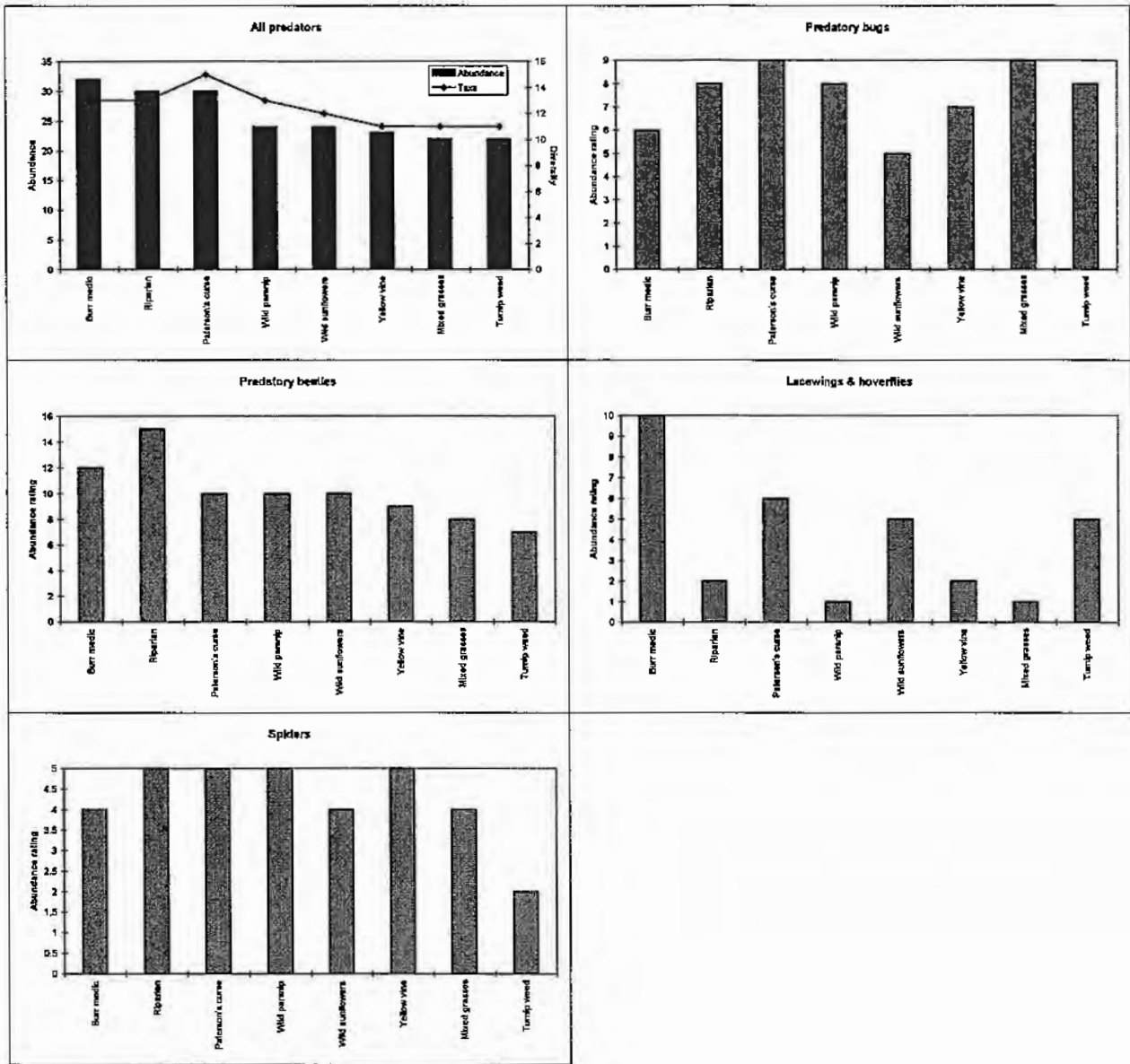


Fig. 6. Seasonal abundance and number of cotton predatory taxa caught in d-vac samples from crop habitats in the Namoi Valley. Monthly averages for samples taken between December 1995 and April 1998.

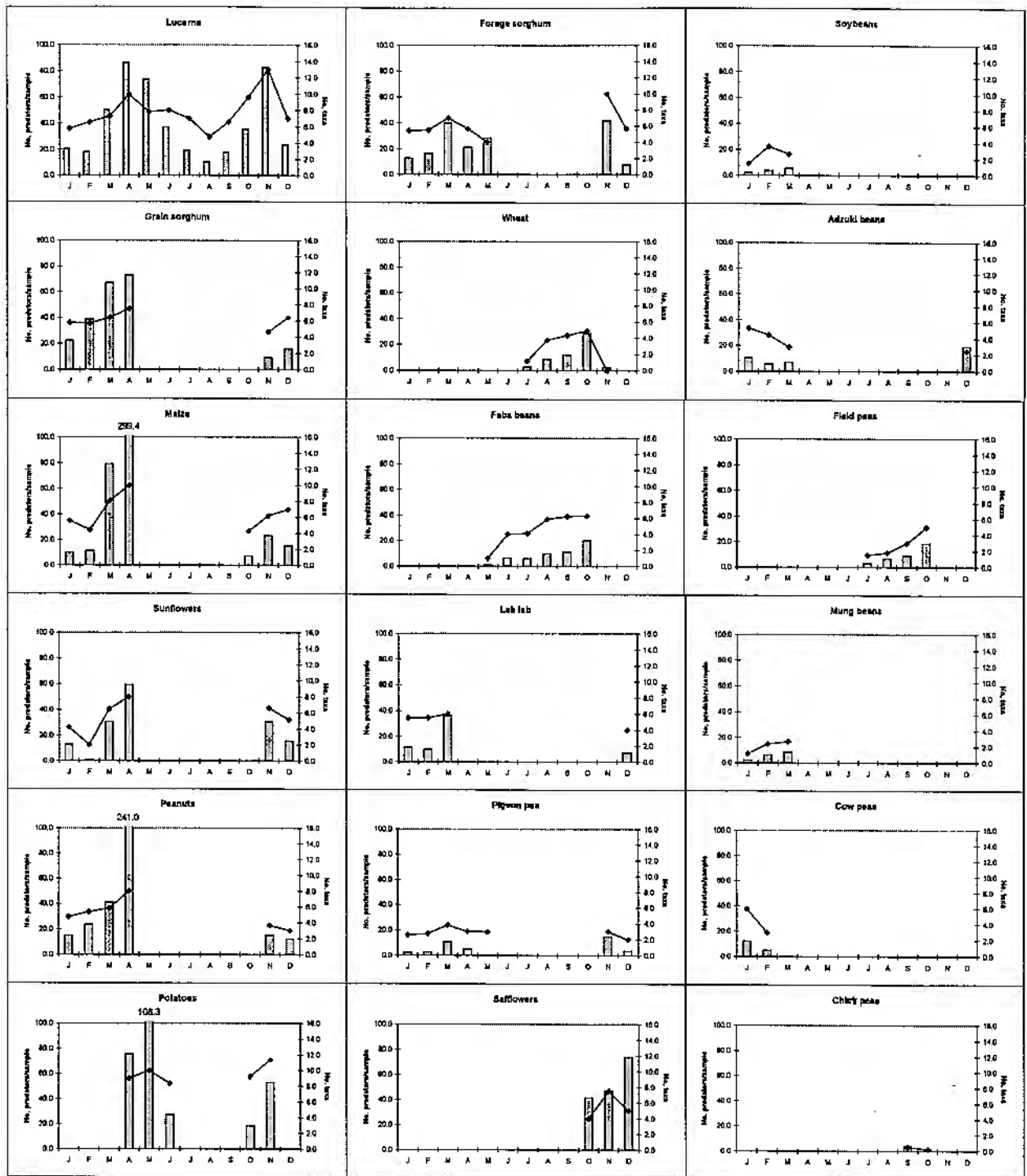




Fig. 8. Seasonal abundance and number of cotton predatory taxa caught in d-vac samples from non-crop habitats in the Namoi Valley. Monthly averages for samples taken between December 1995 and April 1998.

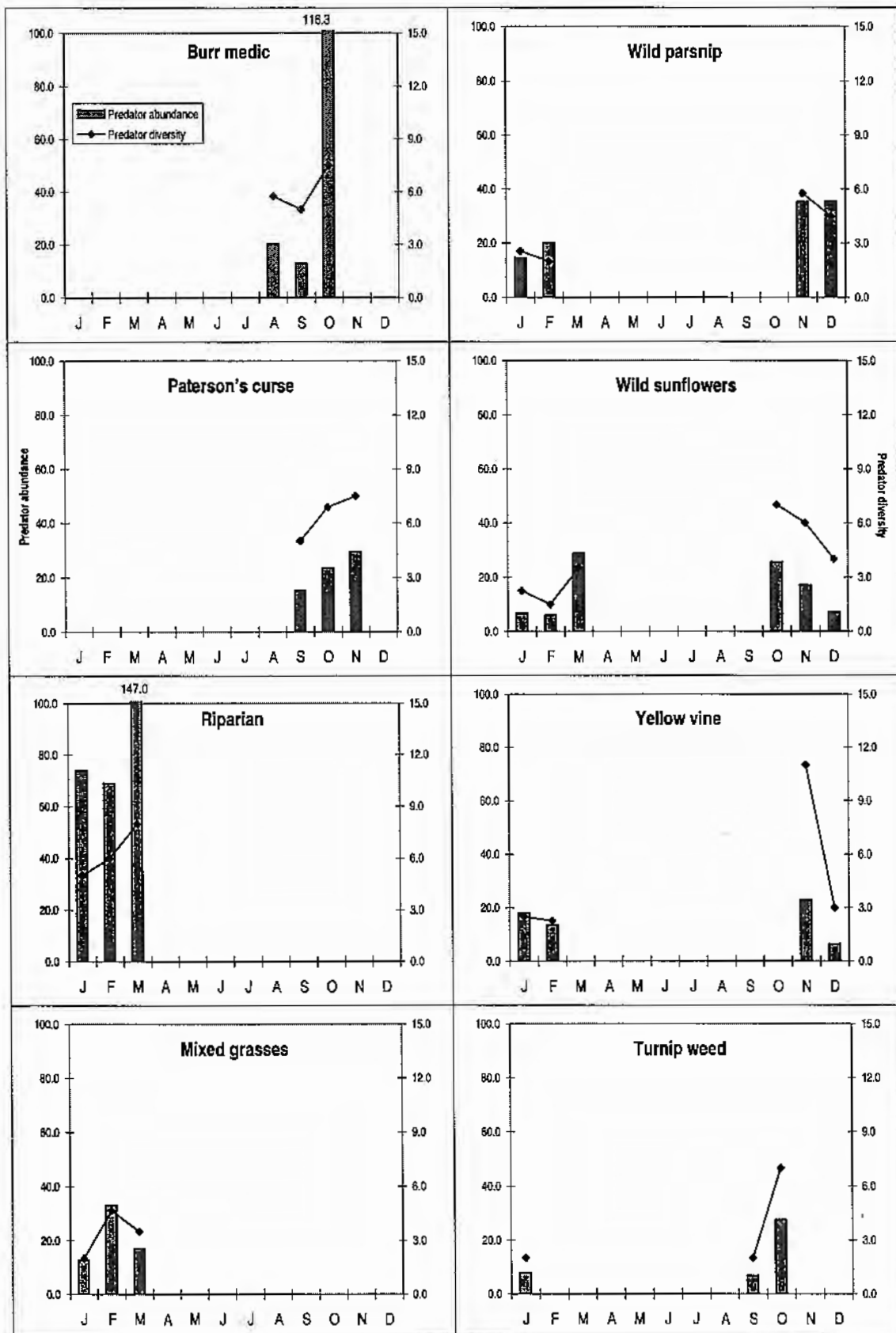


Fig. 9. Shannon-Weaver diversity index ( $H'$ ) for cotton predators caught in d-vac samples from non-crop habitats in the Namoi Valley. Monthly averages for samples taken between December 1995 and April 1998.

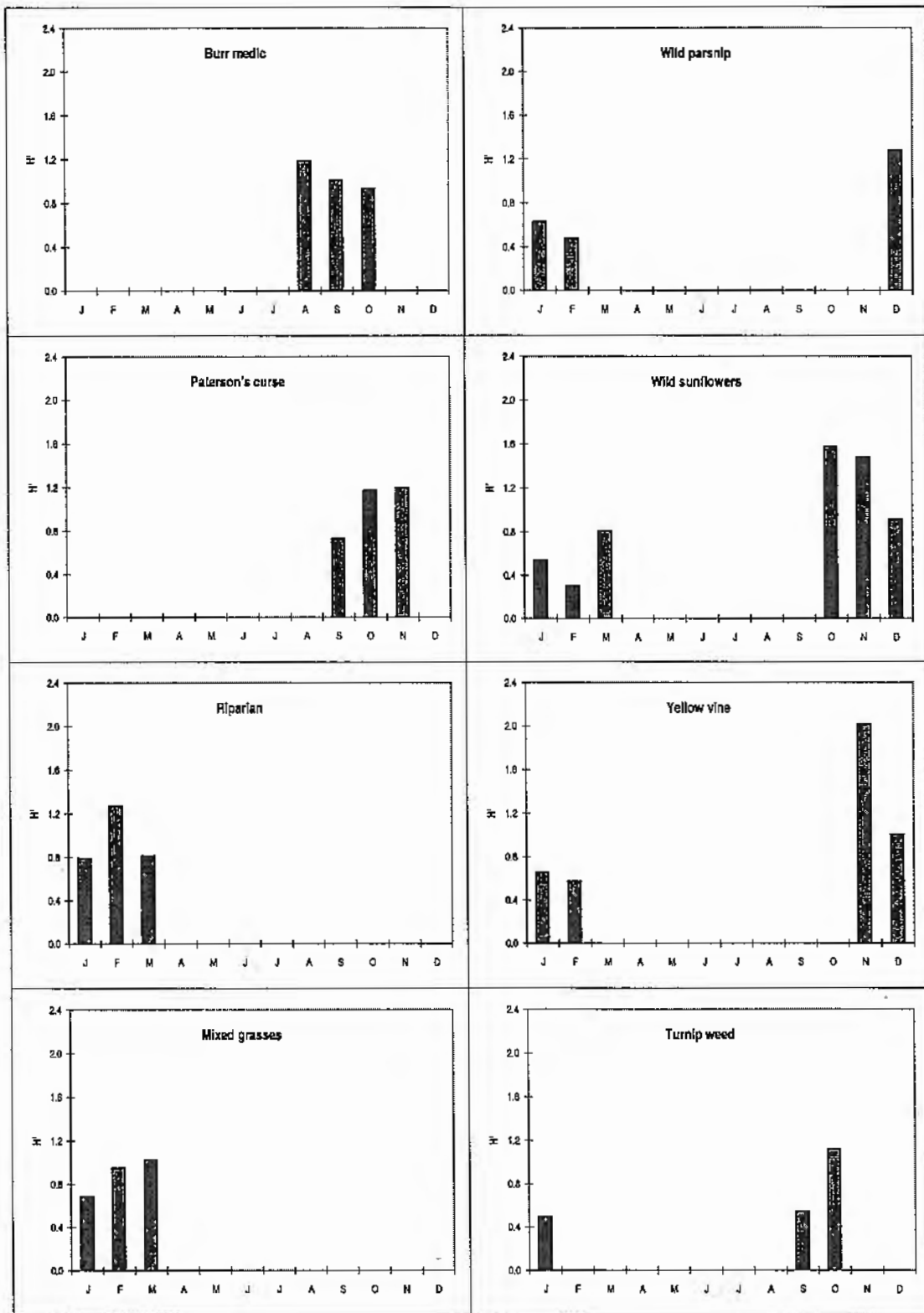


Fig. 10. Total number of predators caught in early plant (EP) and late plant (LP) plot trials at ACRI, during the 1995/96 cotton season: (A) All predators, (B) Predatory beetles, (C) Predatory bugs, (D) Lacewings and hoverflies and (E) Spiders. Columns within each planting date followed by the same letter are not significantly different at  $p = 0.05$ .

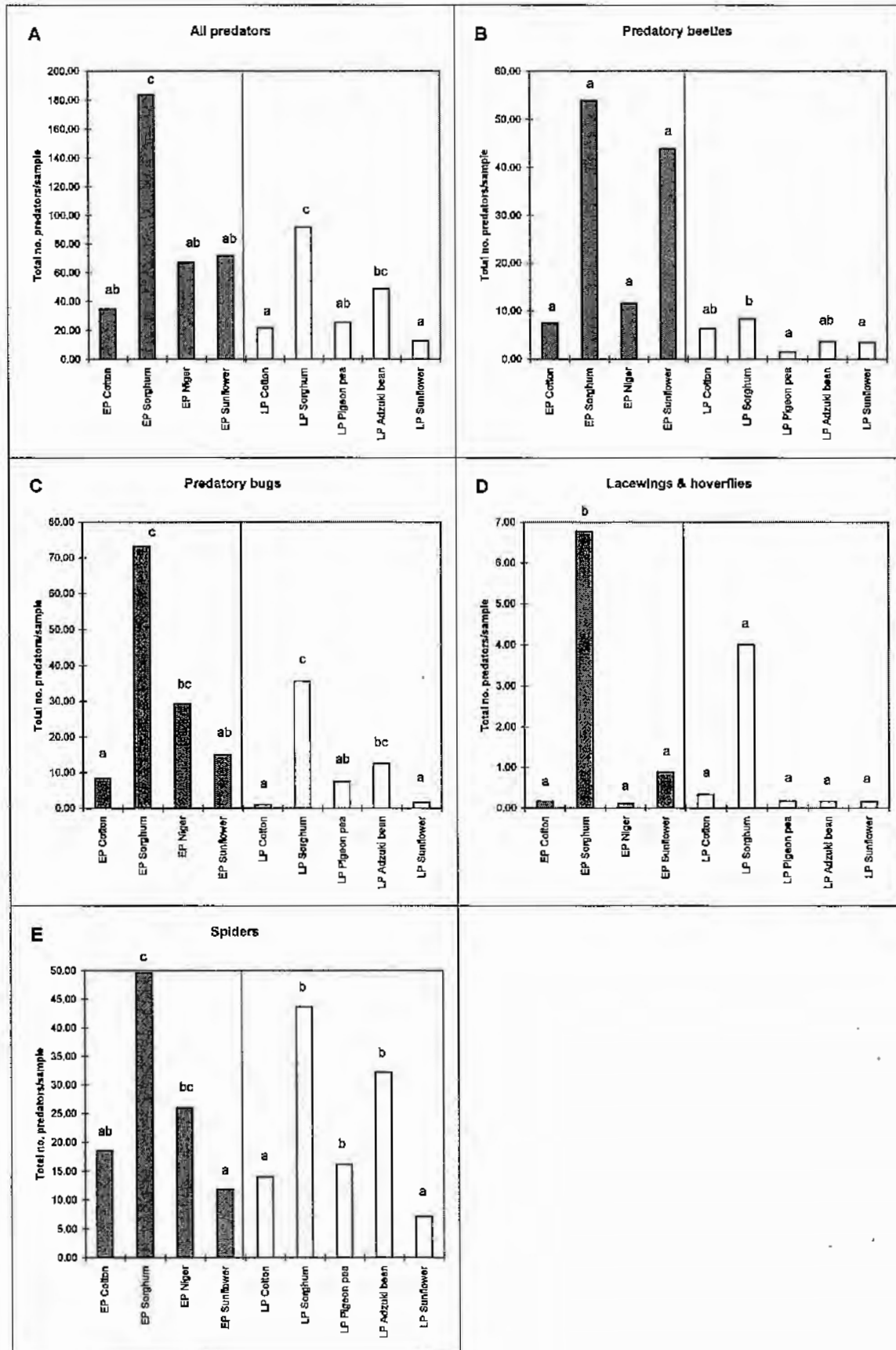


Fig. 11. Total number of predators caught in early plant (EP) and late plant (LP) plot trials at Auscott, Narrabri, during the 1996/97 cotton season: (A) All predators, (B) Predatory beetles, (C) Predatory bugs, (D) Lacewings and hoverflies and (E) Spiders. Columns within each planting date followed by the same letter are not significantly different at  $p = 0.05$ .

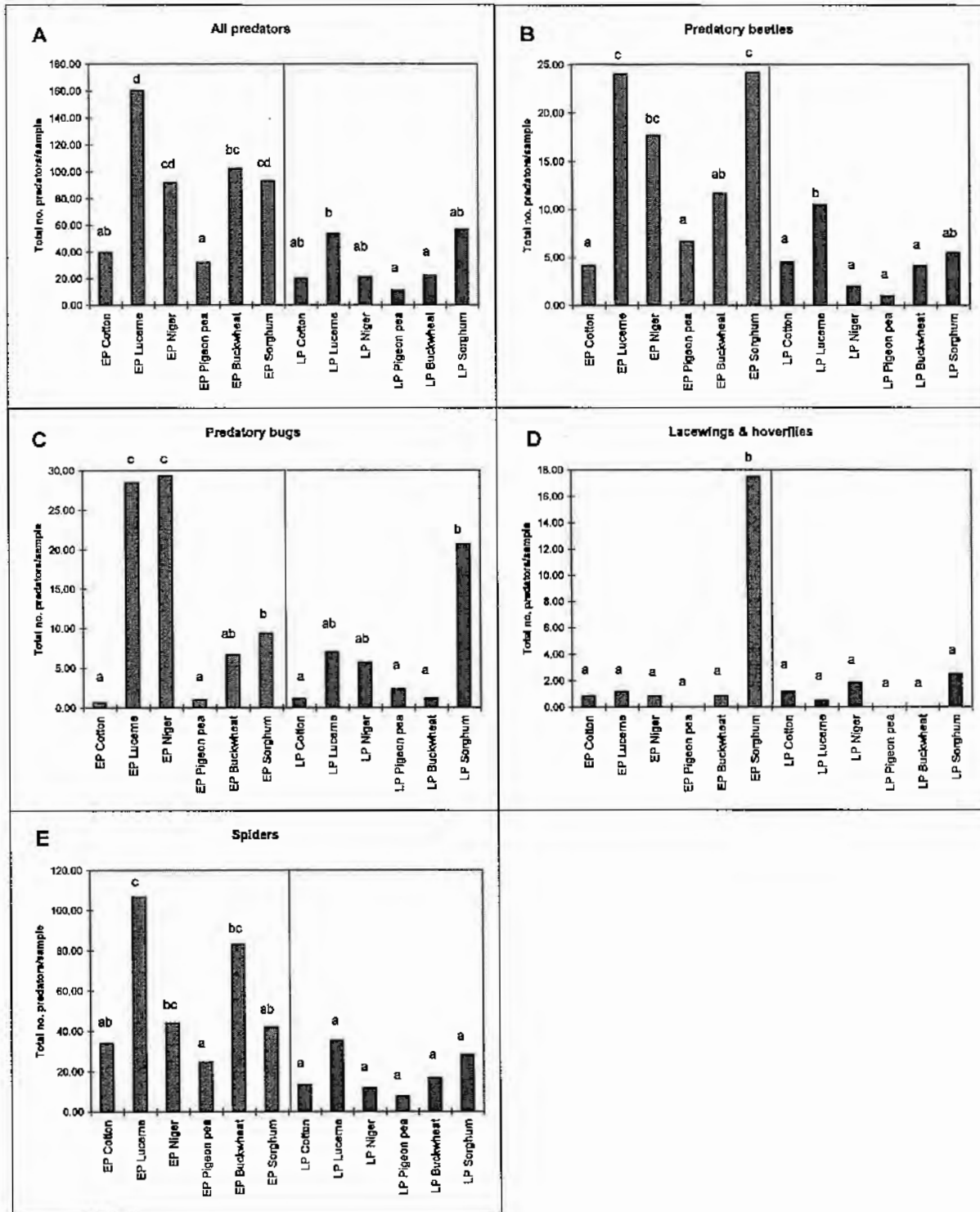
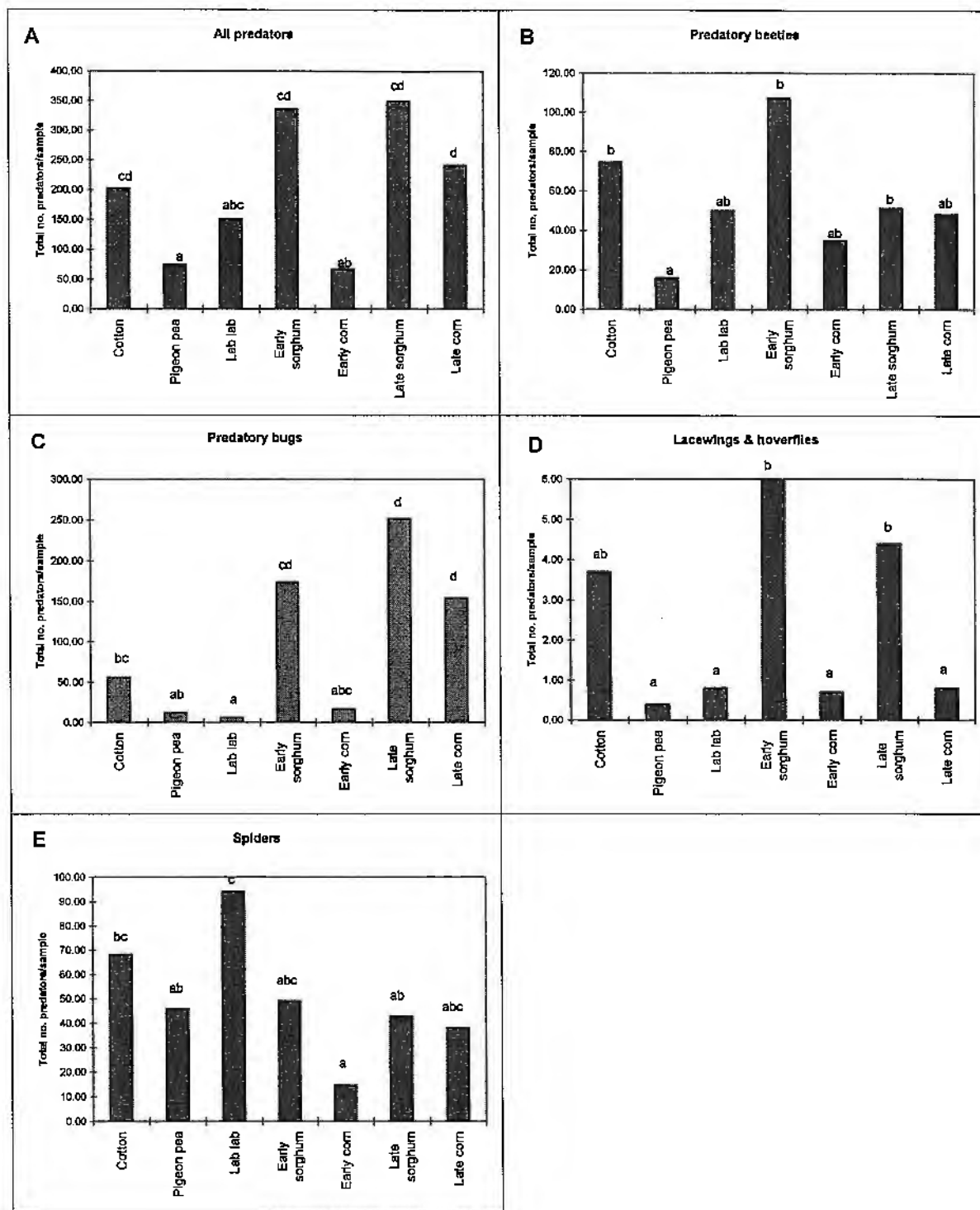


Fig. 12. Total number of predators caught in Ingard refuge plots at Milchinegowrie, near Boggabri, during the 1997/98 cotton season; (A) All predators, (B) Predatory beetles, (C) Predatory bugs, (D) Lacewings & hoverflies and (E) spiders. Columns followed by the same letter are not significantly different at  $p = 0.05$ .



## APPENDIX A

### Parasitoids of *Helicoverpa* spp. in Australian cotton agroecosystems

Walker P. W. and Fitt G. P.

CSIRO Entomology and CRC for Sustainable Cotton Production, Locked Bag 59,  
Narrabri, NSW 2390, Australia

#### Abstract

In Australian cotton fields, *Helicoverpa armigera* and *Helicoverpa punctigera* are attacked by a diverse range of parasitic wasps and flies. This paper gives a critical review on the role these parasitoids play in controlling *Helicoverpa* spp. populations in Australian cotton agroecosystems. Regional differences in levels of parasitism are highlighted with special reference being made to a large database of parasitism records collected over a nine year period in south-eastern Australia. Current options for augmenting and conserving parasitoid populations in conventional and transgenic cotton are reviewed.

#### Introduction

In Australia, *Helicoverpa armigera* (Hübner) and *H. punctigera* (Wallengren) are parasitised by over 30 species of Hymenoptera and Diptera (Zalucki *et al.* 1986). Although the incidence of parasitism is well documented, the role that these parasitoids play in regulating *Helicoverpa* populations is not fully understood. In cotton, as in many commercial crops, it is unlikely that *Helicoverpa* can ever be effectively controlled by naturally occurring parasitoids alone, even in the absence of pesticide sprays (Fitt 1994). *Helicoverpa* can rapidly infest crops via migration from other crop or non-crop sources. Unless populations of parasitoids are already well established, they cannot respond rapidly enough to achieve economic control.

Ways of effectively augmenting *Helicoverpa* parasitoid populations in field crops have been sought after for many years (King and Coleman 1989). Traditionally, biological control programmes involve the inoculative ('classical') or mass ('inundative') release of natural enemies. In Australia, several exotic species of *Helicoverpa* parasitoids have been released, the most successful being *Trichogramma pretiosum* Ril. from the USA. This species was released into the Ord River Irrigation Area (ORIA), Western Australia, during the 1970's (Michael and Woods 1980). Populations rapidly became established on *Anomis* spp. and *Helicoverpa* spp. eggs and parasitism levels of over 90% were often recorded in a wide range of crops (Strickland and Lacey 1996, Zalucki *et al.* 1986). In the Namoi Valley and Gywdir Valleys of northern NSW, where *T. pretiosum* is thought to be absent, parasitism of *Helicoverpa* eggs is very rare at less than 1% (P. W. Walker unpublished data). Further inoculative releases of *T. pretiosum* into these agroecosystems may be worth pursuing to determine whether populations could be established. Inundative releases of *Helicoverpa* egg parasitoids have also been made in various Australian field crops,

including cotton, but with little success (Scholz and Zalucki 1998). Many of the parasitoids evaluated in inoculative and inundative release programmes fail to become established because of an incomplete understanding of the agents' ecological requirements (Gurr *et al.* 1998). Also, historically, biological control programmes have often been evaluated as a stand-alone replacement for insecticides. Such expectations have proven unrealistic and emphasis is now being placed on integrating parasitoids into a IPM program where they are part of a *Helicoverpa* management strategy (Scholz and Zalucki 1998).

Another approach to biological control, termed 'conservation biological control', relies on the more effective use of the existing natural enemy fauna through habitat manipulation (Gurr *et al.* 1998). Habitat manipulation aims to strategically diversify the crop or its surroundings in order to optimise conditions for the survival and reproduction of natural enemies. This may be achieved by growing alternative vegetation within or outside the crop or by improved management of the crop itself. Such a system for increasing numbers of predatory insects has been developed for cotton in Australia using lucerne strips and food sprays (Mensah 1998). However, the effect of this habitat manipulation method on parasitoids has not been evaluated and it remains to be seen whether other techniques are more suitable for increasing rates of parasitism in *Helicoverpa*. In Australia, the release of transgenic Bt cotton has provided a unique opportunity to test new ways in which numbers of beneficial insects can be increased by habitat manipulation. As part of a resistance management for Bt cotton, farmers are required to plant refuge crops to maintain a high frequency of susceptible genotypes in populations of *H. armigera* (Fitt and Tann 1996). Selection of a refuge crop that favours high rates of *Helicoverpa* parasitism may be advantageous if those parasitoids can then be attracted into cotton crops, particularly towards the end of the season when larval populations in Bt transgenic cotton increase (Fitt and Tann 1996).

If habitat manipulation is to provide a means of augmenting populations of *Helicoverpa* parasitoids in Australian cotton ecosystems, then much more detailed information is needed on the ecological requirements of key species. In this paper we present a preliminary analysis of a large database containing parasitism records of *Helicoverpa* larvae and pupae, collected over a nine year period. We examine the species composition and seasonal phenology of the parasitoid complex and identify *Helicoverpa* host plants which host plants may be the most suitable for augmenting parasitoid populations.

### **Materials and methods**

Parasitism records were extracted from a database containing *Helicoverpa* larval and pupal collections from crop and non-crop hosts located in the cotton agroecosystems of northern NSW and south-eastern Queensland, between August 1988 and July 1997. Larvae were also collected from non-crop hosts located in inland Australia where large populations of *H. punctigera* develop on native Asteraceae, Goodeniaceae and Fabaceae during winter and spring months (Gregg *et al.* 1993). *Helicoverpa* larvae were collected from host plants using the most appropriate sampling technique. Most crops were searched visually for larvae, sampling entire plants in 6 x 1m<sup>2</sup> area of vegetation in broadacre crops or 6 x 1m row of vegetation in irrigated crops. Non-

crop hosts and lucerne crops were sampled for larvae using a sweep net, taking a total of 100 sweeps per sample. Grain sorghum was sampled by removing 30-50 randomly chosen fruiting heads which were spun by hand in buckets to dislodge larvae. Maize crops were sampled by inspecting 30-50 randomly chosen cobs for larvae. When present, the corn silks were removed from the cobs, transported back to the laboratory and searched for *Helicoverpa* larvae under a magnifying glass. All larvae found were reared on artificial diet to determine rates of parasitism. *Helicoverpa* pupae were sampled from beneath crop residues following the methods of Fitt and Daly (1990). At each site 14 - 20 x 1m<sup>2</sup> area of soil was searched for pupae using a trowel. All *Helicoverpa* prepupae, pupae and parasitoids found in the soil were transported back to the laboratory and retained until emergence of a moth or parasitoid. Data for each host plant was pooled to give the total number of *Helicoverpa* collected and the total number parasitised over the entire collection period. Rates of parasitism for individual sample sites or dates are not presented. Records of parasitoids were further analysed to determine the species composition for each host plant and to compare their seasonal phenology.

## Results and discussion

Parasitism records for 20,936 larvae and 9,909 pupae, collected from 14 host plant taxa, were extracted from the database. Records of *Helicoverpa* larval collections from several native Asteraceae were combined as too few larvae were collected from individual plant species for analysis. *Helicoverpa* larvae were collected from over 20 species of Asteraceae, mainly belonging to the genera *Helichrysum* and *Helipterum*. The only other non-crop hosts containing adequate numbers of records for analysis were medic (*Medicago* spp.) and Paterson's curse (*Echium plantagineum*). In the study area, both hosts grew mainly during late autumn, winter and spring months becoming dormant in the hot and dry conditions of summer.

Levels of parasitism of larvae and pupae varied markedly between host plants (Fig. 1A). Parasitism was highest in larvae collected from Asteraceae (11.8%), pigeon pea (11.2%), adzuki beans (10.7%) and sorghum (10.6%). Larval parasitism was lowest in chick pea (1.0%), maize (2.1%) and cotton (4.4%). Levels of pupal parasitism were much higher than larval parasitism for all host plants but the rank order was similar (Fig. 1B). Pupal parasitism was highest in sorghum at 41.3%. For most other host plants pupal parasitism ranged between 20 - 30% but was low in maize (7.8%), chick pea (11.3%), adzuki beans (15.3%) and cotton (16.5%). The species composition of the parasitoid complex also varied markedly between host plants and seasons (Figs. 2 and 3). Parasitoids emerging from the larval collections were dominated by *Microplitis demolitor* Wilkinson (47%). This braconid wasp was particularly dominant in sorghum, soybeans and cotton (Fig. 2A) during summer months (Fig. 3A). *Heteropelma scaposum* (Morley) was also common but tended to be more prevalent during autumn months (Fig. 2B). All species of tachinid flies were grouped together for analysis due to problems in their accurate identification. The tachinids mainly comprised of species belonging to the genera *Carcelia*, *Chaetophthalmus* and *Goniophthalmus* while *Exorista* was also prevalent particularly in collections of larvae from inland areas of Australia. Collectively the tachinids represented 32% of all parasitoids emerging from *Helicoverpa* larvae. Tachinids were more prevalent in larvae collected from non-crop hosts or early planted crops (Fig. 2A), and during

winter or spring months (Fig. 2A). *Netelia producta* (Brulle) was rarely found in collections of larvae (2%), particularly during summer months (Fig. 2B). The species composition of parasitoids emerging from pupae was dominated by *H. scaposum* (57%), particularly in sorghum, soybeans and cotton (Fig. 2B) during all seasons except spring (Fig. 3B). *Pterocormus promissorius* Erichson, a true pupal parasitoid (Fitt and Mares 1992), represented 13% of all parasitoids emerging from pupae and was mainly found during spring months (Fig. 3B). *Brachymeria* sp., *Lissopimpla excelsa* (Costa), and *N. producta* were found only in low numbers. Similarly, tachinids comprised a relatively small proportion of all pupal parasitoids (13%) except in sunflowers (Fig. 2B) and did not show a marked seasonal change in frequency (Fig. 3B). A number of parasitoids emerging from larvae (5%) and pupae (7%) remain unidentified but are thought to be mainly hyperparasitoids of tachinids.

The results from this database suggest that crops such as sorghum, sunflowers and pigeon pea may be useful as refuges for *Helicoverpa* larval and pupal parasitoids while chick peas and maize are not. Native Asteraceae were also good sources of *Helicoverpa* parasitoids and their conservation in farming areas may be of value. The seasonal phenology of host plants is also of importance to ensure that parasitoids are present in the agroecosystem all year round. Most of the Asteraceae sampled grew during winter and spring months at a time when crop hosts were unsuitable or unavailable for *Helicoverpa*. Although levels of larval parasitism in lucerne were comparatively low (6.7%), a high proportion of the larvae collected were infected with disease (33.2%). This is in agreement with other studies cited by Zalucki *et al.* (1986). Consequently, lucerne may act as an important reservoir of *Helicoverpa* larval diseases and the possible role beneficial insects play in the transmission of diseases to other areas warrants investigation.

## Conclusions

Total reliance on parasitoids to control *Helicoverpa* populations in cotton is an unrealistic expectation. Past inundative releases of *Helicoverpa* parasitoids around the world over the last 60 years have failed to lead to commercially useable strategies (King and Coleman 1989, Scholz and Zalucki 1998). Instead, *Helicoverpa* parasitoids must be continued to be viewed as important part of an IPM program. Practices which maximise their conservation in cotton need to be further promoted and refined. Conservation biological control, through habitat manipulation, may be the best approach to increasing parasitoid populations in cotton agroecosystems. The use of unsprayed refuges for parasitoids is a feasible option if integrated with other management practices such as those currently being developed in Australia to prevent the development of resistance to Bt transgenic cotton in *H. armigera*. However, much more research is needed to determine the ecological requirements of key parasitoid species. Opportunities to import and establish more effective *Helicoverpa* parasitoids into Australia should also be considered given the success of *T. pretiosum* in the ORIA. Inoculative releases of *T. pretiosum* into the cotton agroecosystems of eastern Australia should be conducted to determine whether parasitoid populations can be established in these areas.

## Acknowledgments

We thank the Australian Cotton Research and Development Corporation for long term funding which has supported the accumulation of the data presented here.

## References

- Fitt, G. P. (1994). Cotton pest management: Part 3. An Australian perspective. *Ann. Rev. Entomol.* 39, 543-562.
- Fitt, G. P. and Tann, C. (1996). Quantifying the value of refuges for resistance management of transgenic Bt cotton, pp. 77-83. In: Proceedings of the 8th Australian Cotton Conference, August 1996, Gold Coast. Australian Cotton Growers Research Association, Brisbane.
- Fitt, G. P. and Daly, J. C. (1990). Abundance of overwintering pupae and the spring generation of *Helicoverpa* spp. (Lepidoptera: Noctuidae) in northern New South Wales, Australia: implications of pest management. *J. Econ. Entomol.* 83, 1827-1836.
- Fitt, G. P. and Mares, C. L. (1992). Aspects of the biology and ecology of *Ichneumon promissorius*, a true pupal parasitoid of *Helicoverpa* spp., pp. 269-276. In: Proceedings of the 6th Australian Cotton Conference, August 1992, Surfers Paradise. Australian Cotton Growers Research Association, Brisbane.
- Gregg, P. C., Fitt, G. P., Zalucki, M. P., Murray, D. A. H. and McDonald, G. (1993). Winter breeding and spring migration of *Helicoverpa* spp. in inland Australia, 1989-1991. In: Corey, S. A., Dall, D. J. and Milne, W. M. (Eds.) *Pest Control and Sustainable Agriculture*, pp. 460-463. CSIRO Publications, Melbourne.
- Gurr, G. M., Wratten, S. D., Irvin, N. A., Hossain, Z., Baggen, L. R., Mensah, R. K. and Walker, P. W. (1998). Habitat manipulation in Australasia: recent progress and prospects for adoption. In: Proceedings of the Sixth Australian Applied Entomological Research Conference, September 1998, Brisbane. The University of Queensland, Brisbane.
- King, E. G. and Coleman, R. J. (1989). Potential for biological control of *Heliothis* species. *Ann. Rev. Entomol.* 34, 53-75.
- Mensah, R. K. (1998). Habitat diversity: Implications for the conservation of and use of predatory insects of *Helicoverpa* spp. in cotton systems in Australia. *Int. J. Pest Manag* (in press).
- Michael, P. J. and Woods, W. M. (1980). An entomological review of cotton growing in the Ord River area of Western Australia. *West. Aust. Dep. Agric. Tech. Bull.* No. 48.

Scholz, B. C. G. and Zalucki, M. P. (1998). *Trichogramma* - their value in heliothis IPM. In: Proceedings of the Sixth Australian Applied Entomological Research Conference, September 1998, Brisbane. The University of Queensland, Brisbane.

Strickland, G. and Lacey, I. (1996). The seasonal abundance of *Trichogramma pretiosum* in cotton grown with different pest management strategies in the Ord River Irrigation Area (ORIA), pp. 273-277. In: Proceedings of the 8th Australian Cotton Conference, August 1996, Gold Coast. Australian Cotton Growers Research Association, Brisbane.

Zalucki, M. P., Darglish, G., Firempong, S. and Twine, P. (1986). The biology and ecology of *Heliothis armigera* (Hübner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae) in Australia: what do we know? Aust. J. Zool. 34, 779-814.

Fig. A1. Levels of parasitism of *Helicoverpa* spp. larvae (A) and pupae (B) collected from different host plants between 1988 and 1997. The total numbers of *Helicoverpa* spp. collected shown in parantheses.

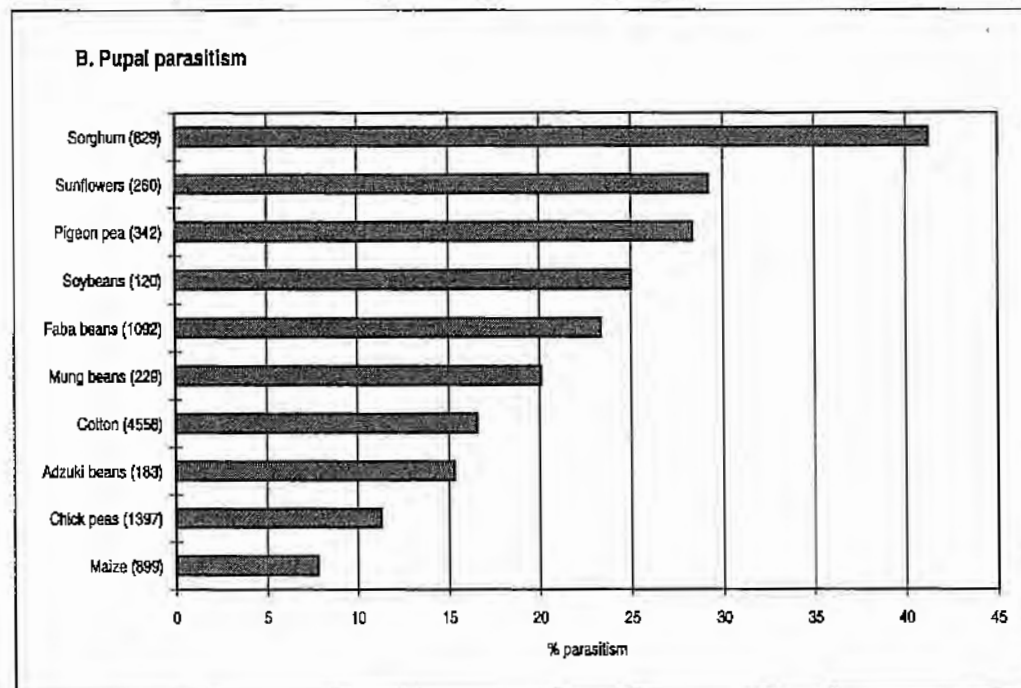
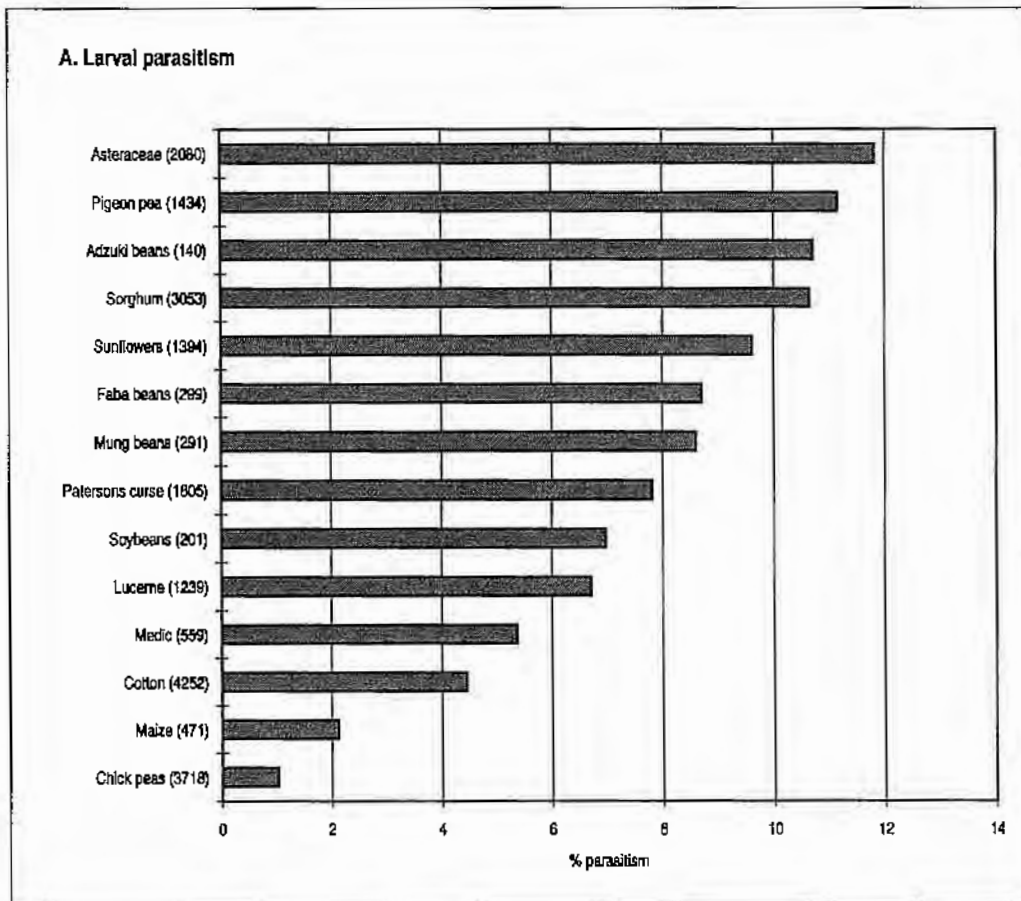


Fig. A2. Composition of parasitoids emerging from *Helicoverpa* spp. larvae (A) and pupae (B) collected in different seasons of the year for the period 1988-1997. The total number of *Helicoverpa* spp. collected in each season shown in parentheses.

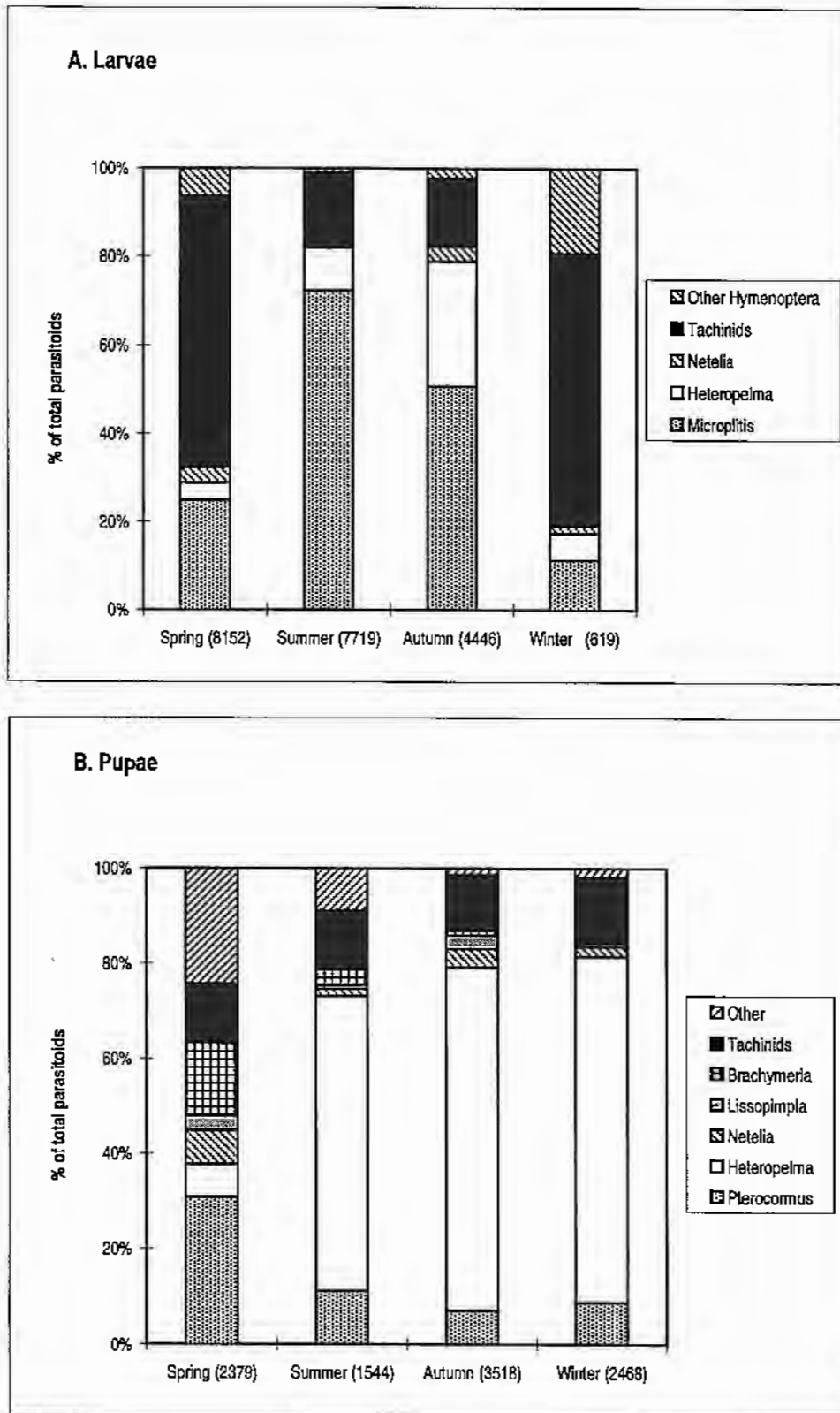


Fig. A3. Composition of parasitoids emerging from samples of *Helicoverpa* spp. larvae (A) and pupae (B) collected from different host plants between 1988 and 1997.

