

**REPORTS**

**Part 1 - Summary Details**

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

**CRDC Project Number:** **CRC40C**

**Annual Report:**  Due 30-September

**Progress Report:**  Due 31-January

**Final Report:**  Due 30-September

(or within 3 months of completion of project)

**Project Title:** The comparison of spider communities in cotton around Australia.

**Project Commencement Date:** March 2002 **Project Completion Date:** Sept. 2003

**Research Program:** 3 Crop Protection

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### ***Part 3.3 – Final Reports***

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(The points below are to be used as a guideline when completing your final report. Postgraduates please note the instructions outlined at the end of this Section.)

#### **1. Outline the background to the project**

The aim of Integrated Pest Management (IPM) is to manage pest infestations in agricultural systems by using natural enemies and more selective products. The most abundant group of predators in agricultural systems are spiders. Spiders make up 50% of the predators in unsprayed cotton crops in Australia (Bishop & Blood 1981), up to 57 % in African cotton (Epieru *et al* 1998) and up to 80% in Chinese cotton (Zhang 1992); but these predators are often overlooked as biological control agents.

In order to be an effective biological control agent predators are thought to require specific characteristics, such as a high degree of prey specificity, short development time relative to prey, and high reproductive potential (Huffaker and Messenger 1976, Beddington *et al* 1978). Spiders are often discounted as useful biological control agents because: they are generalist predators which attack other beneficials; they have long generation times relative to prey; some are territorial; and they seldom show density dependent tracking of prey (Provencher 1988, Riechert 1999, Pearce 2004).

Some of these negative attributes may be beneficial (Murdoch *et al* 1985) especially if the aim is to control a range of pests. For example, intraguild predation is not necessarily detrimental to pest control as it may even lead to better control of a pest (Dinter 2002, Snyder and Ives 2003) or a more diverse community of predators that cover all niches. By reducing ‘predator free space’ a diverse community of predators can maintain pests at manageable levels (Riechert and Bishop 1990, Sunderland 1999).

A method to understand how a spider community affects pest populations is to classify spiders into guilds (groups) based on foraging behaviour. Spiders within different guilds focus on different types of prey (Nyffeler 1999). By identifying the spider guilds within a crop we can better predict which prey are being attacked.

When spider guild classifications are applied to different crop types, two distinct groups of structurally similar spider communities are identified (Uetz *et al* 1999): crops whose spider fauna is dominated by ground runners and wandering sheet web-builders (peanut, alfalfa, soybean, rice) and crops whose spider fauna is more complex and also includes many orb weavers and stalkers (cotton, corn, sugar, sorghum). A more complex spider fauna, such as that in cotton, is more effective against a range of pest species because it reduces “enemy free space” for the pests. Consequently it is in agricultural systems such as cotton where spiders may be best used to help suppress pests.

The aim of this study was to:

- 1) Identify the spider communities associated with cotton in different locations around Australia;
- 2) Establish whether these communities around Australia are structurally identical (that is, whether they consist of the same guilds represented by different species); and
- 3) Establish whether the community structure changes over the course of a year, and if so, if the changes are similar at the different sites.

## 2. Project objectives and achievements

- (1) *Identify the spider communities associated with cotton in different locations around Australia.*

This objective was achieved.

We identified to family nearly 5000 spiders from 7 sites around Australia, ranging from Kununurra in the tropical north to Murrumbidgee in the far south. This survey enabled us to categorize the spider communities at the different sites.

- (2) *Establish whether these communities around Australia are structurally identical (that is, whether they consist of the same guilds represented by different species).*

This objective was achieved.

We found that the spider communities around Australia are not structurally identical. In the spider community sampled by beatsheets, Oxyopidae, a stalker, dominated the communities in the south; in central locations, the dominant family changed over the course of a season; while in the north the community was dominated by Cycloctenidae, a foliage runner.

The spider community sampled by pitfall traps was also influenced by seasonal changes, but this was less important than the BDI (or spraying regime) the field had received.

- (3) *Establish whether the community structure changes over the course of a year, and if so, if the changes are similar at the different sites.*

This objective was achieved.

In the spider community sampled by beatsheets, the community structure did not change so much in the South (Murrumbidgee) or the far north (Kununurra) but it did change in more central locations, rotating through Oxyopidae (stalker), Clubionidae (foliage runner), Salticidae (stalker), Theridiidae (web builder), to Clubionidae (foliage runner).

The spider community sampled by pitfall traps was overwhelmingly dominated by Lycosidae (wolf spiders, which are ground runners) throughout the year. An exception was a few samples taken at the beginning of the season under low BDI where other families, such as Gnaphosidae (also a ground runner) nearly equalled Lycosidae in numbers. Most of these samples were from Katherine.

As a result of this project we have an excellent spider reference collection at Narrabri, which we are using in our current project on the predators of mirids (CRC 6.1.2 AC/CRDC252).

### 3. Methods

Spiders were sampled during the 2001/2002 field season at seven sites around Australia, extending from temperate climates in the south, to tropical climates in the north (Fig. 1). Between 1-3 fields were sampled at each site, and these varied in size, cotton variety, and spray regime (Table 1). In each field 20 pitfall traps and 20 beat sheets were sampled 3 to 5 times during the cotton growing season (which occurred at different times during the year, Table 1).

	Cotton type	Field size (ha)	Sowing date	First sample 400 DD			Second sample 800 DD			Third sample 1200 DD			Fourth sample 1600 DD			Fifth sample 2000 DD			
				beat-sheet	pitfall traps	BDI	beat-sheet	pitfall traps	BDI	beat-sheet	pitfall traps	BDI	beat-sheet	pitfall traps	BDI	beat-sheet	pitfall traps	BDI	
Griffith-Murrumbidgee	Brooklyn	Ingard	126		38	13	0	82	6	1	61	18	1	43	26	21	35	13	21
	Merrowie	Ingard	110		60	32	0	89	39	0	104	17	8	191	9	8	229	10	8
	Merrowie	Ingard	144		22	33	0	17	10	2	3	9	43	6	22	29	2	22	
Pilliga	Lowana	Conventional Sicot 80	90.5	17.09.01	24	9	3	84	10	15				153	15	22			
		Conventional 189 Sicot RR																	
Namoi	Myall Vale	QAP	0.8	02.10.01	15	5	0	85	17	0				526	60	0			
Bogabilla	Fairfield	Ingard 289i	74.5	26.09.01				48	17	4		32	4				321	28	4
		Sicot																	
		Ingard 289i	25	29.09.01	28	32	0												
		Sicot																	
	Morella	Conventional Sicot 289	23.6	29.09.01							51		10						
	Conventional Sicot 189	44.3	29.09.01	14	23	1	70	24	1	49	19	7	153	23	14				
	Eumorella	Conventional Sicot 189	111		24	26	1	19		10	14	18	21				32	23	45
Darling Downs-Ji	Coondarra	Conventional with chickpea	6.2	3.11.01	9	13	0	84	7	0	181		0	307	19	0			
Biloela	RS	Ingard	3		11	8	0				10		0		15	0			
	RS	Conventional	3		14	15	0	10	14	0	6		0						
Kununarra	Frank Wise Ins	Ingard 289i	7	27.4.02	47	6	0	28	0	0	31	0	2						
		Sicot																	
	Barradale	Ingard 289i	48	23.4.02	17	7	0	47	1	0	34	5	7						
Katherine	RS	Ingard Siokra V16i	13.5	9.4.02	5	19	0	10	7	0	21	6	0	21	9	22	3		22
	RS	Conventional Sicola 40	2.2	24.4.02	2	23	0	12	8	0	22	4	0	9	21	0	33	27	0

**Table 1.** field information and sampling dates at the seven sites around Australia.

around Australia.



**Fig. 2.** Pitfall trap in cotton.

*Pitfall traps:* The 20 pitfall traps were plastic cups 9cm wide at the top. Two cups were used for each pitfall trap. One cup was put into the ground and stayed there for the length of the season. The second cup (the sampling cup) was placed inside the first cup. It contained about 2-3 cm of Ethanol in the bottom to kill and preserve the captured spiders (Fig. 2). Traps were left open for 3 days, and were closed between sampling periods by putting a lid over the cup. The first pitfall trap was placed at least 20 metres from the

edge of the field; the second was placed 15 metres further into the field and one row over; and the third was placed a further 15 m into the field and one row over. This pattern was repeated so that once all 20 pitfall traps were in place, the last one was about 285m into the field, and 20 rows were being sampled.



**Fig. 3.** Collecting spiders

*Beatsheets:* Beatsheet sampling involved placing the edge of a yellow plastic sheet (1.5 x 2 m) below the sample row, and then stretching the rest of the sheet along the ground and up over the adjacent row (Fig. 3). Plants in the sample row were shaken vigorously 10 times working from the base to the top of the crop canopy using a one metre stick, causing insects and spiders to fall from the plants onto the sheet. All spiders knocked onto the beatsheet were collected and preserved in 70% ethanol for latter identification. This method is more efficient than other common sampling techniques for beneficial arthropods such as suction sampling or visual inspection, particularly

late in the growing season when the crop canopy is well developed (Deutscher et al. 2003).

## ***Analysis***

Samples were categorised into 5 different time periods during the growing season, as indicated by the cotton's development and "Degree Days" (DD). These were: 1, at first square (400 DD); 2, at first flower (800 DD); 3, at peak squaring (1200 DD); 4, at peak boll (1600 DD); 5 when 60% of the bolls are open (2000 DD).

For the ordination analysis, data from the beatsheet and pitfall traps were analysed separately and combined. When analysed separately, the unit of measurement was the all the beatsheets (or pitfall traps) taken from a field on a sample date. When we combined the data, the unit of measurement was the field on a sample date. No one sampling method can accurately sample the whole spider community. With Beatsheets we sampled diurnal hunters and web-builders (but perhaps not the larger web builders). With the pitfall traps we sampled

diurnal and nocturnal ground runners, and males looking for females. By using these two methods we have a better cross section of the spider community as a whole.

We used the program CONOCO (ter Braak 1986) to calculate the ordinations. We used a Detrended Correspondence Analysis (DCA) as an indirect analysis to see how similar the species composition of different samples were to each other, and a Canonical Correspondence Analysis (CCA) to see the effect of key environmental variables on the species composition of the samples. The environmental variables tested were: site (or the location where the samples were taken); field size; 'Bt' (whether the crop was a Bt transgenic or not); DD period; and BDI. BDI, or Biological Disruption Index, is a measure of disruption to beneficial insects caused by spraying insecticides (Hoque *et al* 2002). This index ranges from 0 - 8 and reflects the proportional reduction in beneficial arthropod abundance observed after a single application of an insecticide compared with beneficial arthropod abundance prior to application (e.g. BDI = 5 means a 50% decline in abundance after application). The final BDI for a particular cotton field is determined by combining the scores for each spray applied over the season. The lower the final score, the softer the regime. Sites were ranked on an ordinal scale (1 – 7, Fig. 1) as they extended from Murrumbidgee (1) in the south, through the cotton growing belt to Kununurra (7) in the north.

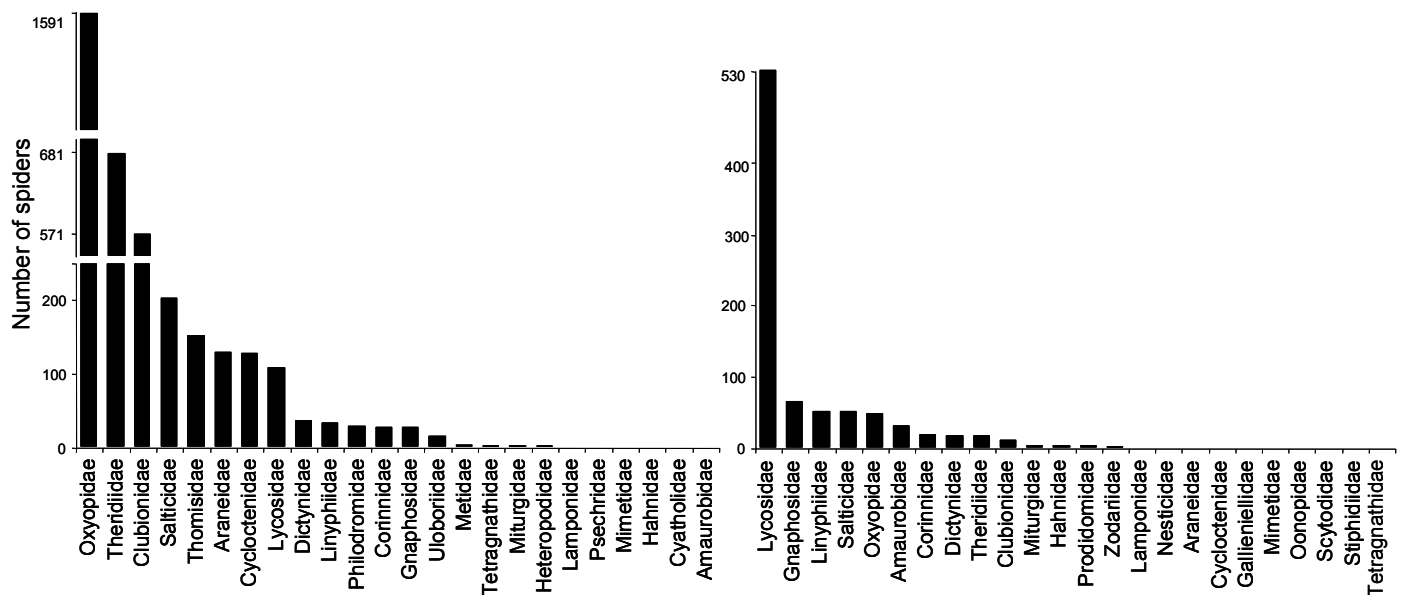
As diversity indices differ in their strength and weaknesses, we compared the species diversity of spiders using three diversity indices. We used the Simpson index (Simpson 1949) and Shannon-Wiener index (Tothmeresz 1995) to measure evenness (a measure of the distribution of relative abundances of different taxa in a sample) and rarefaction curves (Sanders 1968) to measure richness (the number of species in a sample). The Simpson and Shannon-Wiener indices are at different ends of Renyi's diversity order (Tothmeresz 1995) and so give a good overview of evenness. The Simpson index we used is corrected for sample-size bias ( $SI = \sum((n^2 - n)/(N^2 - N))$ ) and modified ( $-\ln SI$ ) following Rosenzweig (1997) so that the units increase with an increase in diversity. The Simpson index is more sensitive to dominant species, while the Shannon index ( $H = -\sum p_i \ln p_i$ ) is more sensitive to rare species.

To calculate the rarefaction curves we used the program developed by S.M. Holland which is available on the web at: [www.uga.edu/~strata/software/AnRareReadme.html](http://www.uga.edu/~strata/software/AnRareReadme.html).

## **Identification**

Spiders were identified to family following the classification of Australian genera used by Raven *et al* (2002).

## 4. Results



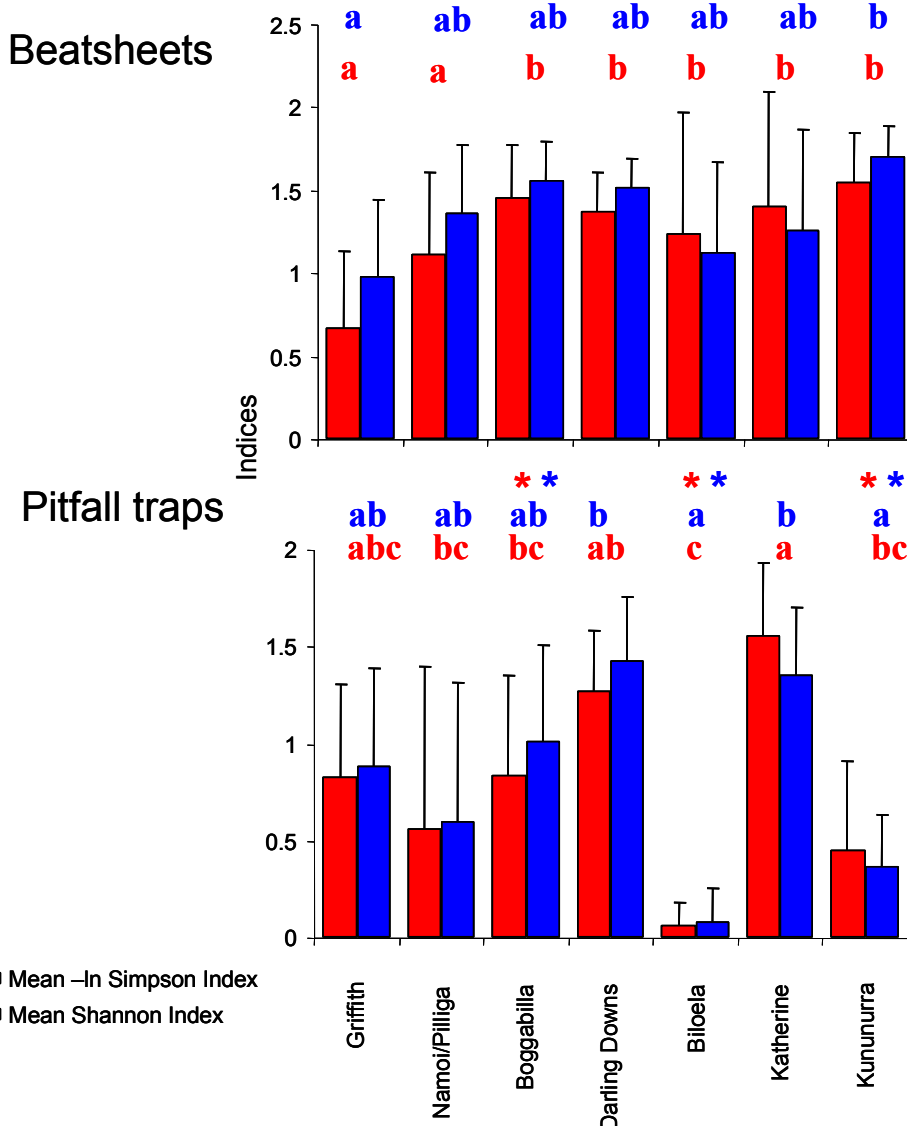
**Fig. 4. Histograms of spiders caught using beatsheets (left) and pitfall traps (right). 3763 spiders from 24 families in 58 samples were caught using beatsheets. 852 spiders from 24 families in 52 samples were caught using pitfall traps**

### Abundance and diversity

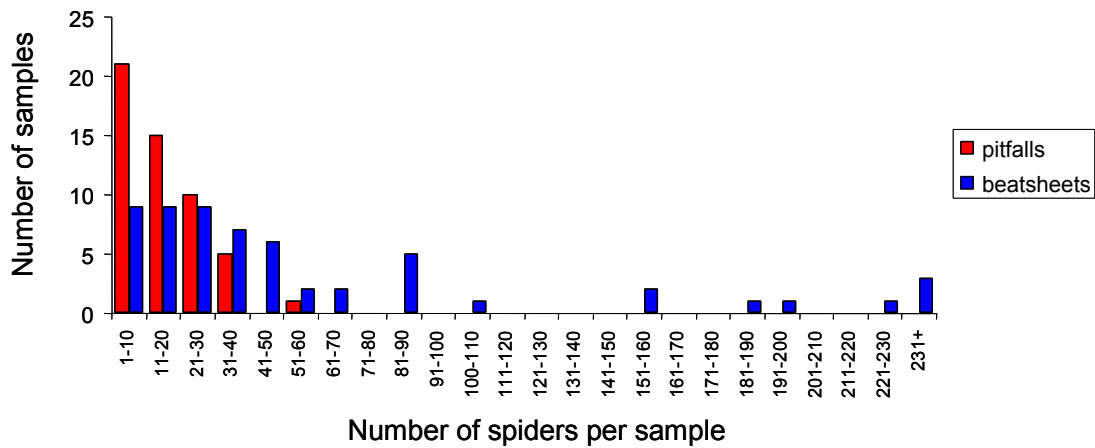
Over 4500 spiders were sampled from 24 families using beatsheets and pitfall traps (Fig. 4, Table 2). Of these, seven families made up 92% of the spiders captured. These were (in numerical order): Oxyopidae, Theridiidae, Lycosidae, Clubionidae, Salticidae, Thomisidae, Araneidae and Cycloctenidae (Fig. 4, Table 2).

Family	TOTAL	Pitfall traps							Beatsheets						
		Griffith	Namol/ Pilliga	Boggabilla	Darling Downs	Biloela	Katherine	Kununurra	Griffith	Namol/ Pilliga	Boggabilla	Darling Downs	Biloela	Katherine	Kununurra
Amaurobidae	33	3	4	16	5		4			1					
Araneidae	131						1		13	33	14	10	23	6	31
Clubionidae	583	1	1	4	1		5		38	143	236	125	3	12	14
Corinnidae	49	9	3	4	3	1			11	4	3	4		3	4
Cyatholidae	1														1
Cycloctenidae	129						1		11	4		8	2	24	79
Dictynidae	57	15	1		1		2		9	3	4	16		2	4
Gallieniellidae	1				1										
Gnaphosidae	95	28	3	7	7		22		3	1	15	7		2	
Hahnidae	5	0	0	1	3							1			
Heteropodidae	3								1		1				1
Lamponidae	4	1		1							1				1
Linyphiidae	87	8	3	29	1		7	4	7	8	8	7		1	4
Lycosidae	639	127	93	163	30	52	46	19	23	16	67		1	1	1
Metidae	4								3		1				
Mimetidae	2						1				1				
Miturgidae	8	2		1	1		1				3				
Nesticidae	2			1			1								
Oonopidae	1						1								
Oxyopidae	1640	32	3	6	5		3		806	310	175	209	10	55	26
Prodidomidae	4			1	3										
Philodromidae	30								14	1	10	4		1	
Psechridae	1														1
Salticidae	256	7	3	20			22		23	52	94	11	1	13	10
Scytodidae	1						1								
Stiphidiidae	1			1											
Tetragnathidae	4		1								1		1		
Theridiidae	699	4	1	7			6		71	286	168	117	5	17	17
Thomisidae	153								42	15	14	61	5	6	10
Uloboriidae	16								1	9	6				
Zodariidae	3			3											

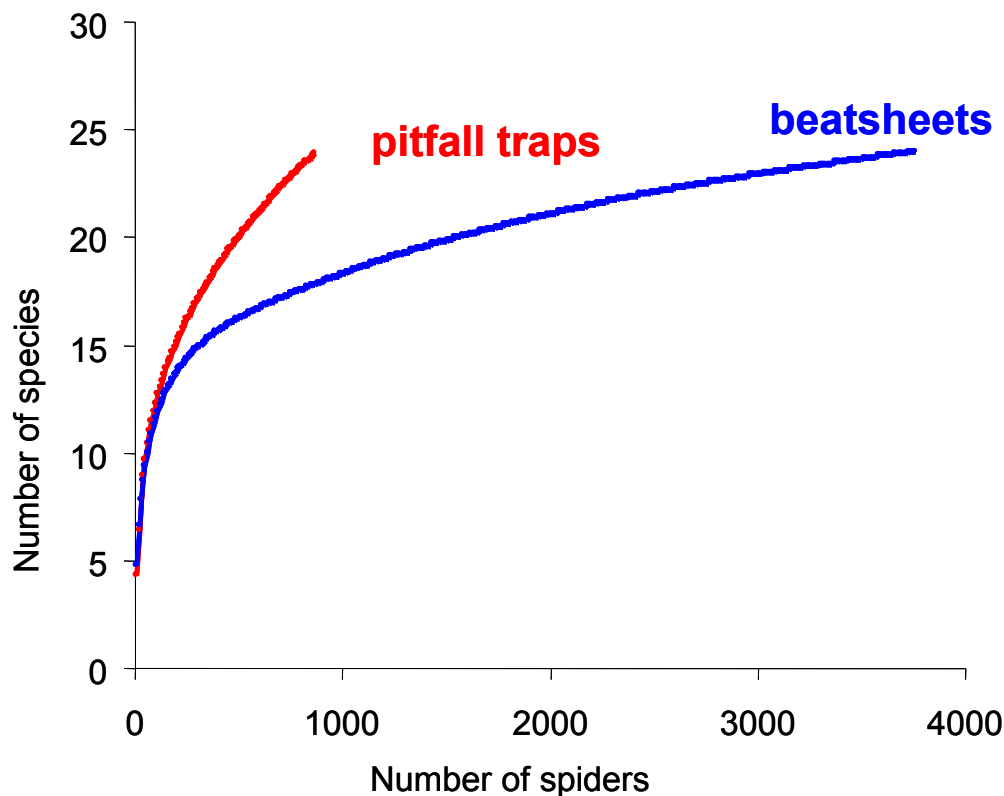
**Table 2.** The spider families found in pitfall traps and beatsheets at the different sites around Australia.



**Fig. 5** Diversity indices of spiders caught using beatsheets and pitfall traps at the seven locations. \* indicates locations where the diversity of the pitfall traps is significantly lower than that of the beatsheets. Different letters in the same colour indicate the locations which are significantly different from each other for the Simpson (red) or Shannon (blue) index.



**Fig. 6.** Number of spiders caught in beatsheet and pitfall trap samples.



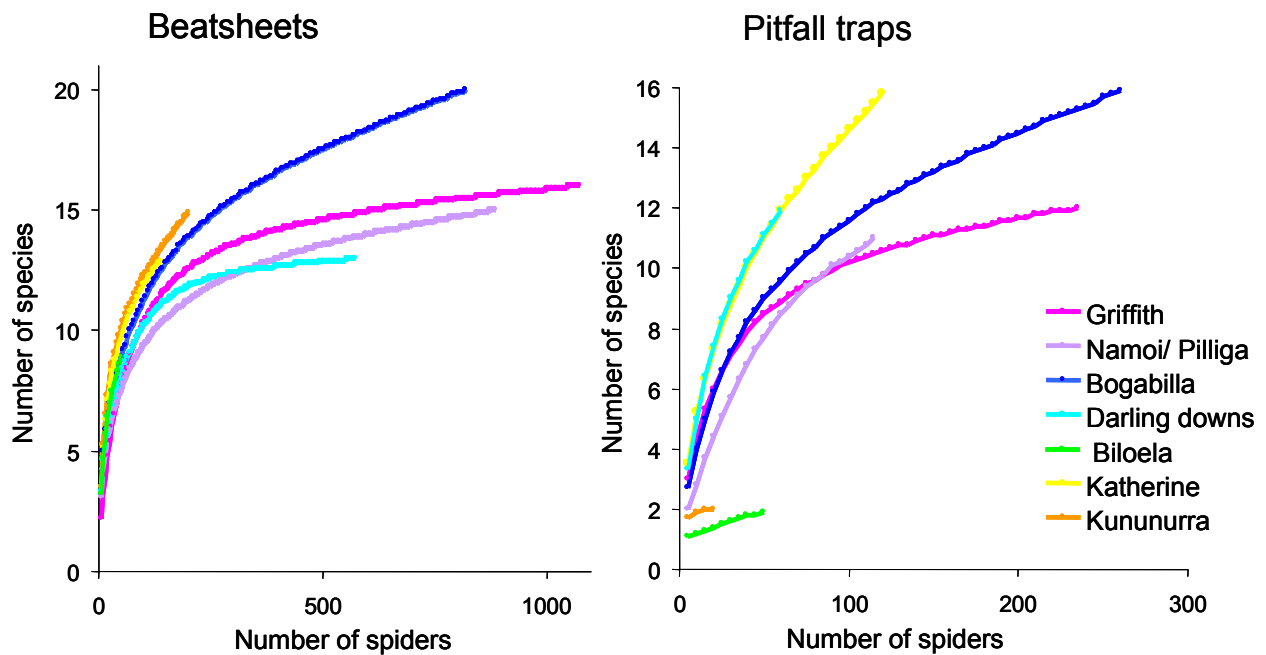
**Fig. 7. Rarefaction curves of all beatsheet and pitfall traps, sampled in groups of 10 spiders.**

The Simpson and Shannon indices were highly correlated across all sites using both sampling methods (Spearman's rank correlation coefficient:  $r^2 = 0.96$ ,  $df=12$ ,  $p<0.001$ ). The diversity indices of the beatsheet communities were more even than those of the pitfall trap communities. An ANOVA examining the effect of site and sampling method on the diversity indices found a significant difference between 1) the diversity of spiders at the different sites ( $df=6,81$ , Shannon index:  $F=3.69$ ,  $P<0.003$ ; Simpson index:  $F=6.52$ ,  $P<0.001$ ); 2) the diversity of spiders caught using beatsheets and pitfall traps ( $df=1,81$ , Shannon index:  $F=28.78$ ,  $P<0.001$ ; Simpson index:  $F=13.1$ ,  $P<0.001$ ; Fig 5); and 3) an interaction effect of sampling method and site ( $df=1,81$ ; Shannon index:  $F=4.68$ ,  $P<0.001$ ; Simpson index:  $F=5.17$ ,  $P<0.001$ ). In particular, Kununurra had the most diverse spider community captured using beatsheets, whereas Katherine had the most diverse pitfall trap community. Biloela had an especially non-diverse pitfall trap community, with all spiders except 2 being Lycosidae. Beatsheet communities were more diverse than pitfall trap communities, and significantly so in the case of Boggabilla, Biloela and Katherine (Fig. 5). There was also a significant interaction effect of site and sampling method, indicating that the differences between the sampling methods was not consistent.

Beatsheet samples were more diverse than pitfall trap samples (average Simpson index for beatsheets was 1.248 and pitfall traps was 0.926; while the average Shannon index for beatsheets was 1.374 and pitfall traps was 0.953) even though the same number of families were caught in the beatsheet and pitfall traps (Fig. 7.). This is largely because of the overwhelming dominance of lycosid spiders in pitfall traps (Lycosidae made up 62% of all spiders caught in pitfall traps).

Fewer individuals were caught in the pitfall trap samples (Fig. 6). For example, 21 samples contained 10 or less spiders, and 6 samples contained only 1 family, Lycosidae. Thus clear patterns were harder to ascertain from the pitfall trap data.

This was reflected in the rarefaction curves (Fig. 7), which indicated that the number of species caught in pitfall traps was greater than for beatsheets when compared at the same sample size.



**Fig. 8. Rarefaction curves of spiders caught in beatsheets and pitfall traps at the different sites around Australia, sampled in groups of 5 spiders.**

When the rarefaction curves from the different locations are compared (Fig 8) it appears that the beatsheet spider communities at Katherine, Kununurra and Boggabilla have more families than those at Griffith, Namoi/Pilliga and Darling Downs. The sampling of Biloela did not fully sample the community, but suggests that it could have as many families as Boggabilla. The pitfall trap communities at the different sites were a lot more variable in terms of family richness. Biloela and Kununurra were particularly poor with only two families caught at both sites. Katherine and Darling Downs appear to be family rich sites.

#### Community similarities

An indirect ordination analysis (DCA) which compared the similarity of spider communities collected in each sample, confirmed that beatsheet and pitfall traps sampled different spider communities as the samples tended to form two distinct groups (Fig. 9, first axis explains 24.4% of total variance, the first 2 axes explain 34.9%, sum of all eigenvalues = 2.7). The exceptions were two pitfall traps, one from both Katherine and Murrumbidgee. Within the beatsheet samples there was a tendency for samples to fall along a north/south gradient, with the more northern samples at the top of the diagram, and the more southern samples at the bottom. This indicates that the spider community varies across Australia. A similar trend was seen in the pitfall traps, but the small sample sizes and the dominance of Lycosidae reduced the strength of the pattern.

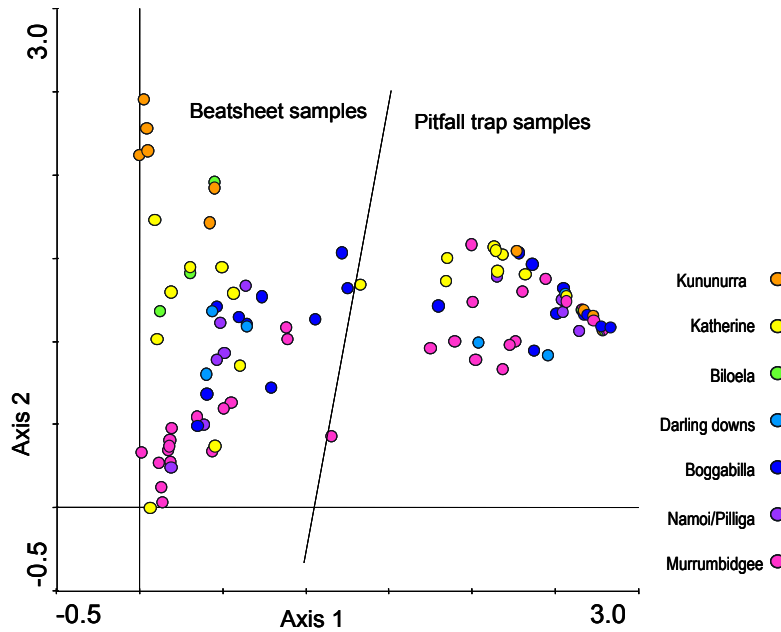


Fig. 9. Indirect ordination analysis (DCA) of beatsheet and pitfall trap samples.

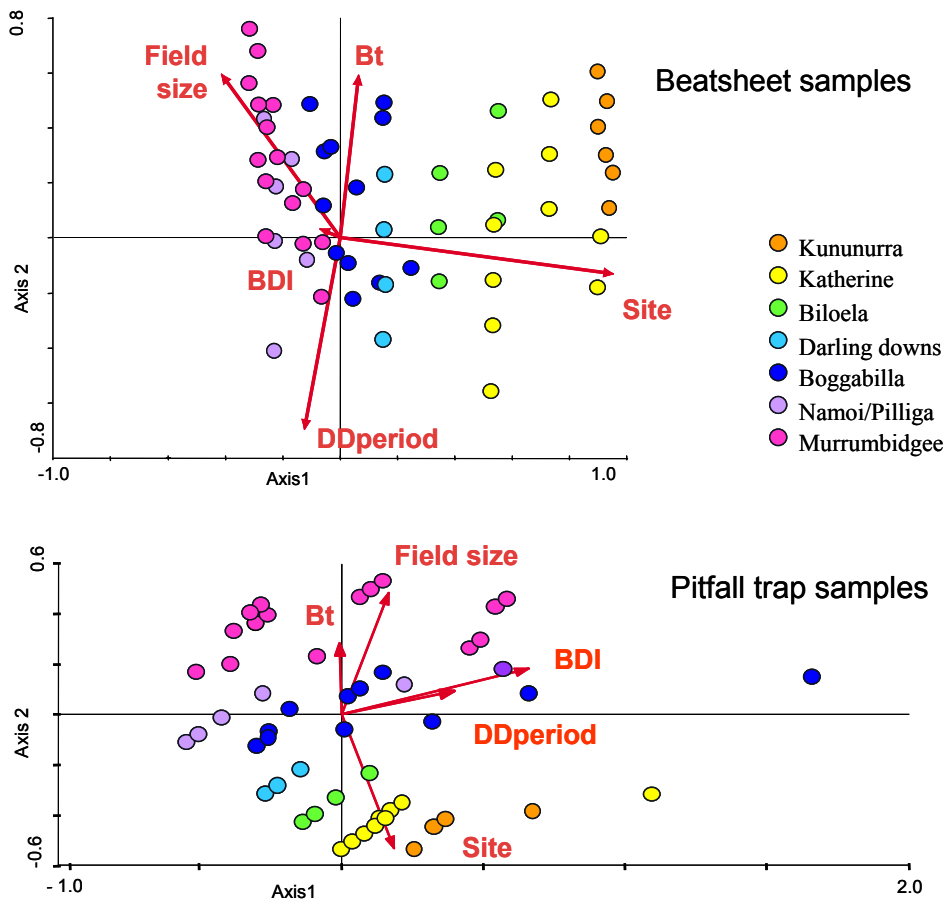


Fig. 10. Direct ordination analysis (CCA) beatsheet and pitfall trap samples in relation to environmental variables.

A direct ordination analyses of the beatsheet and pitfall trap data (CCA, Fig.10) positioned samples with respect to the

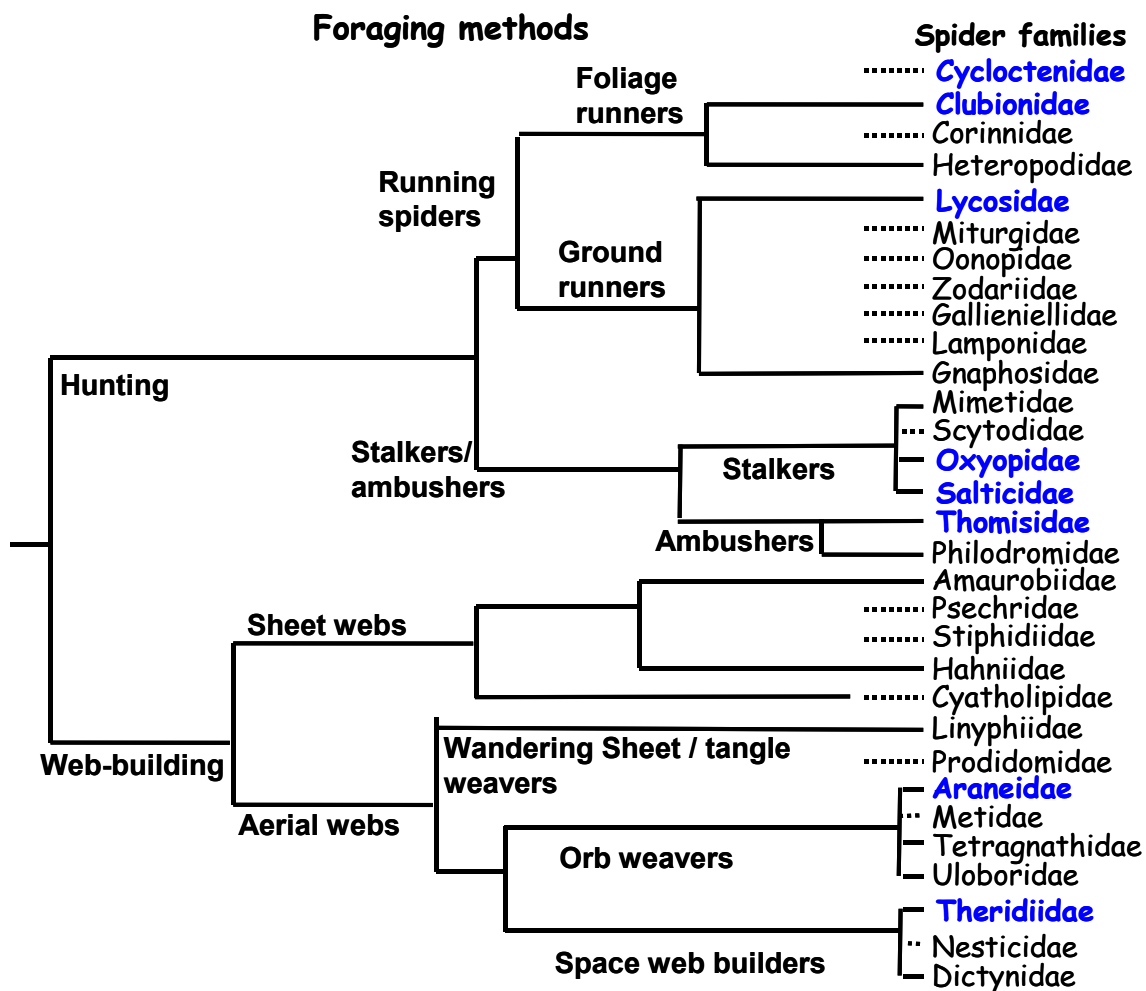
environmental variables: Site, Degree day, BDI, Bt crop, and Field size. This analysis revealed that these variables had a significant effect on the spider communities (beatsheet

samples: monte carlo test, F-ratio=5.53, P=0.002, first 2 axes explaining 27% of the variance; pitfall trap samples: monte carlo test, F-ratio=1.88, P=0.002, first 2 axes explaining 12% of the variance).

Among the beatsheet samples, site had the strongest effect, contributing the most to the first axis. Degree day and whether the crop was Bt or not contributed strongly to the second axis. Field size was most relevant to the samples taken from southern sites. The BDI had little impact on the spider community.

Among the pitfall trap samples, site was only of secondary importance, contributing strongly to the second axis, even though samples grouped out according to site. In the pitfall trap samples, BDI had the strongest effect on the spider communities. Field size was again most relevant to the southern samples.

### Family composition



**Fig. 11** A dendrogram (based on Uetz et al 1999; for American spiders) showing the spider families found during our survey and the hunting guild to which they are associated. The dashed lines indicate families not reported in the American study. The eight most abundant families (which combined contributed to 92% of the total number captured) are highlighted in blue.

Spiders from all foraging guilds were found in the cotton, although the majority of animals were from the hunting guilds (six out of the eight most abundant families were hunters, Fig. 11, Table 2).

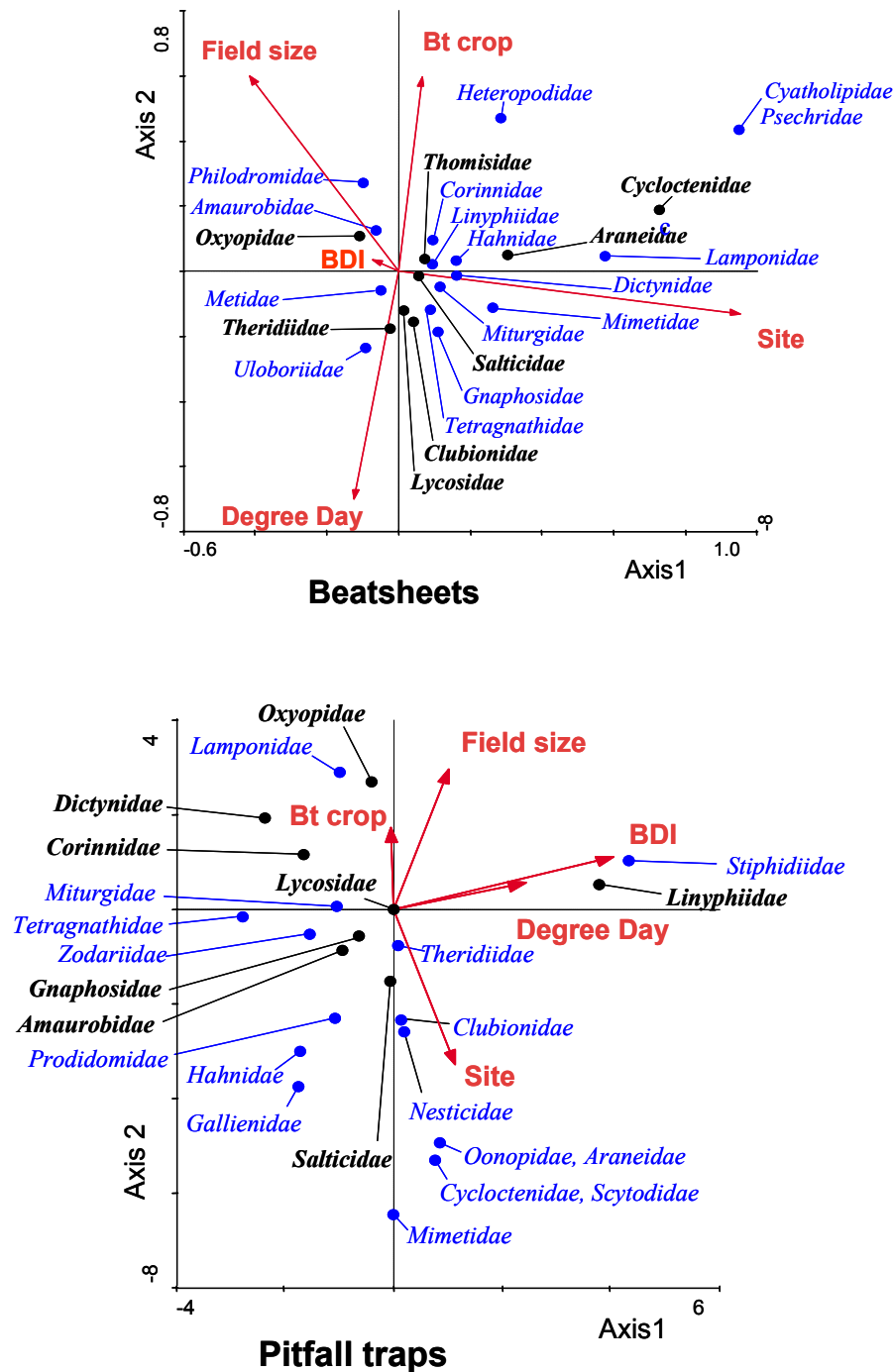


Fig 12. Spider families found in beatsheets and pitfall traps in relation to environmental variables using a direct ordination (CCA). The eight most common families in abeatsheet and pitfalltrp samples are highlighted in black

Of the eight most common families found in beatsheets and pitfall traps, three (Lycosidae, Oxyopidae, Salticidae) were common in both sample types (Figs 4 & 12). In both beatsheets and pitfall traps, the eight most common spider families were not spread evenly between the samples. In beatsheets Cycloctenidae were strongly associated with

northern sites, Oxyopidae were more common in larger fields (Although this may be because the larger fields tended to be in the south – fields of comparable size in more northern sites did not have such high numbers of Oxyopidae) and Theridiidae and Clubionidae were more common latter in the season (Table 2, Fig 12).

In the pitfall traps, Oxyopidae were again more common in larger fields, and Linyphiidae were more common in sites with a high BDI. Lycosidae are right at the center of the diagram, indicating that they were equally common in all pitfall traps, regardless of conditions.

*Do spider communities change over the course of a season?*

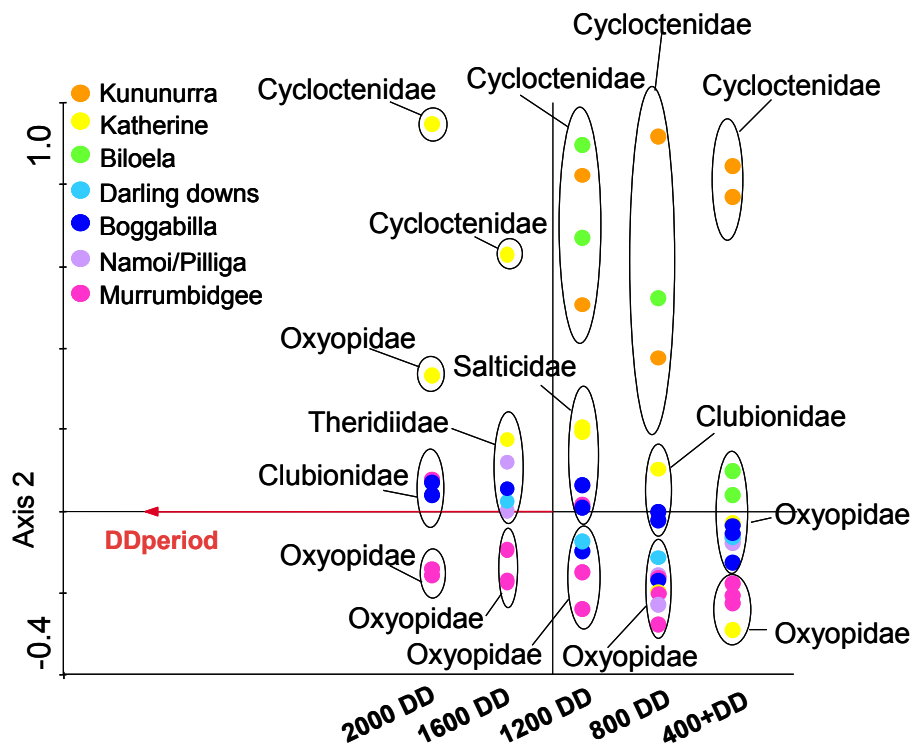


Fig. 13. CCA ordination of the beatsheet samples. The samples were aligned along the environmental variable, Degree days. Within each degree day, similar samples are circled. The most abundant family for each circle of samples is indicated.

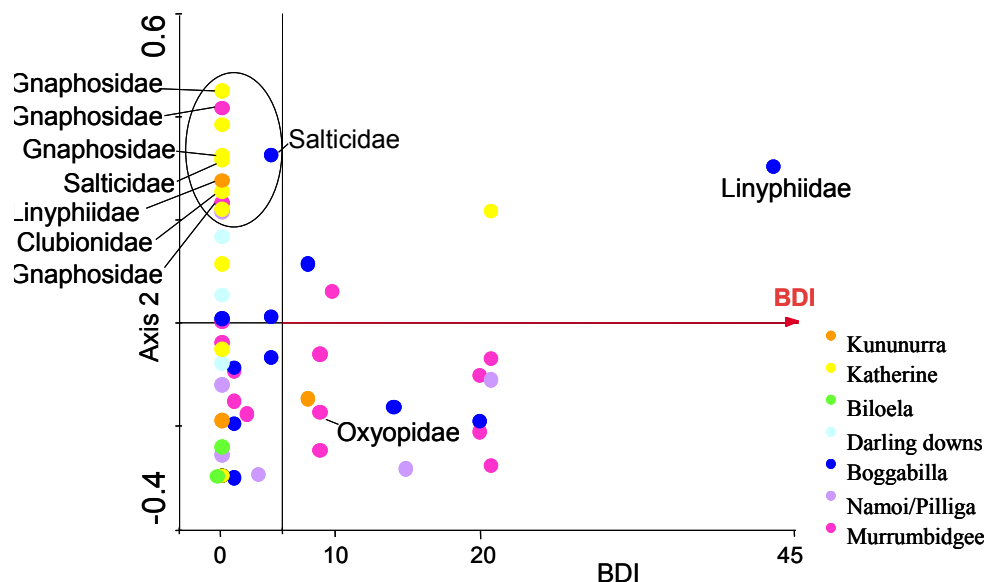


Fig. 14. CCA ordinations of pitfall trap samples. The samples were aligned along the BDI environmental variable. A family name indicates a sample in which that family equalled Lycosidae in abundance. A large concentration of these were found at 0 BDI (circled).



The beatsheet ordinations indicated that site played a major role in the characteristics of the spider communities, and that changes during the season had a secondary effect. To compare the communities at the different sites found throughout the season, we did a direct ordination analysis using degree days as the environmental variable. This forced the samples to align themselves along the x axis with respect to degree days (crop development) which explained 6.1% of the variance between the samples (monte carlo test: F-ratio=3.65, P=0.002). It revealed that the samples could be divided roughly into three groups throughout the season: samples collected in the south (mainly Murrumbidgee) those collected in the far north (mainly Kununurra) and those collected at more central latitudes (Fig. 13.). For each of these groups we identified the most abundant family. Of the southern samples, Oxyopidae was always the most abundant. In the north, Cycloctenidae was always the most abundant, while in the center the most abundant family changed throughout the course of the season. The families came from different foraging guilds (Oxyopidae and Salticids: stalkers; Cycloctenidae and Clubionidae: foliage runners; and Theridiidae: space web builders).

The pitfall trap ordinations indicated that the effect of seasonal changes (as indicated by degree days) on the spider community was overshadowed by the effect of spraying (as indicated by the BDI, Fig. 12). Thus we decided to compare the communities at the different sites found under different BDIs (Fig. 14). Do to this we did a direct ordination analysis using BDI as the environmental variable. This forced the samples to align themselves along the x axis with respect to BDI or amount of spraying (which normally increases as the season progresses, although some sites did not receive any sprays as their BDIs were 0 throughout the season; Table 1). BDI explained 6.5% of the variance between samples (monte carlo test: F-ratio=3.5 P=0.012). Lycosidae strongly dominated most of the pitfall trap samples. To try to understand differences in the communities we identified samples when a family was equally abundant or more abundant than Lycosidae (Fig. 14). The ordination indicated that at low BDI, the samples from the north (Katherine) were less likely to be dominated by Lycosidae, and that other hunting spiders (Fig. 9) such as Gnaphosidae, Clubionidae, or Salticidae, could be the most abundant. In the sample with the highest BDI (45) the most abundant family was Linyphiidae. Of the group of samples circled in Fig 14, 21% of the spiders caught were Gnaphosidae, while 28% were Lycosidae (of all the spiders caught in pitfall traps, 62% were Lycosidae).

## Discussion

### Species composition

The spider communities sampled by beatsheets and pitfall traps were quite distinct.

The Beatsheet communities, unlike the pitfall trap communities, were strongly influenced by changes through the season, but they varied in their response to the changes. The beatsheet communities in the far north and the far south were dominated by one family throughout the season (Cycloctenidae and Oxyopidae respectively). Communities in the center followed a seasonal succession of dominant families (Oxyopidae, Clubionidae, Salticidae, Theridiidae and Clubionidae). Although it is unclear why there is a succession of dominant families at some sites but not others, it means that management of pests using spiders will need to be modified at the different sites, because the spider community will respond differently to pest pressure.

Although spiders are regarded as generalist predators (Turnbill 1973) many families, including the ones prominent in this study, have a strong effect on key pests. Oxyopidae, or Lynx spiders, are stalkers (Fig. 15). Bishop and Blood (1981) found that *Oxyopes mundalis* is an important predator of *Helicoverpa* spp larvae in Australian cotton crops. Oxyopidae are known to be particularly effective at attacking mirids, with the striped lynx spider (*Oxyopes salticus*) responsible for 15-18% of the daily mortality of the cotton fleahopper (*Pseudatomoscelis seriatus*; Miridae) in Texan cotton fields (Nyffeler *et al* 1992). Breene *et al* (1989) found that 31% of all striped lynx spiders captured in a cotton field had consumed immature fleahoppers. The dominance of this family in the south, particularly at Murrumbidgee, may indicate that this community could respond more effectively to a mirid problem than those in other parts of the country.

Although Cycloctenidae dominated the beatsheet samples in the north, little is known about its prey preferences or ecology, other than it is a stalker like lynx spiders (Raven *et al* 2002). More work is needed to understand the role of this spider in cotton.

Clubionids dominated the beatsheet samples at 800 DD and 2000 DD in the central locations. Most of these spiders were the yellow night stalkers from the *Cheiracanthium* genus (Fig. 16). *Cheiracanthium diversum* is reported to be an important predator of *Helicoverpa* spp larvae in Australian cotton (Bishop and Blood 1981). Yellow night stalkers are reported responsible for 80% of the *Helicoverpa* eggs taken from cards placed in cotton fields (Sholtz 2000) and they were the only spider to take *Helicoverpa* eggs in a laboratory study (Pearce *et al* 2004).

*Cheiracanthium* are also known to attack cotton fleahoppers (Breene *et al* 1989) and



Fig 15. Oxyopidae (Lynx spider)



Fig. 16. *Cheiracanthium* (Clubionidae) or yellow night stalker.

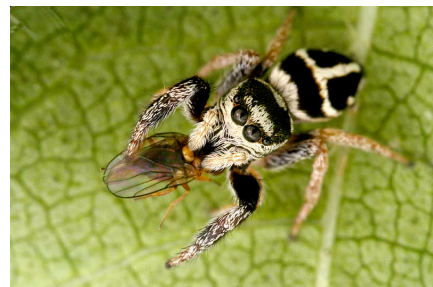


Fig. 17. Salticidae, or jumping spider

*Cheiracanthium mildei* was the most effective spider against the carmine spider mites, *Tetranychus cinnabarinus*, in a laboratory study (Mansour *et al* 1995) capturing 27.5 mites/day/predator (compared to 16.8mites/day/predator for Oxyopidae, and 11.3 mites/day/5 predators of the predacious mite, *Phytoseiulus persimilis*).

Salticidae (jumping spiders, Fig. 17) show a preference for jasids in apple orchards (Brown *et al* 2003) and are also major predators of mirids in cotton (Breene *et al* 1989). The jumping spider *Heliophanus pistaciae* was found to attack the Rutherglen bug *Nysius natalensis* (Hemipter:Lygaeidae) in field trials in pistachio orchards at the rate of 1 pest/day, although they greatly preferred drosophila in laboratory trials.

One group less prominent in the samples than expected are the web-building spiders. Their absence was particularly surprising given that they were a major component of the spider community in Texan cotton fields (Breene *et al* 1993). Web-building spiders often build retreats, and may be difficult to shake off plants using beatsheets once in their retreats.



Fig. 18. Theridiidae, or tangle web

Nevertheless, one web-building group that was commonly captured was the Theridiidae, or tangle web spider (Fig. 18). Theridiidae are known to capture jassids and aphids in Australian cotton (Bishop and Blood 1981) but they do not track their prey's numbers.

The pitfall trap community was heavily dominated by wolf spiders (Fig. 19) which made up 62% of all spiders caught in pitfall traps throughout Australia, throughout the year (Fig 4). Wolf spiders are known to attack pest Lepidopterans and mirids in cotton, as well as beneficial arthropods including other wolf spiders, Nabis, shield bugs, and lacewings (Hayes and Lockely 1990). Work done as part of a CRC student project by M. McMahon found that the presence of wolf spiders in 1m square enclosures reduced the number of *Helicoverpa* moths emerging in those enclosures.

An exception to the dominance of Lycosidae in pitfall traps occurred in a group of samples at 0 BDI, most of which were from Katherine (Fig. 14). In this group of samples, Lycosidae made up 28% of the spiders in the samples while Gnaphosidae made up 21%.Gnaphosidae, like Lycosidae, is a ground runner, although it tends to be smaller. Little is known about the feeding preferences of this family group in cotton.

Linyphiidae is the other group of spiders that were prominent in pitfall traps, especially at Boggabilla in a field with high BDI (Fig. 14). Linyphiidae is a very effective controller of the cereal aphid (*Rhopalosiphum padi*) in



Fig. 19. Lycosidae, or wolf spider.

pastures in South Australia (de Barro 1992). Sunderland *et al* (1986) also found that Linyphiidae had a strong effect on cereal aphid numbers. He found that 12% of prey consumed by Linyphiidae in winter wheat in England were cereal aphids which had dropped onto the webs from the plants above.

## Spiders as generalist predators

The spider community we found in Australian cotton covered a wide range of hunting guilds and is more similar to the general spider agricultural communities reported in the United States, which are dominated by hunters (Oxyopidae, Salticidae, Clubionidae, Thomisidae, Lycosidae) than those in Europe, which are simpler and dominated by the sheet web builders, Linyphiidae (Nyffeler and Sunderland 2003). The Australian cotton spider community was similar to that reported for Israeli cotton (Mansour 1987) although we found lower abundance of web builders than that reported for American cotton (Breene *et al* 1993, Heiss *et al* 1988) and African cotton (Dippenaar-Schoeman *et al* 1999). This difference may be an artifact, as web builders may be more difficult than hunters to shake off cotton using beatsheets. Visual searches would perhaps provide a better measurement of web builder abundance. Nevertheless, the wide range of foraging guilds present in Australian cotton indicate that it is amenable to controlling a suite of pests (Brown *et al* 2003, Marc & Canard 1997).

One potential problem reducing diversity of the spider community is the overwhelming dominance of wolf spiders collected in the pitfall traps. Although wolf spider numbers seemed extreme, the absolute number of wolf spiders were not extreme compared to those of other families caught in beatsheets. The large differences in the spider communities seen in beatsheet and pitfall trap samples again illustrates the problems of focusing on one sampling method (Harris *et al* 2003) especially pitfall traps which tend to over-represent Linyphiidae and Lycosidae (Topping and Sunderland 1992). By using both beatsheets and pitfall traps we found that no family completely dominated the spider community in Australian cotton.

We caught the same number of species on beatsheets and pitfall traps even though: 1) pitfall traps were heavily dominated by wolf spiders, and 2) we caught over 4 times more spiders in beatsheets than pitfall traps. The rarefaction curve shows that the number of species caught in pitfall traps was greater than that for beatsheets when compared at the same sample size.

Some authors argue that the steeper the initial rate of increase in a rarefaction curve, the greater the measure of “evenness” or diversity (Olszewski 2004, Hurlbert 2004). In our case the steepness was due to a secondary plateauing of the less common families, with one family, Lycosidae, dominating the pitfall trap community (Fig. 4). Consequently, in our case, the steep curve did not indicate high diversity of the community as a whole, but of the community once the dominant family was removed (Whitehouse & Harden, in prep.). These results show that care must be taken when trying to understand evenness from species accumulation curves.

## The influence of BDI on the spider community

The pitfall trap community was strongly influenced by BDI, whereas BDI had no effect on the beatsheet community. Why BDI should affect pitfall traps and not beatsheets is unclear.

It may indicate a sub-lethal effect of sprays. To be caught in a pitfall trap, the spiders, which are often male, have to be actively moving around. To be caught in a beatsheet the spider just has to be knocked out of the plant. A high BDI may reduce spider activity, making them less likely to be caught in pitfall traps, but not influencing their tendency to be caught in beatsheets.

Although spiders may be reasonably tolerant of harder sprays such as organophosphates or carbamates in comparison to insects (Bajwa & Aliniaze 2001) they are nevertheless affected by insecticides. A laboratory based study (Mansour & Nentwig 1988) found that pesticides most toxic to spiders (in the families Philodromidae, Clubionidae, Araneidae and Linyphiidae) were acaricides such as cyhexatin, flubenzimine, dicofol, and azocyclotin; the organochlorine endosulfan; followed by pyrethroids; organophosphates; and carbamates. Some insecticides including deltamethrin (a pyrethroid), dimethoate (an organophosphate), and phosalone, do not cause substantial spider mortality. Work in orchards (Bogya, *et al* 2000) showed that spider abundance and species richness in IPM plots (managed using selective insecticides) was higher than those in plots managed using broad spectrum insecticides. Work in cotton field trials showed that the pyrethroid Alphamethrin had the strongest effect on spider families, reducing spider numbers by 76% while endosulfan reduced spider numbers by 41% (the untreated control dropped by 12% over the same period; Berg *et al.* 1990). Likewise the pyrethroids esfenvalerate and permethrin were more toxic to spiders in apple orchards than the organophosphate azinphosmethyl or the carbamate carbaryl; while the organophosphate phosmet and the insect growth regulator diflubenzuron were generally harmless (Bajwa and Aliniaze 2001). The insect growth regulator, Hexaflumuron, was found also to not significantly increase mortality in species of Araneidae, Clubionidae, Dictynidae, Lycosidae, Philodromidae and Theridiidae (Pekar 1999). BDI may affect pitfall trap communities more than beatsheet communities because spider families caught in pitfall traps may be more susceptible to insecticides.

Tetragnathidae, which we found in both beatsheets and pitfall traps, appear to be more susceptible to the carbamate carbaryl and the pyrethroid fenvalerate than other spider families (Whitford *et al.* 1987).

Oxyopidae, which were prominent in our beatsheet samples, appear to be less affected by sprays than other spider families in cotton (Roach and Hopkins 1981) and in orchards (Brown *et al* 2003). Populations of the striped lynx spider, *Oxyopes salticus* in parts of the Mississippi delta with a long history of insecticide use on cotton have been shown to have 3 to 7 fold resistance to methyl parathion compared with population from less frequently sprayed areas in Mississippi (Redmond and Brazzel 1968).

Linyphiidae, which we caught in pitfall traps, is more susceptible to pyrethroids and the carbamate carbaryl than Salticidae (according to surveys conducted in apple orchards, Bajwa and Aliniaze 2001). Linyphiidae is also severely affected by the pyrethroid Alphamethrin and the organochlorine endosulfan (in cotton field trials; Berg *et al.* 1990).

Lycosidae (the dominant family in pitfall traps) and Clubionidae (which were more common in beatsheets) are more susceptible to the pyrethroid Alphamethrin than endosulfan (in cotton field trials, Berg *et al.* 1990); while Theridiidae, which we normally caught in beatsheets, is not adversely affected by Alphamethrin or endosulfan sprays.

The lack of susceptibility of Theridiidae to hard insecticides is supported by Pekar (1999) who found that its web offers protection against sprays. He found that the webs of *Theridion impressum* (Theridiidae) significantly reduced its mortality to the pyrethroid, Permethrin and the organophosphorous, Phosalone. The Dictynidae web also offered protection to *Dictyna uncinata* against Permethrin, while the flimsy orb web of *Aranella opisthographa* offered no protection.

Nevertheless, Theridiidae were less common in sprayed "level 2" IPM orchard plots than unsprayed plots (Wisniewska and Prokopy 1997) while Philodromidae, which we only

caught in beatsheets, were proportionately more common. Philodromidae may be especially resistant to organophosphorous. Pekar (1999) found that *Philodromus cespitum*, a diurnal ambush spider hunting on leaves and exposed to direct spraying, was not susceptible to Phosalone, although it was susceptible to Permethrin. The Clubionidae, *Clubiona neglecta*, and the Lycosidae, *Pardos agrestis*, were both affected by Permethrin and Phosalone (Pekar 1999).

Thus it appears that common pitfall trap species such as Lycosidae and Linyphiidae may be more susceptible to insecticides, while common beatsheet species, such as Oxyopidae, Philodromidae, Theridiidae and to some extent Salticidae are less susceptible, and this may explain the lack of effect of BDI on beatsheet samples.

### **5. Provide a conclusion as to research outcomes compared with objectives. What are the “take home messages”?**

This project has shown that the cotton spider community changes in different parts of the country, both in terms of the most common families, and in terms of the dominant foraging guilds. Thus the spider communities in different parts of the country are not structurally identical, but structurally distinct.

The communities also respond differently to crop development: in the most northern and southern part of the cotton growing belt, the dominant family does not change throughout the cotton growing season, while in more central latitudes there is a succession of dominant families throughout the season.

These differences mean that the response of the beneficial guild to specific pests will differ at different sites. Thus IPM strategies incorporating spiders will need to be closely attuned to specific locations.

### **6. Detail how your research has addressed the Corporation’s three Outputs - Economic, Environmental and Social?**

This project supports the sustainability and profitability of the cotton industry by bringing spiders into focus. Spiders are the most abundant predators in Australian cotton, but they are often overlooked in IPM. This project is the first step in deploying these animals in the defense against pests in cotton.

The project demonstrates that spiders are diverse and abundant in cotton throughout Australia, but that the most abundant families differ in different parts of the country, and at different stages during the season. By building on these findings spiders will be better utilized in the IPM framework.

Increasing reliance on beneficial arthropods such as spiders can save growers significant amounts of money in sprays, providing an economic benefit. Reducing the number of sprays reduces the amount of insecticides in the environment which is better for the community as a whole.

**7. Provide a summary of the project ensuring the following areas are addressed:**

- a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)**
- b) other information developed from research (eg discoveries in methodology, equipment design, etc.)**
- c) are changes to the Intellectual Property register required?**

This project reiterates the usefulness of the beatsheet as a quick and thorough sampling technique.

**8. Detail a plan for the activities or other steps that may be taken:**

- (a) to further develop or to exploit the project technology.**
- (b) for the future presentation and dissemination of the project outcomes.**
- (c) for future research.**

We now have a better understanding of which spiders are present in cotton at different locations around Australia throughout the season. We now need to know how effective the spider communities are at stopping pests becoming a problem, and if different locations are better protected against some pests than other locations. To tackle this problem we need to establish the resilience of spider communities to a suite of pests. This done by first establishing which spider species are effective against which pest, and then testing a community of these spiders against a range of pests. In addition we need to know if different spider communities are resilient against a sudden influx of an emerging pest, such as mirids or jassids. This will indicate if some spider communities can stop an outbreak of specific pests.

The project results have been reported to growers, consultants, and scientists. Below are a list of current and future dissemination of project outcomes.

**9. List the publications arising from the research project and/or a publication plan.**

Manuscripts submitted

Mansfield S., Dillon M.L. and Whitehouse M.E.A. The impact of season-long insecticide regimes on beneficial arthropod communities in Australian cotton fields. Submitted to: *Agriculture, Ecosystems and Environment*.

Manuscripts in prep.

Whitehouse M.E.A., Hardwick S., Scholtz B., Annells A., Ward A., Grundy P. A comparison of spiders in cotton communities around Australia.

Whitehouse M.E.A. and Harden S. Communities dominated by one species can result in misleading indications of evenness by rarefaction curves.

Whitehouse M.E.A., Richards C., Mc Mahon M. The effectiveness of wolf spiders to control the emergence of *Helicoverpa* moths under different management practices.

## Grower magazines and Articles

Whitehouse M.E.A. and Lawrence L. 2001. Are spiders the perfect predator? *The Australian Cotton Grower* 22:30-33.

Whitehouse M.E.A. and Lawrence L. 2002. Spiders offer crop pest control benefits. *Farming Ahead* 127: 47

### Industry related meetings

2003 Australian Cotton Cooperative Research Centre Annual Science Review  
*Spiders of Australia unite*

2002 Farming systems IPM  
The comparison of spider communities in cotton around Australia

2001 Cotton Consultants Australia Inc Cotton Production Seminar  
cotton: the awful truth Spiders and

2002 The Ecological Society of Australia Conference Do  
beneficials pay their way? S. Mansfield, M.L. Dillon, & M.E.A. Whitehouse (Not  
attended, poster paper presented by S. Mansfield)

## ***Media interviews***

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Radio interview by 2VM on Spiders in cotton.

### **Seminars and Workshops**

2004 For: *University of New England Cotton production Course*  
On: The role of spiders in cotton

2003 For: *The Australian Cotton Research Institute*  
On: Spiders, Bt and beneficials: unexpected findings and future implications.

2003 For: *School of Biological Sciences, The Flinders University of South Australia*  
On: From the individual to the ecosystem: integrating behavioural ecology and biodiversity.

2003 For: *Woman's Industry Network – Cotton (WINCOTT)*  
On: Spiders in cotton fields

2002 For: *Upper Namoi Cotton Growers Association annual cotton field day*  
On: Spiders in cotton fields

2001 For: Two-river Areawide Management Group  
On: Recognizing spiders in cotton.

### **Grants**

Whitehouse M.E.A. and Dillon M.L. The role of hunting spiders (in particular wolf spiders) in controlling newly emerged *Heliothis* moths in cotton planted into wheat stubble. Australian Cotton CRC Summer Scholarship Project awarded to Matt McMahon 2002.

**10. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.**

These findings show which spider families are prominent in which parts of the country at different times during the cotton growing season. They thereby provide growers with confidence that through the season they have at hand a large contingent of predators to attack pests. Spiders are diverse and abundant in cotton throughout Australia and need to be incorporated more formally in the IPM arsenal. For example, we need to establish if the differences between spider communities around Australia mean that some areas are more resilient against outbreaks of specific pests such as mirids, aphids or jassids, than others.

These results, in conjunction with many others on insect predators, substantiate the importance of beneficial arthropods as part of an IPM program. By deploying beneficial arthropods to control pests, growers can reduce their dependence on hard chemical insecticides thereby slowing the evolution of resistance by pests to these insecticides and saving the grower significant amounts of money that would have been spent on sprays. Spray reduction also benefits the Australian community by reducing the amount of insecticides in the environment.

**11. Acknowledgments**

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Appendix 1

Mansfield S., Dillon M.L. and Whitehouse M.E.A.  
Do beneficiaries pay their way?  
Submitted to: *Agriculture, Ecosystems and Environment*.

## Appendix 2

Whitehouse M.E.A. and Lawrence L. 2001.  
Are spiders the perfect predator?  
*The Australian Cotton Grower* 22:30-33.

### Appendix 3

Whitehouse M.E.A. and Lawrence L. 2002.  
Spiders offer crop pest control benefits.  
*Farming Ahead* 127: 47

## ***Part 4 – Final Report Executive Summary***

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Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

To establish if the spider communities in cotton at different locations around Australia are similar, we sampled, using beatsheets and pitfall traps, over 4500 spiders from seven locations extending from the tropical north to the temperate south.

We found that the spider communities around Australia are not structurally identical in that the most prominent spiders do not forage using the same methods. In the spider community sampled by beatsheets, the communities in the south were dominated by Oxyopidae (lynx spiders) which are stalkers; while the communities in the north were dominated by Cycloctenidae, which is a foliage runner. In the more central locations, the most dominant family rotated through lynx spiders (stalker), Clubionidae (yellow night stalkers; which are foliage runners), Salticidae (jumping spiders, which are stalkers), Theridiidae (tangle web spiders, which are web builders), to Clubionidae.

The spider community sampled by pitfall traps was also influenced by seasonal changes, but this was less important than the BDI (or spraying regime) the field had received. This community was overwhelmingly dominated by Lycosidae (wolf spiders, which are ground runners) throughout the year. Exceptions were a few samples taken at the beginning of the season under low BDI where other families, such as Gnaphosidae, which is also a ground runner, nearly equaled wolf spiders in numbers. Most of these samples were from Katherine.

These results mean that spiders in cotton at different locations around Australia will have different impacts on pest pressure. Consequently, the incorporation of spiders more directly into IPM will need to be tailored for each location.

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