Chapter 4

Experimental Section

4. Suction Sampling of Arthropods in Cotton Crops

4.1 Introduction

All investigations of arthropod populations rely on sampling methods. The prime objective is to reach a compromise between effort (or cost) and precision which is appropriate to the aims of the investigation (Southwood 1966). Generally, however, sampling methods for arthropods, especially predators in cotton, have been widely criticised because convenient relative methods are often used without satisfactory validation (Gonzalez *et al.* 1977, Byerly *et al.* 1978).

There are two types of sampling methods; absolute and relative. Absolute methods collect all the individuals of interest in a small defined area and, if multiplied by the total area the sampling was designed to represent, give an estimate of the total population in that area (Southwood 1966). Any absolute method would be expected to give the same result regardless of the sampling mechanism. On the other hand relative methods only collect a subsample of the individuals from a small defined area. Therefore the total population cannot be calculated from the results of a relative method without studies which correlate the relative method to an absolute one. Furthermore the results may vary between relative sampling methods depending on the efficiency of each method, for example a sweepnet may collect a different proportion of the insects in a given area than a suction sampler. Researchers must also be aware that differences in treatments may produce spurious results by influencing the efficiency of a relative method. For example a suction sampler may extract fewer arthropods from the bushy canopy of a crop growing in a high fertiliser treatment than from the sparser canopy of a low fertiliser treatment. Here a difference in the arthropod catch size may simply reflect the disruption to the air flow by larger leaves rather than a real difference in the arthropod abundance between the two sites. Nevertheless, with appropriate caution, these methods may be useful to make relative comparisons of the abundance of arthropods in different places or under different treatments.

The difficulty in obtaining absolute samples to compare with the relative methods has meant that researchers have been restricted to comparisons between samples collected in exactly the same manner. Even when this restriction is observed, many such comparisons are suspect, for example, in seasonal abundance surveys several factors which could affect sampling efficiency may change between sampling dates (Dinkins *et al.* 1970a and 1970b, Shepard *et al.* 1974, Fuchs & Harding 1976). If these factors can be identified, the interpretation of such data might be improved.

This chapter describes several studies of various characteristics of the suction sampling methods used in the survey sections of this thesis. The effect on sampling efficiency of the type of sampler used, the position in the canopy and amount of crop canopy covered by the intake, and the time of sampling within the diurnal period were explored. The amount of sampling required to conclusively validate suction samples against an absolute method (eg. Leigh *et al.* 1970, Gonzalez *et al.* 1977, Byerly *et al.* 1978 and Ellington *et al.*. 1984a) was beyond the resources of this study. Nevertheless, some important factors which influence sampling efficiency have been identified and the implications these have for the ways in which we use suction devices are discussed.

Knowing the predator and prey density is fundamental to all predation studies but is commonly a major difficulty. Frazer and Gill (1981) considered that the determination of true coccinellid numbers in the field was a major problem with their study. They eventually used field cage releases of known numbers of beetles to test their visual scanning method and found they were only accounting for 25% of the actual numbers present. They concluded that visual counts, sweep nets and suction machines were grossly ineffective. Ives (1981) extended this work using mark recapture techniques and emphasised that understanding the biology of the predators was important in interpreting any method. For example, predator migration immediately after the release of marked predators for reasons associated with prey density could nullify a simple dilution equation.

4.2 Sampling Arthropods on Cotton

4.2.1 Absolute and Relative Sampling Methods

If a relative sampling method correlates well with an absolute method, over a known range of conditions, an adjustment factor may be used to estimate the absolute levels of the population. Such validation has been attempted for the usual relative methods of sampling cotton arthropods but has failed to identify a method which is generally acceptable for the less abundant and relatively active species, such as predators (Gonzalez *et al.* 1977 and Byerly *et al.* 1978). Eggs and larvae of Lepidoptera (including *Helicoverpa* spp.) are relatively sedentary and therefore sampled reasonably well using visual searches, depending on the skill of the personnel (Dillon and Fitt 1995). The relative methods most commonly used for sampling arthropods on cotton (despite their demonstrated deficiencies) include visual counting, plant beating, sweep netting and suction sampling (Garcia *et al.* 1982, Wilson and Room 1982).

4.2.2 How D-Vac® Suction Samples are Collected

There has been widespread adoption of suction sampling on cotton since the development of a relatively convenient, backpack styled suction sampler by Dietrick in 1961 (known as the D-Vac®, Dietrick 1961). Methods of using the D-Vac® have evolved from the original designer's efforts to sample arthropods on alfalfa (Dietrick 1959). He used a petrol driven fan to provide a strong suction through a long flexible hose. An intake cone was attached to the end of this hose. The original cone was 33cm diameter but various sizes have since been used. A bag-like nylon net was secured within the suction hose so that it caught the arthropods drawn in through the intake, in a similar way as a household vacuum cleaner collects dust. The sampling procedure involved starting the suction, then bringing the intake down onto the plants from above and pushing it down as far as possible until the intake lip reached near ground level. The intake cone had mesh covered vents which allowed air to enter even when the cone was pressed against the ground. Therefore the physical variables of this sampling action are the duration and path of positioning the intake cone and the duration of each placement. One placement may be considered a sample, but population densities are seldom high enough for a single sample of this area to collect enough of the arthropods of interest in cotton. Therefore many (usually 50 to 100) randomly selected placements are combined to form a composite sample (Gonzalez *et al.* 1977). When describing D-Vac® styled sampling most researchers report the intake diameter used, the placement position, the number of placements per sample, and how the sampling positions were selected.

The branches of cotton plants are too strong to be pressed to ground level by the intake cone, as is done with alfalfa or soybean plants (Dietrick 1959, Braman & Yeargan 1989). Also the branches of cotton plants, growing at the usual commercial planting densities of 6 to 16 plants per metre, eventually entangle to resemble a hedgerow. This prevents the placement of the cone over a single plant as a sampling unit unless only the top of the plant is of interest. Also the power of the D-Vac® is capable of picking up large quantities of soil if brought down to ground level over cotton because the soil surface under cotton is usually bare, dry and loose. Although Dietrick (1961) reported sampling from cotton by increasing the size of the intake cone as the crop increased in size, no details are given on how the problem of sucking up soil was overcome. In any case, Dietrick's method for cotton does not appear to have been adopted by researchers. Generally some sort of relatively reproducible partial placement (i.e. not to ground level) or sweeping pass has been used. Examples include: Gonzalez *et al.* (1977) who used 25, 50 and 100 terminal placements or 50 &100 side-plant upsweeps with a 23cm intake cone to form each composite sample; Byerly *et al.* (1978) who used 50 terminal placements with a 23cm intake cone for each sample; Smith *et al.* (1976) who moved along one side of a 5 ft interval of row moving the 24.5 cm intake up and down the side of the plants as he passed; and Roach (1984) who used a 23cm intake cone aimed downwards and moved horizontally along the top of a 7.5 m length of row.

Ellington *et al.* (1984b) developed a motorised, high clearance, high volume arthropod vacuuming platform which probably represents the most sophisticated machine devised for suction sampling on crops such as cotton. However its cost, complexity and unsuitability to wet conditions (around irrigations) would limit it uses, even for research purposes.

4.2.3 The Sampling Efficiency of D-Vac® Suction Samples

There has been considerable criticism about the efficiency of D-Vac® styled suction samplers. For many years the sheer effort and cost required to collect satisfactory absolute samples to compare with the D-Vac® method made definite evaluation difficult. However several reports have since been published where suction sampling in cotton has been compared, along with other relative methods including visual counts and sweepnets, to more absolute methods (Smith *et al.* 1976, Gonzalez *et al.* 1977 and Byerly *et al.* 1978) Similar studies have been made in soybeans by Shepard *et al.* (1973), Bechinski & Pedigo (1982) and Schotzko & O'Keeffe (1989). The studies by Gonzalez *et al.* (1977) and Byerly *et al.* (1978) on cotton were the most comprehensive comparisons of the suction methods from the top of the plant canopy, but did not explore a wide range of alternative ways of using the suction devices. The absolute methods used for these evaluations included thorough visual inspections, whole plant bagging, insecticide knock-down and clamshell styled traps (Leigh *et al.* 1970, Gonzalez *et al.* 1977 and Byerly *et al.* 1978). All were very laborious and cumbersome.

Overall, these studies seriously questioned the usefulness of the suction sampling methods in common use on the following grounds:

(a) The levels of variation (expressed as the relative variation, RV) using D-Vacs® are high (>25%), therefore too many replicated samples are required for intensive or even extensive studies.

(b) The suction samplers collect fewer insects per unit area than the absolute methods and therefore underestimate the population. This, however is expected of a relative method and is unimportant if the relative counts can be reliably adjusted to total counts over the population densities of interest.

(c) Correlations with the absolute methods are poor. At worst, suction samplers completely fail to catch some categories of arthropods which are found by the absolute methods. These included virtually all immature stages of predators and those species which are generally found in the lower positions of the canopy or are enclosed by flowers or bracts, especially nabid nymphs and *Orius* spp. (nymphs and adults). Furthermore, the counts of arthropods collected in the suction samples failed to indicate the correct population trends.

Byerly *et al.* (1978) therefore concluded that the D-Vac® (and sweep netting) methods widely adopted on cotton were inadequate and cast serious doubt on all estimates of insect populations gained in this way. They also cautioned against the use of thorough visual sampling as an absolute method because they found visual counts decreased, compared to their absolute method, as the canopy size increased throughout the season.

Gonzalez *et al.*(1977) also concluded that the D-Vac® was not a suitable device for sampling on cotton. However, their pessimism seems unwarranted in view of their own data. The correlations they reported between the suction samples and their absolute method (whole plant bagging) for some important predatory species suggest that for some purposes the method may be acceptable. For example, for *Geocoris* spp. the R^2 was 0.89, for *Nabis* spp. 0.61, for *Notoxus calcaratus* Horn 0.92, for *Chrysopa* spp. (nymphs) 0.80, for *Orius tristicolor* (White) nymphs 0.72 and for spiders 0.92.

In contrast to most studies, Smith *et al.* (1976) concluded that D-Vac® sampling did indicate population trends for predators as a group. This conclusion has been criticised because the results for individual predator species were not presented (Gonzalez *et al.* 1977). A more serious criticism however, is that the absolute methods used by Smith *et al.* (1976) also collected insects using suction and therefore removed insects in a similar way to the D-Vac®. If the inefficiencies of the D-Vac® are due to its inability to extract arthropods from enclosed places, their absolute method may not only have fallen short of being absolute but may also have correlated well to the relative method because of its physical similarities.

Bechinski & Pedigo (1982) and Schotzko & O'Keeffe (1989) rejected the D-Vac® as inadequate with quite limited investigation. Their studies were on soybean crops and used the 33cm intake cone in which airstream velocities were greatly reduced. As mentioned previously, the method of using the D-Vac® on soybeans is quite different from the way it is generally used on cotton. The cone is placed onto the soybean canopy and pushed to the ground and held for a set period, for example, 10 seconds (Braman & Yeargen 1990). Brief trials reported in this thesis using a 33cm diameter intake cone fitted to the Bigvac (Chapter 4) appeared to catch only a very small proportion of the coccinellids clearly visible at the top of the cotton canopy and the intake diameter was subsequently reduced. Most researchers working with cotton have adopted a 23 cm intake to increase air-stream velocities at the position of sampling (Gonzalez *et al.* 1977, Byerly *et al.* 1978).

When reviewing the literature on suction sampling it has often been difficult to ascertain the exact details of how the suction sampling was done. Important variables such as the distance the sampling cone was pushed into the canopy and for how long have not been reported. The approach of the operator to the sampling site is also seldom mentioned, but may have a bearing on efficiency of the collection. For example the operator may shade the sampled spot prior to sampling, or insects may be disturbed by a noisy approach.

Sample Repeatability and Precision

An estimate of population density with a standard error of 25% of the mean is precise enough to detect a 50% increase or decrease in a population (Southwood 1966). Since changes of at least this magnitude are common and relevant in insect pest management this level of precision is usually adequate. These studies are often referred to as extensive and include insect distribution surveys. For intensive studies, such as life tables, detection of smaller population changes are important. For these a standard error of no more than 10% of the mean is usually required (Southwood 1966). Population density and the degree of aggregation determine the number of samples necessary to reach a certain level of precision and very few studies of insect predators achieve the levels suggested by Southwood (1966) for intensive work (Byerly *et al.* 1978).

In view of this criteria for judging the efficiency of sampling, Table 4.1 presents the coefficients of variation (CV) and the standard errors (as a proportion of the mean population density) for many of the predators and pests collected with the Bigvac during this thesis. The data from the soft-option and conventional fields at Midkin 1992/3 (Chapter 5.1) were used because this was the most thoroughly sampled site and therefore best demonstrates the capabilities of the Bigvac method. All records of zero mean population density were omitted from the data so that the absence of a particular species did not bias the average population density which the coefficients of variation (CV and Std. Err./mean) represent.

Smaller population changes become detectable as the precision of sampling increases. Without prior knowledge of the predatory impact on population size, there was no particular level of precision which was obviously necessary for the studies presented in this thesis. However, for an exploratory search for effective predation, the ability to detect a doubling or halving of a population appears to be a reasonable starting point; especially since changes of at least this magnitude will be required for effective control of *Helicoverpa* spp. A standard error which is 25% of the mean is generally capable of achieving this (Southwood 1966).

The means in Table 4.1 are based on 15 degrees of freedom and are capable of detecting a population that was 1.75 times another with a standard error of 25% of the mean. When a standard error of 50% of the mean is presented in Table 4.1 a mean 2.5 times another would be significantly different. These calculations assume a significance level of $P < 0.05$.

Table 4.1 shows, for at least the abundant predators, the Bigvac sampling method was usually acceptable. Furthermore, when combining the counts of predatory species, as might be considered for including general predator abundance in decisions on altering action thresholds, the standard error averaged 13% of the mean. This would appear more than adequate for this purpose. The conventionally treated field had generally lower measures of precision than the soft-option treatment and this probably reflects the lower population densities which prevailed under the 'harder' chemicals. Even so, the average precision of 18% (Std. Err. / mean) was also well within Southwood's expectations for extensive insect surveys which includes crop scouting procedures.

The purpose of the experiments reported in Chapter 6 of this thesis was to detect and possibly correlate population changes of both predators and *Helicoverpa* spp. The average precision for *Helicoverpa* spp. populations was 20% in the soft-option field and 25% in the conventional which again shows that smaller than 50% changes in population density would normally have been detectable, especially when pest abundance was high. Therefore, given the requirement to bring *Helicoverpa* spp. abundance down to such a low economic threshold, the importance of predators could reasonably have been expected to be detectable using the Bigvac suction sampling methods.

Table 4.1 indicates that the precision of Bigvac for the sucking pests (*Campylomma* spp. and *Creontiades dilutus*) of 44-54% (std. err./mean) is not particularly good. However for other more abundant arthropod species, such as the cicadellids, *Austroasca viridigrisea* and *Orosius argentatus,* the Bigvac was highly suitable for extensive sampling purposes.

For <u>intensive</u> studies on cotton, even the time-consuming 'clamshell trap' (Leigh *et al.* 1970), an absolute sampling method used by Gonzalez *et al.* (1977), failed to reach Southwood's standards, despite taking 16 replicate samples in high density populations.

Byerly *et al.* (1978), also on cotton, calculated that 50 to 200 samples would be required in most situations to meet a 20% to 30% level of precision using their absolute method

	Cotton crop treated with Soft-Option Insecticides						Cotton crop treated with Conventional Insecticides					
Predator Species or Group (Adults; unless otherwise stated)	**Population density No. per 10m Bigvac sample (16 samples /daily average)**		**CV Coefficient of Variation Std. Dev. / mean (%)**		**Standard Error / mean (%)**		**Population density No./10 m Bigvac samples, (n = 16)**		**CV Coefficient of Variation Std. Dev. / mean (%)**		**Standard Error / mean (%)**	
	Mean Daily Average (N)	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean Daily Average (N)**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Coccinella transversalis	0.18 (7)	0.06-0.50	289	126-400	72	32-100	0.48 (6)	0.13-0.75	159	91-273	40	23-68
Diomus notescens	0.34 (4)	0.06-0.69	252	157-400	63	39-100	0.16 (7)	0.06-0.56	325	129-400	81	32-100
Dicranolaius bellulus	2.53 (15)	0.31-7.81	85	46-193	21	11-48	1.63 (16)	0.13-4.69	130	51-310	32	13-77
Geocoris sp. predominantly *G. lubra*	0.66 (15)	0.13-1.94	182	81-310	45	20-77	0.16 (8)	0.06-0.44	298	204-400	74	51-100
Nabis kinbergii	2.05 (15)	0.13-8.00	126	29-273	31	7-68	0.66 (9)	0.06-2.38	270	87-400	67	22-100
Oechalia schellenbergii	0.11 (4)	0.06-0.19	322	215-400	81	54-100	0.13 (2)	0.06-0.19	307	215-400	77	54-100
Orius spp. mostly *Orius tantillus*	0.77 (13)	0.06-2.00	165	71-400	41	18-100	0.36 (11)	0.06-1.13	245	91-400	61	23-100
Campylomma spp. *C. liebknechti* & *C. seminigracaput*	2.46 (16)	0.06-14.38	177	42-400	44	10-100	1.39 (8)	0.13-4.13	127	56-273	32	14-68
Creontiades dilutus	0.92 (9)	0.06-4.06	214	61-400	54	15-100	0.47 (6)	0.06-1.38	217	92-400	54	23-100
Oxyopes spp. (Large)	0.40 (13)	0.06-1.69	236	60-400	59	15-100	0.33 (10)	0.06-1.31	274	87-400	69	22-100
Oxyopes spp. (Small)	4.04 (16)	0.75-9.56	72	34-142	18	8-35	1.90 (16)	0.06-5.00	112	51-400	28	13-100
Formicidae	0.46 (15)	0.06-1.63	242	119-400	61	30-100	0.44 (15)	0.06-1.25	238	131-400	59	33-100
Total Predators (minus small spiders)	11.53 (16)	1.81-47.4	53	21-101	13	5-25	5.00 (16)	0.44-19.8	73	28-150	18	7-38
Total Spiders	7.25 (16)	3.75-18.8	48	21-87	12	5-22	4.41 (16)	0.88-11.4	67	35-109	17	9-27
Austroasca viridigrisea	38.63 (15)	0.25-196.6	129	19-310	32	5-77	1.76 (12)	0.13-7.3	159	67-290	40	17-73
Brown Cicadellidae mostly *Orosius argentatus*	68.98 (16)	5.94-129.7	41	21-77	10	5-19	16.46 (15)	0.19-46.6	81	22-290	20	5-73
Cicadellids (Nymphs)	225.93 (16)	1.38-898.7	73	28-184	18	7-46	28.57 (15)	0.06-190.3	174	45-400	44	11-100
Thysanoptera	40.59 (16)	4.81-151.4	64	28-115	16	7-29	19.29 (16)	4.31-44.2	55	26-91	14	6-23
Trichogrammatidae	38.18 (16)	1.69-149.0	70	25-159	17	6-40	3.35 (16)	0.38-11.6	113	62-215	28	15-54
Helicoverpa spp. (Larvae)	5.77 (16)	0.38-36.1	78	33-215	20	8-54	7.80 (16)	0.13-48.8	99	48-273	25	12-68

Table 4.1 Sample repeatability demonstrated by comparisons of the coefficient of variation and standard error/mean for the population densities of selected predators and other abundant or pest insects. Samples were collected by the Bigvac suction method from cotton crops treated with soft-option or conventional insecticides at Midkin 1992/3 (Chapter 3.1). Each arthropod species was not always present on each sampling date, therefore the number of population estimates (N) used in each mean daily average is shown after the entry.

(whole plant bagging). This level of precision was found to be practically impossible using suction samplers or sweepnets (Gonzalez *et al.* 1977). However, Roach (1984) reported levels of 9.9 to 19.4% using suction samplers on cotton. This latter study provides further evidence of the potential usefulness of suction sampling used in a different manner.

A sobering point of view by Pottinger (1967) helps restore perspective to this discussion by reminding us that the 10 to 25% levels of precision presented above are arbitrary. He believes that important population changes are generally proportionately large and therefore may often be detected with far less precision than this.

4.2.4 The Possibility of Improving D-Vac® Sample Efficiency

Gonzalez *et al.* (1977) and Byerly *et al.* (1978) have argued that relative sampling with the D-Vac® from the top of cotton plants, with few exceptions, is inadequate. Since this is how suction samples are often taken, their warnings are important. However, the absolute samples, which were the basis for comparison in both of these studies, were collected from the complete canopy and the suction samples only from part of the canopy. Wilson and Gutierrez (1980) studied the within plant distribution of cotton arthropods and ascribed the poor collection by both the D-Vac® and sweepnets to the position of the arthropods in the canopy. They found that the immature stages of most predators were found lower in the canopy than their respective adults by one to three mainstem nodes.

The limited ways in which the suction samplers have been used in most previous studies suggests that there may be scope for improvement. The efficiency with which arthropods are collected using suction from more protected or lower positions in the canopy could be expected to depend upon the amount of canopy covered by the intake cone and the velocity and volume of the airstream drawn through the canopy. Gonzalez *et al.* (1977) found only a marginal trend toward increased catches of predators in 'upsweeps' of the side of the cotton plants compared to their terminal sampling method. They suggested that this may simply be due to the increased area sampled by the upsweep as the plants grew, but as no improvement was seen in the correlation to their absolute samples they did not pursue this. The upsweeps were similar to the terminal placements in that they were a composite of many (in this case 50) spot samples. Roach (1984) tried several novel ways of using the D-Vac®

units including a procedure which used two suction samplers simultaneously collecting from opposite sides of the same row over a 7.5 metre interval. This incorporated greater coverage of the canopy, greater suction strength and a continuous length of row, as opposed to spots. His single D-Vac® terminal samples, which also covered a 7.5 metre interval, collected only 28% of the double D-Vac® method. This work shows the potential for more thorough suction sampling to increase the arthropod catches. However, it did not include an absolute method to see whether the larger catches improved the correlation with absolute abundance, so the potential for improving techniques for suction sampling needs further study.

Roach's (1984) example also highlights the spatial differences between the absolute methods and the relative suction methods tested by Byerly *et al.* (1978). The terminal suction method was a composite of many spot collections (< one plant per spot) whereas the absolute was a continuous 1 metre section of row. There is a distinct possibility that isolated placements allow some arthropods to escape with quite short movements within the crop canopy, as the sampler approaches. A pass along a section of row may retrieve some of these escapees, especially if the method also incorporates a more thorough coverage of the canopy. The 'herding' effect of moving along a section of row may be more efficient than many spot catches. Thus, a more thorough coverage of the plants including the top and both sides, along a continuous section of row, may improve the suction samples. This approach was the main method used in the survey sections presented in this thesis (Chapter 3).

4.2.5 Why Persist with Suction Sampling In This Thesis Project?

There was no validated relative method for sampling predators in Australian cotton at the beginning of this research project, and a convenient method was required to begin estimating the size of the predator populations. Sweep netting was regarded unsuitable because it only samples from the terminal section of the canopy and this has been shown by Byerly *et al.* (1978) to be inadequate. Sweep nets can also cause considerable damage to the crop when used vigorously. Visual searches were also considered but required too much time and might be prone to operator differences. Therefore suction sampling was selected, albeit tempered by the warnings of Gonzalez *et al.* (1977) and Byerly *et al.* (1978).

The methods of Roach (1984) appeared to incorporate practical alternatives which could be expected to markedly improve the suction results and, as mentioned above, the precision ultimately required for any study depends upon the variability of the populations and the size of the effects being measured. Another consideration was the time available. During this study 3 to 4 hours was generally required to collect the 36 suction samples usually collected on each sampling day from Midkin in 1992/3. The time required to process each sample (removing plant material and counting insects) was 1-2 hours. Equivalent samples using visual counting or some type of clam trap would have taken much longer. Therefore three methods of suction sampling, incorporating some of Roach's (1984) improvements, were used (Chapter 3). The following experimental sections report on several aspects of the efficiency of these methods.

4.3 The Effect of Suction Sampling Method on the Size and Diversity of the Sample

4.3.1 Introduction and Aim

Different suction sampling methods and machines were being used throughout the Australian cotton industry at the time of this study, making comparisons between different data sets difficult. During the study (in 1992) a standard protocol for suction sampling was adopted by the industry (the Macvac method, D.A.H. Murray 1992 pers. comm., Chapter 3). Three different sampling methods were being used in this study, including the industry wide protocol. It was therefore necessary to look for overall differences in the size and diversity of the samples collected by the various methods.

The most obvious differences between the sampling devices and methods involved four aspects; the strength of the suction, where the intake was positioned, the duration of sampling and plant area covered. Generally one could expect that targeting sites in the canopy with the highest concentration of insects for the longest time, with the strongest suction would give the greatest catches. However there is a possibility that a longer time spent searching one area may increase the disturbance to the next section. Covering a greater area quickly may cause less inherent disturbance and so catch insects which would otherwise have escaped. Little is known of the differences between these sampling approaches, especially since little is known of the favoured positions in the canopy for the various insect species, how well they are collected from the different areas and the effects of disturbance.

At many times during the arthropod survey more than one suction sampling method was used concurrently in the same plot. This was done to allow comparisons between sampling methods under various conditions throughout the season particularly as plant size increased. This sampling began with a comparison of the Elecvac, Macvac and Bigvac methods on unsprayed cotton at Midkin in 1993/4. Cotton plants at this stage in the season were small and so represent a comparison where the area searched by the three suction devices would be similar. A later experiment compared sampling from the top or bottom of the plant canopy to help explain the differences observed in the earlier experiments.

4.3.2 Methods

Six Elecvac, then five Macvac and finally five Bigvac samples, taken as described in Chapter 3, were collected from within six hectares of unsprayed cotton at Auscott 'Midkin' between 8.00 and 9.00 am on 5th November 1993. The samples were collected randomly from within a 200 m long by 20 row wide strip of 20cm high cotton plants. This order of sampling was considered necessary to avoid the possibility that the larger vacuum units caused disturbances (possibly noise or the outlet wind blast) which might affect later sampling within the same general area. The effect of time over this period was not considered to be important given the results from the diurnal experiments (Section 4.3). The weather was clear with a light breeze and no obvious changes in these conditions occurred during the sampling period.

4.3.3 Results and Discussion

The complete data set for these studies can be found in Appendix 4.1 on computer disc (Stanley\appen4.xls worksheet 'Appendix 4.1'), and selected data are summarised in Figs. 4.1 to 4.3.

The Bigvac tended to collect the largest samples, especially amongst the group of larger generalist predators, such as *Coccinella transversalis, Dicranolaius bellulus* and *Geocoris* spp. (Figure 4.1). The catch using the Macvac was often similar to the Bigvac but the Elecvac generally produced much smaller samples.

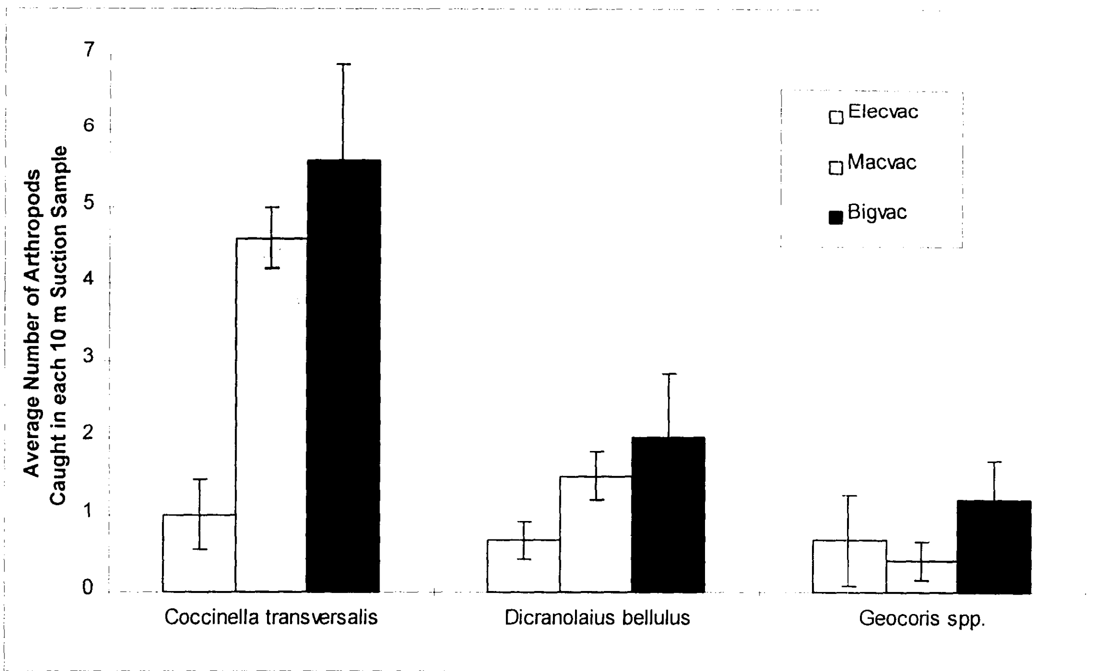

Figure 4.1 The comparison of the number of some of the larger predatory species caught by the Elecvac, Macvac and Bigvac from a cotton plot where insecticides had not been used, at Midkin site on 5th November 1993. The Macvac counts were halved to compare the methods over the same length of cotton row (10m). The error bars represent the standard error of the means.

In some instances, however, the more powerful suction samplers collected considerably fewer arthropods (Figure 4.2). This raised suspicion that the Bigvac and the Macvac were alarming some species, causing them to escape or hide before the intake reached them. The Elecvac was considerably quieter than the petrol driven models, so noise is a possible candidate for this disturbance. However other aspects such as the production of petrol vapours and exhaust fumes are also unique to the petrol driven machines. Trichogrammatidae, in particular, appeared to be sampled less effectively with the Bigvac. The intermediate catch for the Macvac suggests that the faster pass may have compensated to some extent by catching up with possible escapees. However the amount of noise produced and therefore the amount of disturbance could also be expected to be intermediate for the Macvac.

As suction sampling methods are commonly proposed for monitoring pest insects which affect cotton, a comparison of the collections of the major pests is presented in Figure 4.3. This generally showed that the Bigvac collected more individuals of pest species except in the case of *Creontiades dilutus*. This insect is commonly reported to be easily disturbed when approaching the canopy for visual sampling and appears to move rapidly to distances

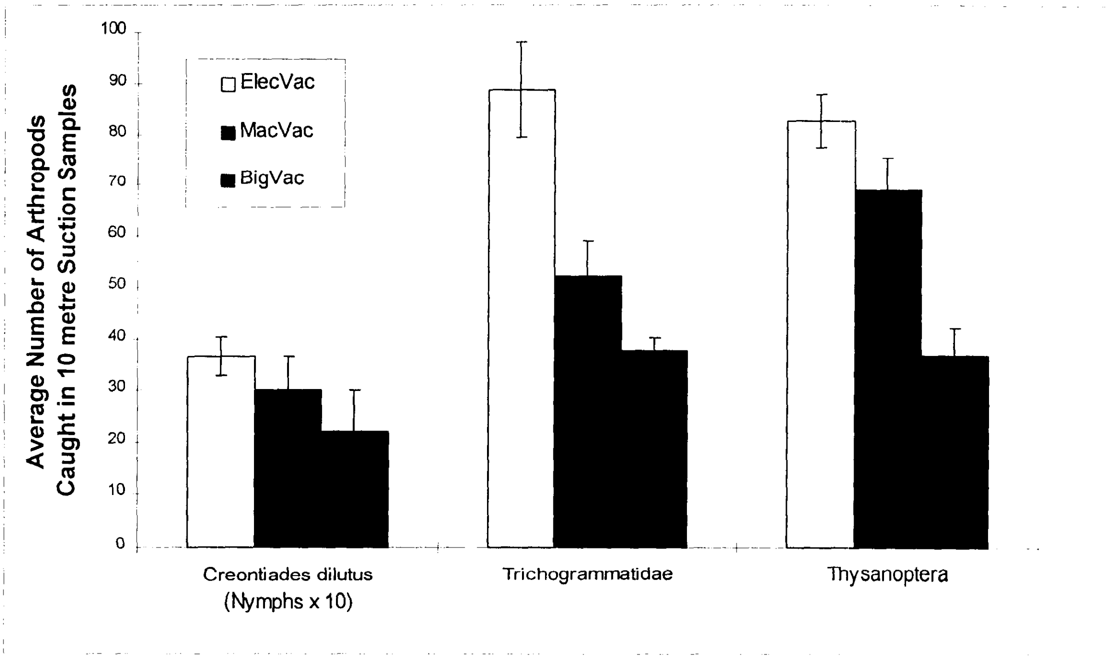

Figure 4.2 Examples where the more powerful petrol-driven suction samplers caught fewer of certain species than the small electrically powered suction sampler (Elecvac). The error bars represent the standard error of the means. Sampling area and date as for Figure 4.1

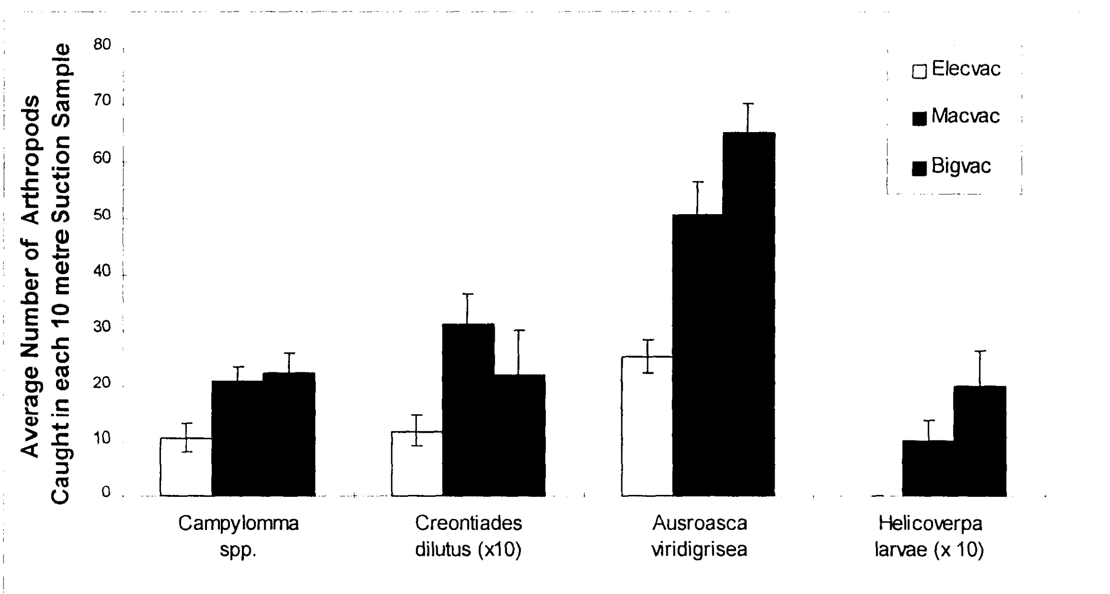

Figure 4.3 The comparison of the numbers of selected cotton insect pests caught by the Elecvac, Macvac and Bigvac sampling methods at the unsprayed Midkin site on 5th November 1993. The error bars represent the standard error of the means. Adults and nymphs of *Campylomma* spp. and *Creontiades dilutus* are included in these counts.

beyond the range of the suction sampler. Miles (1995) reported that the terminal sampling with the Macvac protocol failed to show population trends for this species, particularly juveniles, compared to visual checking. This would imply that it is the ability of the suction method to extract insects from the plants which is the major problem since both the suction sampler and the visual checking would be expected to cause disturbance.

4.4 The Seasonal Influence on the Relative Sampling Efficiency of Suction Sampling

4.4.1 Aim and Methods

The results for Experiment 1 were obtained on small plants early in the season. The aim of this experiment was to extend the comparison to include larger plants and different dates of sampling. Suction sampling for the arthropod survey was carried out on a routine basis using the Bigvac. Concurrent extra sampling was conducted at many sites on many occasions with either of the other two suction devices, (Elecvac or Macvac) to produce comparable samples from a range of sites and conditions over the growing season. The methods were those reported in Chapter 3 for the relevant suction sampling method.

4.4.2 Results and Discussion:

Data for this section are presented in Appendix 4.2 on computer disc (Stanley\appen4.xls worksheet 'Appendix 4.2') and selected data are summarised in Figures 4.4 and 4.5

Abundance of Predators

The numbers of predators in Macvac samples decreased considerably, relative to the Bigvac samples over the cotton season (Figure 4.4). This was possibly due to the increase in plant size. This seriously questions the validity of the Macvac sampling method beyond the first two months of the season (corresponding to the first week in December in these areas). The ability to compare relative abundance between sampling dates appears to be considerably compromised. Furthermore, the small proportion of the predator population sampled in the later half of the season by the Macvac method suggests that the correlation with absolute abundance is also likely to be very poor.

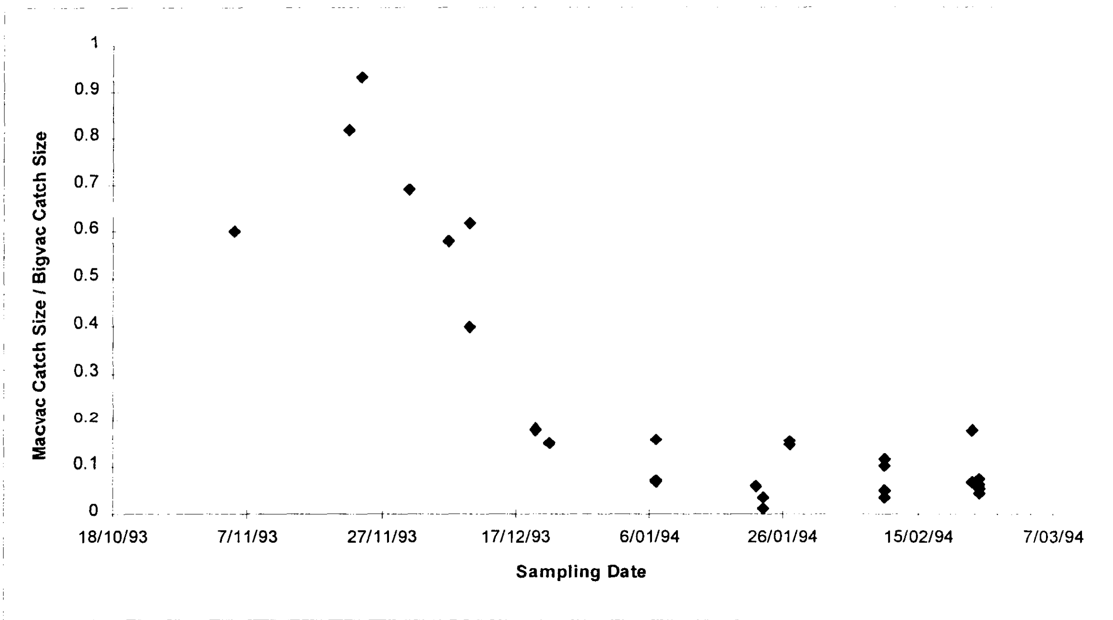

Figure 4.4 The Macvac sample size as a proportion of the Bigvac sample size for combined predators. This data set includes samples from all the sites established in the 1993/4 cotton growing season ('Midkin', 'Alcheringa' and 'Wilby' Chapter 3).

Diversity of Suction Catch

The diversity (number of species) recorded by the Macvac as a proportion of those sampled by the Bigvac was not so markedly affected as the abundance as the season progressed (Figure 4.5). A decline in the comparative diversity is more apparent within some sites, especially at Midkin 1993/4, than when data from different sites was combined.

The early Macvac samples recorded a greater diversity than the Bigvac. At this time both methods indicated that diversity was generally low, therefore small absolute differences would tend to exaggerate the proportional differences presented on the chart. However the differences appeared to be due to the inclusion of a greater number of large spider species in the Macvac samples earlier in the season, including large Salticidae (Appendix 4.2; appen4.xls). Salticidae may have escaped the slower approaching Bigvac or been recorded when at lower population levels by the greater length of the Macvac pass (refer to Chapter 3 for details of the sampling procedures with each suction machine).

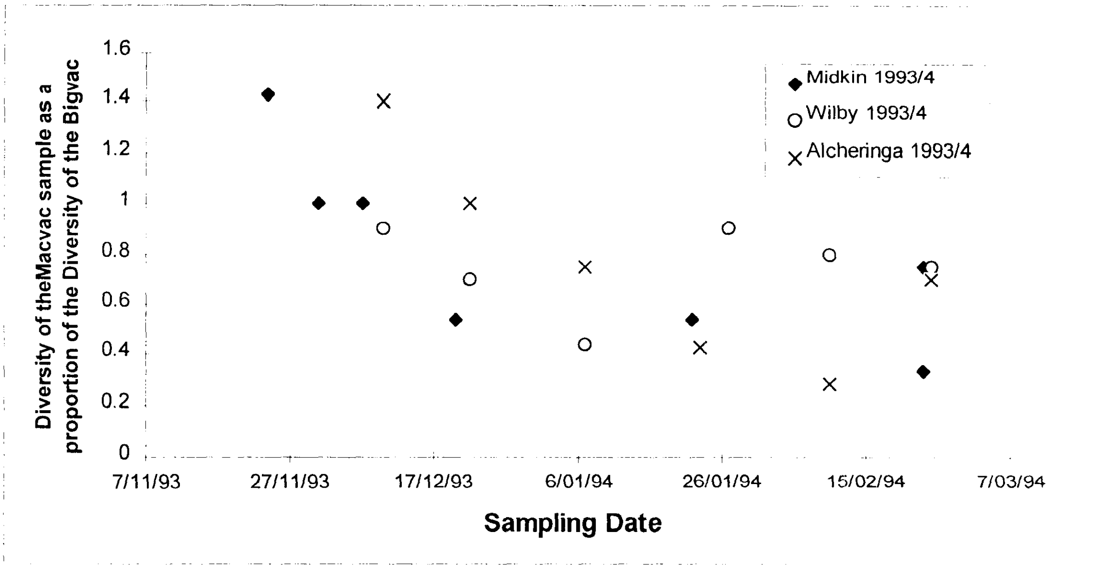

Figure 4.5 The diversity of the combined predators (not including *Campylomma* spp., *Creontiades dilutus* and small spiders) in the Macvac samples as a proportion of the diversity of those in the Bigvac samples throughout the 1993/4 cotton growing season at 'Midkin' (♦), 'Wilby' (o) and 'Alcheringa' (x). Only data from untreated and soft-option insecticide treatments are included.

The overall conclusion is that the Macvac generally collected representatives of most species early in the season, but performance declined as the season progressed. As with catch size this is possibly due to the progressively larger plants having relatively fewer species present towards the top of the canopy as the season progressed.

4.5 Sampling from the Top or Bottom of the Canopy

4.5.1 Aim

A major difference between the sampling protocol of the Bigvac and the Macvac was the position in the canopy from which the sample was taken. The previous sections have alluded to the possibility that terminal sampling was not acceptably representative. The following experiment was designed to investigate this possibility.

4.5.2 Methods

This experiment was conducted late in the season (20th February 1994) on large cotton plants. Ten replicate samples were made using the protocol described for the Macvac in the general methods (Chapter 3). Ten were also collected in an identical fashion except that the nozzle was directed towards the lower branches of the cotton canopy (30cm above the ground level at furrow base) rather than the top. The intake tube, which was 60 cm long, had to be held at an angle of approximately 30 degrees to horizontal to avoid pushing the motor unit through the next row of plants when taking the lower canopy samples, but otherwise was perpendicular to the cotton row. The samples were all collected from a 200m long x 16 row wide plot within the control area 200m closer to the head ditch of the control plot than for the predator survey at 'Alcheringa' (Figure 3.5). The position within the plot and the sequence of collecting individual top or bottom samples was varied randomly.

4.5.3 Results and Discussion

Data for this experiment can be found in Appendix 4.3 on computer disc (Stanley\appen4.xls worksheet 'Appendix 4.3'). Selected data are presented in Figure 4.6.

Although the general abundance of predators was low, there were significantly ($P < 0.01$) higher numbers of predators caught in the samples from the base of the plant canopy compared with those from the top (7.2 $\pm$ 0.80 s.e. per 20 m compared to 1.5 $\pm$ 0.40 s.e. per 20m, $n = 10$, $t = 6.37$). This is consistent with the discrepancies between the samples taken using the Bigvac and the Macvac discussed in the previous section, because the Bigvac method includes the lower portion of the plants. Most other arthropods were also more abundant in samples from lower in the canopy (Appendix 4.3; appen4.xls). This suggests that either they inhabit these areas or attempt to escape by this route when disturbed by the approaching sampler.

Gonzalez *et al.* (1977) compared an upsweep to a terminal placement of the suction cone. They tended to collect more predators with the upsweep method but suggested that this could be expected because it covered a greater area of the canopy, especially as the crop grew. The current experiment suggests that the distribution of predators within the canopy may also have contributed to this result. However, the size of the plants they sampled was probably quite small because they were able to totally cover the plants with a 23cm diameter intake cone in their early samples and only continued to sample for the next 6.5 weeks. The inclusion of the base of the plants in the early samples and the generally small size of the plants diminishes the rigour of their study as a comparison between top and bottom sampling.

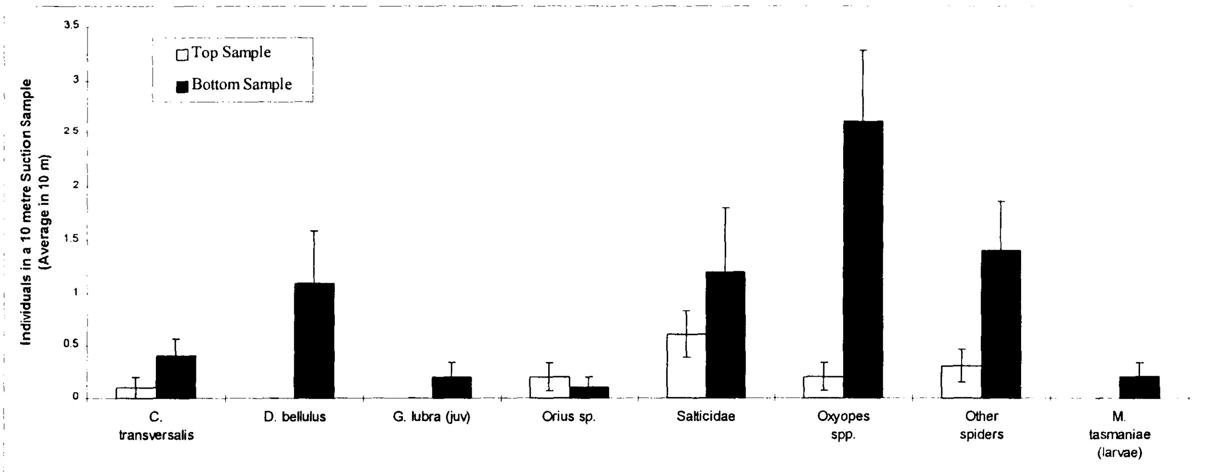

Figure 4.6 The average number of predatory arthropods caught in a 20 second pass with the Macvac intake directed towards the top (open column) or bottom (shaded column) of the cotton crop canopy. Error bars represent the standard error of the means (n=10).

Roach *et al.* (1984) also compared sampling from the complete canopy to terminal suctions and found that sampling tops was only 28% as efficient as sampling the complete canopy. The complete canopy method involved a D-Vac® sampling from one side of the row while another collected from the bottom of the other side for a 7.5 metre interval.

On the other hand in the present study, insects which inhabit flowers were present in higher numbers at the top of the plants, where the flowers were at this stage in crop development. Groups for which these trends were apparent included thrips and *Carpophilus* spp. (Appendix 4.3; appen4.xls).

The implication of this restricted investigation is that the inclusion of the complete canopy in cotton sampling is likely to produce larger and more diverse samples than selecting any particular section of the canopy for sampling. This may also improve the comparisons between suction samples and whole canopy absolute sampling methods.

4.6 Diurnal Effects on Suction Catch.

4.6.1 Introduction and Aim

It has been known for many years that many insects exhibit clear diurnal patterns of behaviour. These include particular periods or conditions for moving, feeding, reproducing, and resting. Any or all of these activities could be expected to alter the efficiency with which a suction sampler can extract a particular species from a crop canopy. One simple example of how this could occur would be a species which moved into a sheltered cavity to escape the hotter, drier or brighter periods of the day, and would therefore be more difficult to catch at those times. Whether such responses are entrained diurnal patterns or direct responses to particular environmental variables, it would be helpful to identify periods which give the largest catch with the lowest variability in order to improve the efficiency of monitoring predators with suction samplers.

The effect of the diurnal patterns on the size and diversity of the suction catch was explored during three 'day-night' experiments. These report the catch from a single plot at regular intervals over a complete diurnal period on three separate occasions. This was conducted to establish the best time for collecting suction samples for crop scouting and research purposes.

4.6.2 Methods

Suction samples were collected at hourly or two hourly intervals throughout a consecutive day and night on three separate occasions. Four replicate samples were collected at each sampling time from randomly chosen positions in a one hectare plot within a 100 hectare cotton field. Sampling from any previously sampled section of row was avoided.

The first experiment was conducted in a plot established 200m south of plot 5 in field 2 at Midkin (Figure 3.3 labelled 'DS Ex 1'), on 30th November 1992, before any insecticides had been applied to this field. The Bigvac had not been built at this stage so the Elecvac was used. This field was later to become the conventional insecticide treatment for the 1992/3 survey.

The second experiment was conducted on 15th January 1993. This also used Elecvac sampling but was located in the soft-option field 1 between plots 3 and 4 (Figure 3.3 labelled 'DS EX 2') because insecticide treatments had begun at the site of the first diurnal experiment. The third experiment occurred on 24th January 1993 in the same plot used in the second experiment but used the Bigvac. All the suction methods were those reported in Chapter 3 for the various devices used in the 1992/3 survey.

4.6.3 Results and Discussion

Data for these experiments are found in Appendix 4.4 on computer disc (Stanley\appen4.xls worksheet 'Appendix 4.4'), and selected data are summarised in Figures 4.7 to 4.9.

Several species exhibited a considerable diurnal variation in numbers, especially when the Elecvac was used. Trichogrammatidae and other micro-hymenoptera showed the most striking difference between day and night numbers (Figure 4.7). This distinctive pattern found with the Elecvac might be correlated to the activity of the insect. Possibly day-time activity places the insect in a more easily captured position, such as hovering around the periphery of the canopy.

The absence of a diurnal difference in the later experiments may therefore be explained by factors which might encourage more consistent activity over the diurnal period, such as more consistent temperatures. However the disappearance of the diurnal effect when the large suction sampler was used raises the question of just what the presence or absence of an arthropod in a suction sample really means. Does absence from a suction sample mean absence from the crop, or does it simply mean that the insect has moved into a protected position within it? Or does the type or level of activity of the insect (stationary, crawling or flying) affect its chance of being collected? It could be expected that insects of the size of Trichogrammatidae are unlikely to make daily movements of the distances necessary to leave the crop, especially while abundant hosts remain. This lack of diurnal migrations is also likely to be true of most of the predators in these fields given the inhospitability of the surroundings (dry wheat stubble or pastoral areas, in this study). Therefore diurnal differences in catches are probably due to intra-canopy movement or differences in activity which lead to varying sampling efficiency. If this is so, the loss of the diurnal pattern exhibited by Trichogramma with the larger Bigvac may reflect the greater power of the larger suction sampler to remove insects which are inactive or have retreated further into the crop canopy. Overall however, the numbers of Trichogrammatidae caught in the third experiment were relatively low, suggesting, as previously noted (Figure 4.2) that the Bigvac may simply be an inefficient collector of Trichogrammatidae.

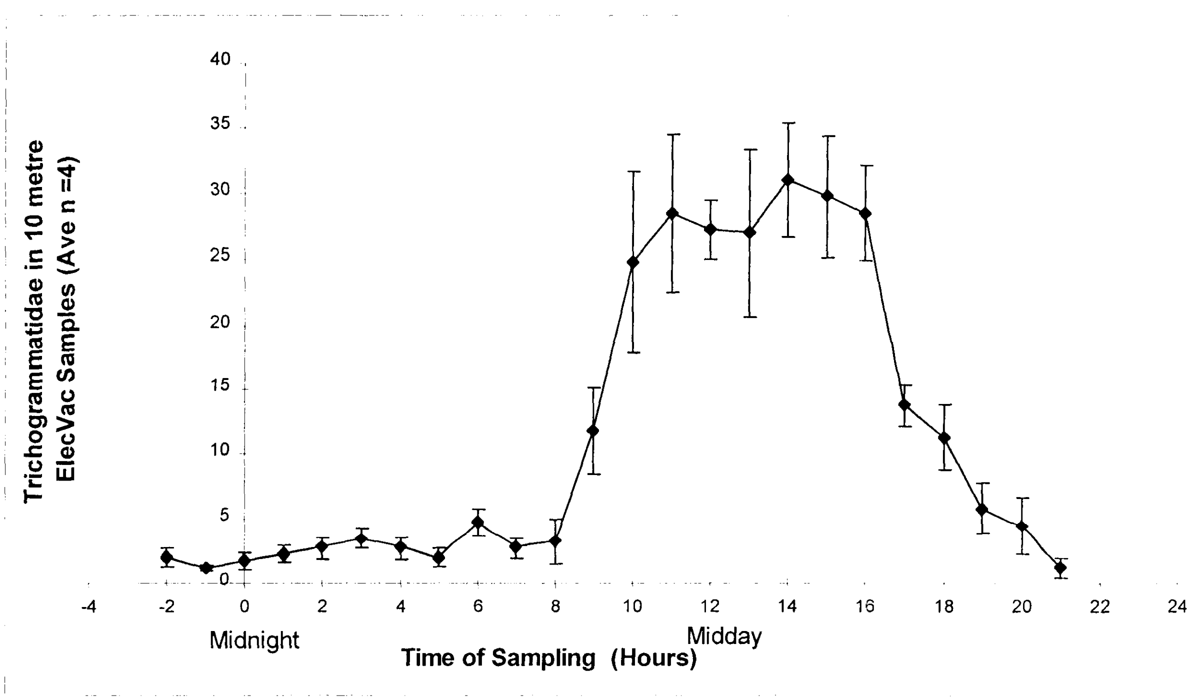

Figure 4.7 Trichogrammatidae caught in suction samples collected hourly using the Elecvac over one diurnal period 21.00 hrs 30/11/92 to 21.00 hrs 1/12/92 (Diurnal Experiment 1). The error bars indicate the standard errors of the means (n=4).

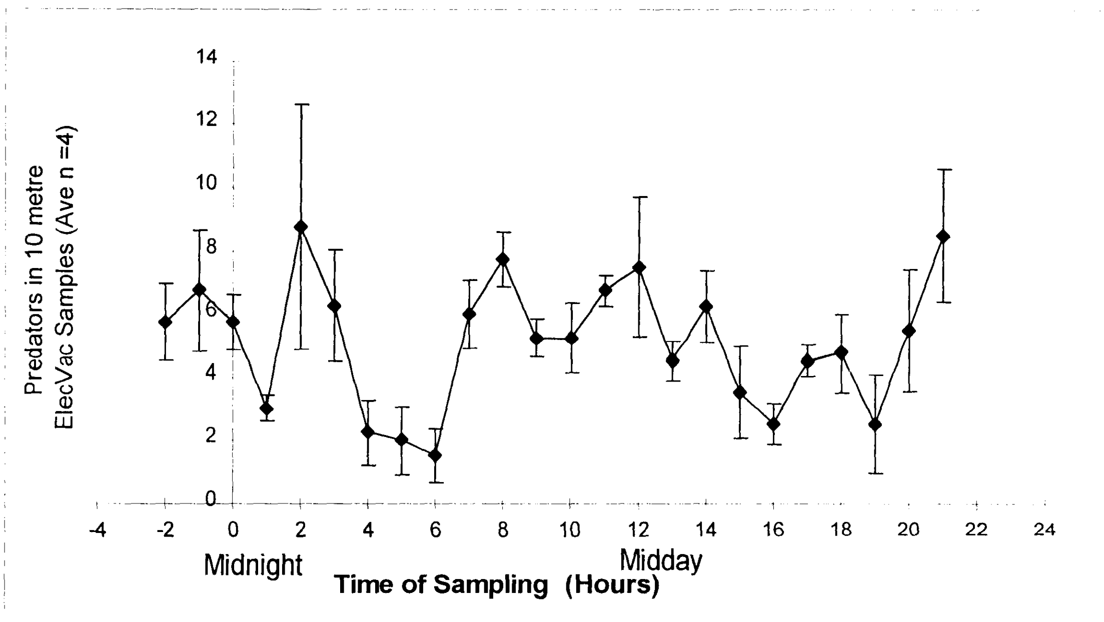

Figure 4.8 Total predators (not including small spiders) collected from a cotton crop canopy using the Elecvac for one diurnal period starting at 22.00 pm on the 30/11/92 (Diurnal Experiment 1). The error bars represent the standard errors of the means (n=4)

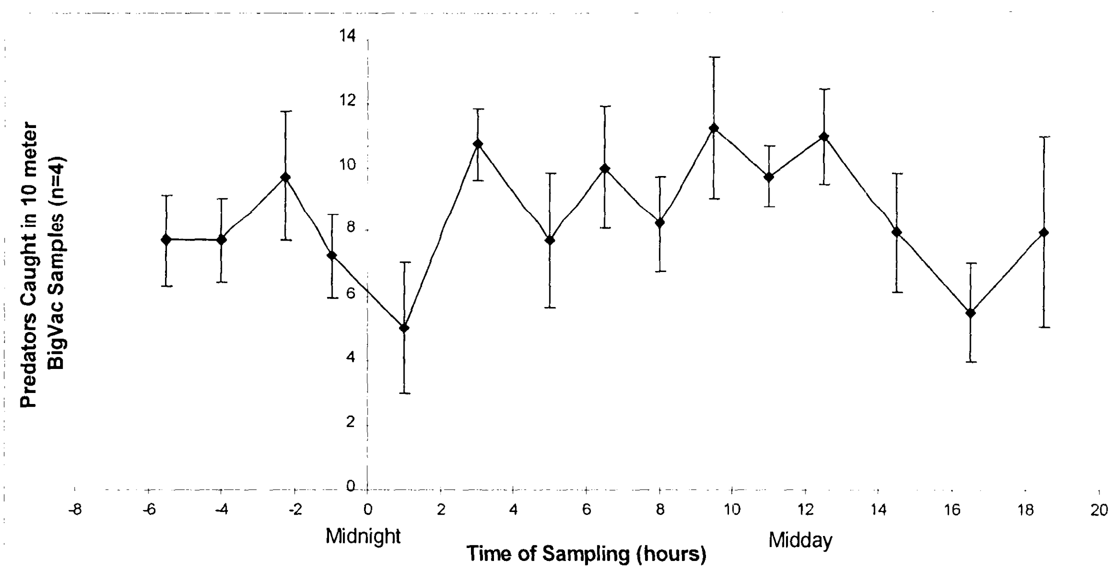

Figure 4.9 Total predators (not including small spiders) from a cotton crop canopy using the Bigvac for one diurnal period starting at 18.00 pm on the 24/1/93 (Diurnal Experiment 3). The error bars represent the Standard Errors of the mean (n=4)

Figures 4.8 and 4.9 show that the size of the total predator catches were often lowest between 12 midnight and 6 am which probably coincides with the coldest period in each trial. Samples were also low during the hottest period in the late afternoon (3 pm to 5 pm). Therefore, insects which retreat to more sheltered or humid positions deeper in the crop canopy during both hot and/or cold times may evade capture, especially by the less powerful suction of the Elecvac.

Generally, however outside the two periods of decline the sampling of predators by suction appears to be relatively consistent throughout the day and night. This agrees with the work conducted by Gonzalez (1977) who compared morning (between 6.00 and 9.00) to afternoon (17.00 to 20.00) collections. The only insects for which they noted differences were *Geocoris* spp (adults and nymphs), *Orius* spp.(adults) and *Chrysopa* spp. (nymphs). Roach (1984) found the size of predator catches generally declined throughout the day comparing samples collected at three time intervals; morning (8-00 to 9-30), midday (13-00 to 14-30) and evening (17-00 to 18-30). The evening samples were always significantly smaller (Duncan's multiple range $P < 0.05$) than the morning catches. Whether the midday samples were significantly smaller than those collected in the morning varied with species. Spiders and *Notoxus* spp. were more difficult to catch after the morning period. This experiment also compared choosing fixed or random locations within the field for sampling. Only spiders decreased significantly in the fixed location samples. In a later experiment by Roach (1984) where a single D-vac was compared to using two D-vacs simultaneously and where top or bottom canopy samples were compared, the diurnal differences disappeared. However the general predator abundance was considerably lower in these experiments.

The implications of the repeat-suction experiments are consistent with a theory that the Bigvac method estimates a relatively constant abundance of a broad suite of cotton arthropods because of the strength of its suction and the inclusion of the entire canopy. Less than complete canopy coverage or a weaker airflow rate would probably produce samples more markedly affected by the diurnal variables of temperature, humidity and light because these can be expected to alter the activity or position of the insects which would in turn affect their catchability. The most efficient and consistent time for collecting the general suite of predatory arthropods in cotton using suction samplers appeared to be between 8.00 am and 12.00 noon.

4.7 Experiment 5: Repeat Suction Validation trials

4.7.1 Introduction and Aim

The studies by Gonzalez *et al.* (1977) and Byerly *et al.* (1978) showed that the usual methods of using D-vacs do not correlate well enough with absolute methods to apply a correction factor to D-vac data to produce absolute estimates of predator abundance. Although the use of absolute methods of sampling was beyond the scope of this study, a less labour intensive method was attempted to indicate the proportion of insects removed from the cotton by the Bigvac method.

4.7.2 Methods

A 10 metre section of cotton row was suction sampled using the methods for the Bigvac detailed in Chapter 3. This section was then immediately resampled in the same way three more times, producing four separate successive samples of arthropods from the same 10 metre section of row. A visual inspection was conducted immediately followed the fourth (last) suction sample at each 10 meter interval. The visual appraisal began with a quick scan of the entire 10 metre section in order to record escaping insects. This was followed by two 15 minute searches of two, 1 metre subsections of that interval carried out simultaneously by two observers. The visual searches were not intended to represent absolute samples but to indicate whether a substantial number of arthropods were being obviously missed. Four 10 metre sections of row were sampled in this way; two in the organically treated area of cotton and two in the control plot, both in Field 5 at 'Alcheringa' in 1993/4 on the 23rd January 1994.

4.7.3 Results and Discussion:

Results for these experiments are given in Appendix 4.5 on computer disc (Stanley\appen4.xls worksheet 'Appendix 4.5'), and selected data are summarised in Figures 4.10 to 4.16. The pattern of collection by the Bigvac suction sampler was similar for most species of arthropods. The first sample removed the greatest proportion, usually 50-80% percent of the total in the four samples. The following passes collected progressively smaller numbers. Figures 4.10 to 4.16 show examples of the proportion of the total catch collected in each pass, particularly for predatory species and other arthropods of interest. A species which was particularly poorly represented in the first pass was *Mallada signata* larvae (28.6%) possibly because it inhabits cryptic positions in the canopy, such as behind the bracts of cotton squares (Figure 4.13).

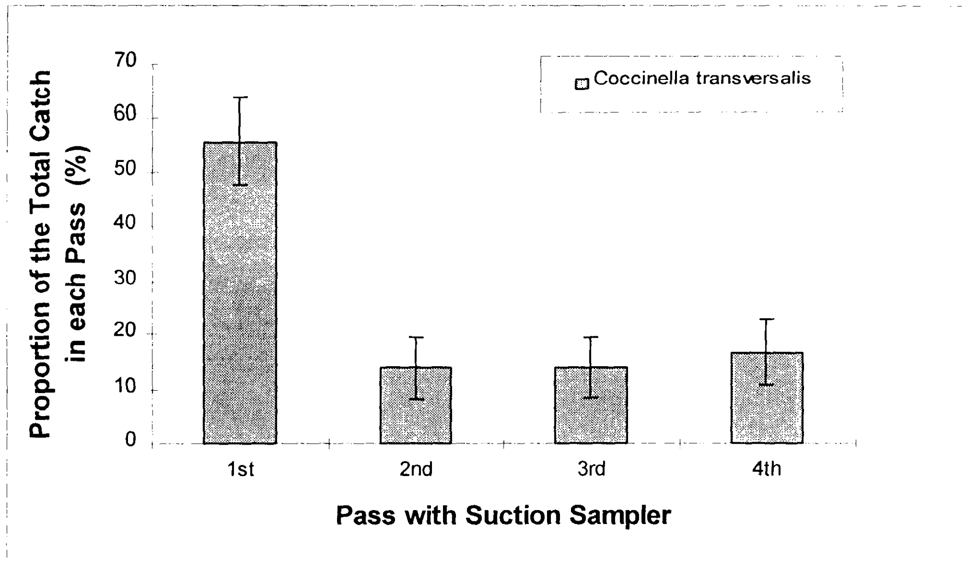

Figure 4.10 The proportion of *Coccinella transversalis* caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

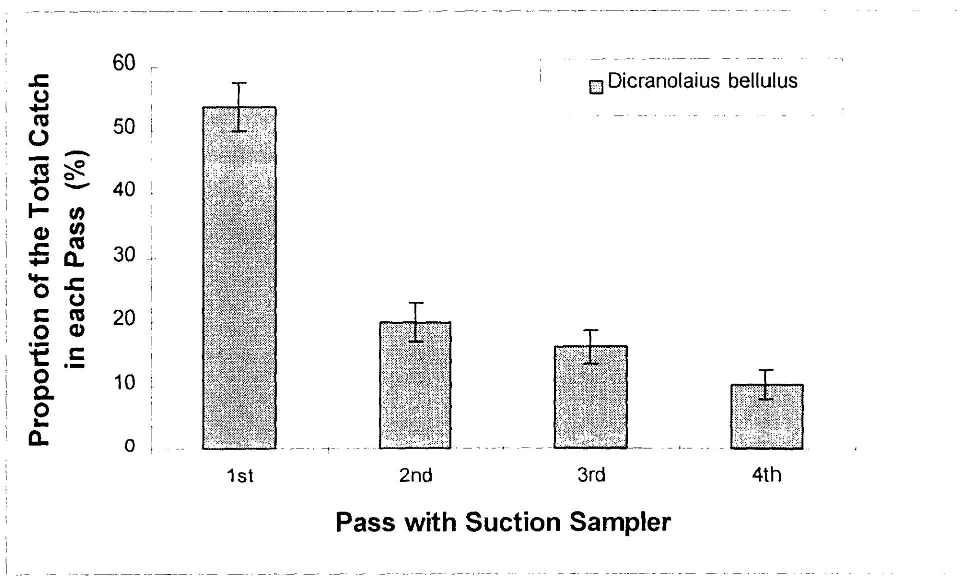

Figure 4.11 The proportion of *Dicranolaius bellulus* caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

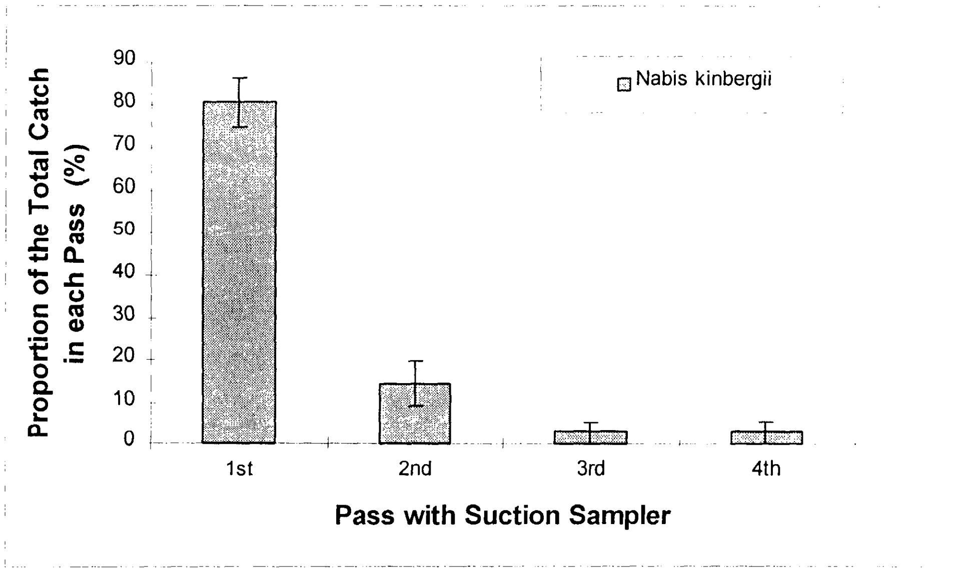

Figure 4.12 The proportion of *Nabis kinbergii* caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

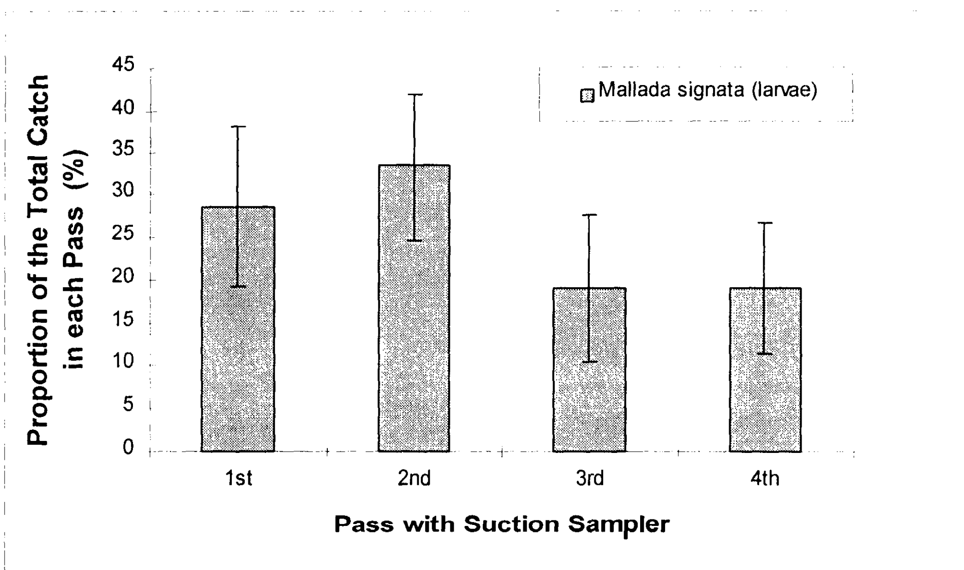

Figure 4.13 The proportion of *Mallada signata* (larvae) caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

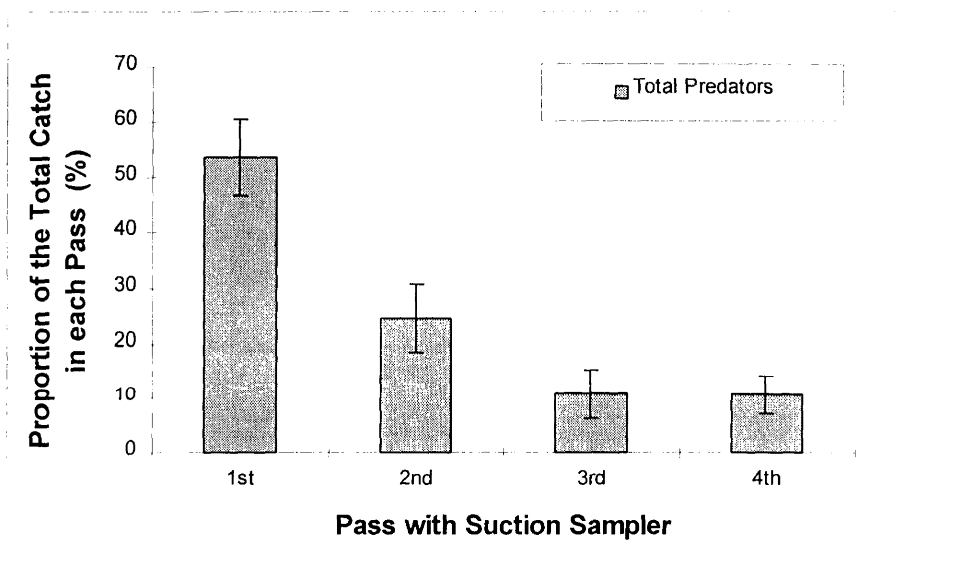

Figure 4.14 The proportion of Total Predators caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

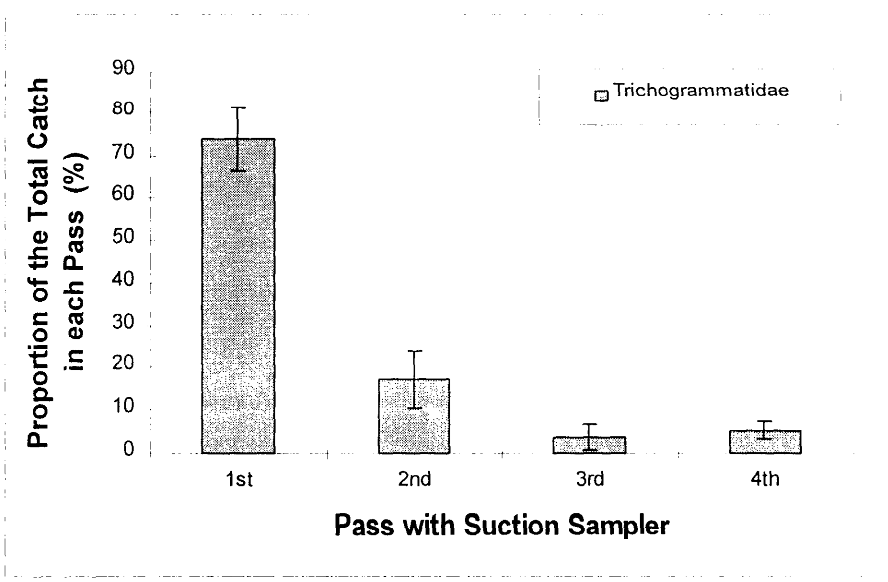

Figure 4.15 The proportion of Trichogrammatidae caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

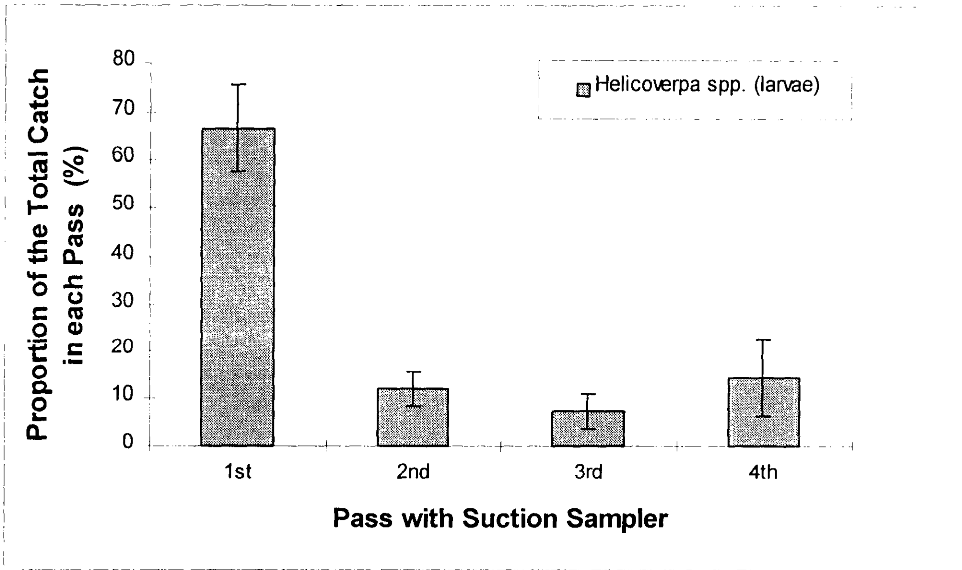

Figure 4.16 The proportion of *Helicoverpa* spp. (larvae) caught in sequential Bigvac suction samples of the same 10 metres of cotton row. The means have been weighted by the total number caught in each replicate so that samples from areas of higher arthropod density have a greater influence on the estimate of the proportion in each pass. The error bars represent the standard errors of the means assuming a binomial distribution.

Visual Appraisal following Suction Sampling

The quick scan following each set of four suction passes did find some escaping arthropods on the soil surface. These included one cotton seed bug (*Oxycarenus luctuosus*), one *Creontiades dilutus* nymph and one *Oxyopes* spp. However, two of the four scans recorded zero escapees. This scanning method is obviously limited and may have recorded more escapees if conducted during the initial disturbance during the 1st approach of the sampler. By the time the fourth sample was completed, 12 to 16 minutes had elapsed. However, an obvious exodus of many insects was not observed by the operator scanning the path ahead during the collection, though small insects such as Trichogrammatidae would not be noticed by this method.

The 15 minute searches of the two 1 metre sections of the sampled interval recorded several insects which had evaded collection by the suction method and remained in the canopy. *Helicoverpa* spp. (larvae) were represented as were small insects which inhabit the flowers (thrips and *Carpophilus* spp.). Predators such as *D. bellulus* and Oxyopidae, found during the visual search on the lower leaves, were also missed by the suction sampler. Some apple dimpling bugs (*Campylomma* spp.), *O. luctuosus* and *C. dilutus* were also missed. These were found behind bracts in squares.

The small proportion of arthropods apparently missed by this suction method and the considerable proportion of the insects collected with the first pass, suggests that the Bigvac method might correlate better with the absolute sampling than those methods previously tested by Gonzalez *et al.* (1977) and Byerly *et al.* (1978). However the major obstacle which prevents deducing the efficiency of the suction method via this experiment is the possibility that a substantial or highly variable proportion of the arthropods were frightened away by the sampling process.

The alternative explanations for these results are:

(1) Insects may have escaped, particularly during and shortly after the first pass. This was not generally apparent at the low densities being sampled here. Some insects may even have entered the collection zone as others escaped it. The extent to which each was happening would depend upon how the insects respond to the disturbance. It is the balance of this transfer that is the net loss due to disturbance, and this may be small relative to the size of the total sample.

(2) Some individuals may remain unsampled. The visual sample which followed the fourth suction pass was expected to detect the presence of unsampled arthropods. With the exception of *Helicoverpa* spp. very little was recorded. Large predatory species were unlikely to be missed during this process although tiny immature and highly active species such as *Orius* spp. nymphs and Trichogrammatids were obviously not satisfactorily recorded. Therefore these results imply that the Bigvac suction sampler might be adequate for estimating the larger predatory species in cotton. However, it is impossible to estimate the level of escape without a reliable absolute method. Adult predators which are large and only moderately active, such as coccinellids, *D. bellulus* and nabids appear be the best candidates for this style of sampling.

4.8 General Conclusions.

The Bigvac collected the largest catches, especially of the group of larger generalist predators, such as *D. bellulus* and coccinellids (Figure 4.1). The catch of the Macvac method was generally similar to the Bigvac early in the season but declined to less than 10% of the Bigvac catch over the later half of the season. This probably reflected the larger area covered by the Bigvac method and the inclusion of the lower canopy as the plants increased in size. Many species showed little difference in the catch sizes between day and night, especially predators when the Bigvac method was used. The results of the diurnal trials are consistent with the hypothesis that the predators continually inhabit the canopy and do not make daily migratory flights to the surrounding bushland. This suggests that the diurnal patterns exhibited whilst using the smaller suction sampler were generated by the variations in sampling efficiency caused by intra-canopy movements and varying insect activity levels. The interval between 8-00 am and 12-00 am appeared to be a good general time for sampling predators because this period produced the highest counts, while maintaining the smallest variability. This applied to all predatory species covered by these studies, including small spiders.

The series of repeated samples from the same section of row broadly indicates that few of the generalist predators of interest for this study escape collection. On these grounds this method was accepted for the surveys in this thesis despite the problems raised by other studies using D-vacs in other ways.

Chapter 5

Experimental Section

5. Field Survey of the Seasonal Abundance of Predators, and the Effects of Insecticides, in Different Pest Management Regimes

5.1 Introduction

The seasonal abundance of endemic predatory arthropods provides the first indication of the potential of such predators to contribute to pest control. Clearly a marked absence of predators at critical times indicates a low potential. On the other hand, an abundance of predators at appropriate times is a necessary, but not sufficient, criterion to guarantee control. Regular sampling of arthropods from unsprayed plots was conducted to indicate the seasonal profiles of predators which commonly inhabit cotton crops.

Furthermore, to incorporate the impact of predators into integrated pest management programs (IPM), it will be important to know how other pest control practices affect the abundance of predators. With the current reliance on chemical insecticides for growing cotton in Australia the compatibility of the various insecticide options with predators is of most importance. Comparisons between the abundance of predators in crops treated with conventional insecticides, softer options or those left untreated provided an appreciation of the potential to conserve predators by the abstinence from or judicious use of particular insecticides.

Although the focus of this study was *Helicoverpa* spp. and its potential predators, all arthropods collected during the survey were identified or categorised and counted. This wide scope was employed to improve our understanding of other factors which could be affecting the abundance of the predators but which might not be directly associated with the target pest. These possibilities included the abundance of alternative prey which may also be affected by the insecticides aimed at *Helicoverpa* spp.

Therefore this chapter presents records of suction samples collected over two cotton seasons to show which species of predator were present, when they occurred and how abundant they became. This study was essentially an ecological survey of arthropod populations within an agricultural habitat. It differed from most natural ecological studies because the vegetation was a monoculture of cotton plants and the environment included pest management practices, especially insecticide applications. However, the scale of the survey and the range of uncontrollable variables presented the same difficulties faced by ecological comparisons in natural environments, especially regarding replication and description of treatments. The history and widespread use of insecticides on a regional basis may have affected the type and abundance of the predators and prey recorded here, compared to a totally unsprayed region. This possibility is implicit throughout the discussions which follow.

5.2 Materials and Methods

The locations and layouts of the farms and sites are given in the general methods chapter (Chapter 3). The details of the general sampling procedures are also presented there. The following material is therefore confined to the particular experimental design and treatments imposed at each site.

Sites and Treatments

There were three farms involved in this study; 'Midkin', 'Alcheringa' and 'Wilby'. 'Midkin' was surveyed over two seasons, 1992/3 and 1993/4. 'Alcheringa' and 'Wilby' were only surveyed over the 1993/4 season. There were two insecticide treatments at each site in each year, except at 'Midkin' in 1993/4, where there were three. Thus, comparisons can be made between farms, between years within farms, and between treatments within years.

Figure 5.1 provides a schematic diagram of the treatment layout. Tables 5.1 and 5.2 present the insecticide schedule for the treatments applied at 'Midkin' through the 1992/3 and 1993/4 seasons, respectively. Tables 5.3 and 5.4 provides the same information for 'Alcheringa' and 'Wilby', respectively. These tables can be used in conjunction with the arthropod abundance charts (Figures 5.2 to 5.52) in each section to identify the insecticide treatments indicated above the data in each chart. Marked mortality following an insecticide application might provide an alternative explanation for changes in abundance to seasonal or predatory effects.

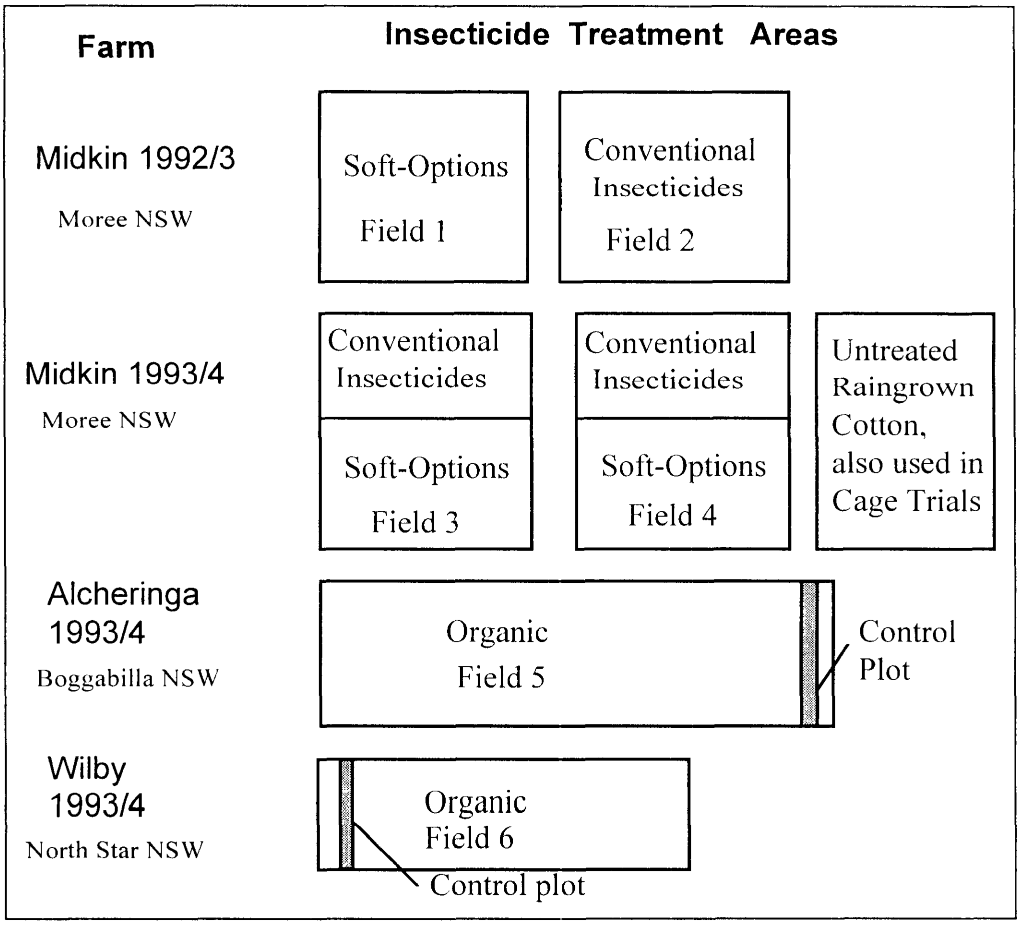

Figure 5.1 A schematic diagram of the insecticide treatments applied to the fields on all the farms involved in the predator survey. Each rectangle represents a treatment area. Arthropod sampling was conducted in fixed 0.5 hectare subplots within each treatment area throughout the cotton growing season.

'Midkin' 1992/93

Field 1 was a 72 hectare field of irrigated cotton treated with softer-option insecticides. Under this regime, industry crop scouts monitored the cotton for pests and insecticides were applied according to the current threshold recommendations. Endosulfan, synthetic pyrethroids and organophosphates were not permitted. The alternative insecticides, referred to as softer-options because at the time they were believed to be less destructive to the non-target insects, were: Thiodicarb (Larvin®), Chlorfluazuron (Helix®), *Bacillus thuringensis* (Bt; Dipel®) and Pirimicarb (Pirimor®). The details of these treatments are provided in Tables 5.1 and 5.2. The commercial sources of these products are presented in Appendix 5.6.

Field 2, comprising 150 hectares of irrigated cotton, was managed for pests using the conventional treatment. Industry crop scouts monitored the cotton for pests and insecticides were applied according to the current threshold recommendations. The insecticide resistance management strategy (Forrester *et al.* 1987) was adhered to in Australian cotton, including the sites described in this chapter. This involved using particular insecticide groups within designated periods to avoid treating too many successive generations of *Helicoverpa* spp. with the same active ingredient. This limitation was particularly severe on the use of pyrethroids. At the time of this study, the season was divided into three stages: Stage 1; prior to 10th January, where endosulfan but not pyrethroids could be used, Stage 2; 11th January to 13th February, where both endosulfan and pyrethroids could be used, and Stage 3; after 13th February when neither could be used. Both fields received in furrow application of aldercarb (Temik®) at sowing for thrip control.

Selection of Insecticide Treatments

The insecticides used to imposed the treatments investigated during this study were chosen and applied by the cotton growers. They were selected to provide alternatives to the conventional options of endosulfan, synthetic pyrethroids and organophosphates and the judgements were based on experience, marketing information and the availability of the various chemicals. Therefore the intention of the growers was not solely to select insecticides which might have been expected to maximise the conservation of natural enemies. In particular, the requirement to substitute endosulfan and the lack of independent information on the impact of the alternative insecticides (essentially, thiodicarb and chlorfluazuron) may have led to the selection of chemicals which may not have been the 'softer' options.

The following is a brief review of recent information on the alternative insecticides much of which was not available when this study began. It is presented to provide a basis for the discussion throughout this chapter on the potentially negative effects of the alternatives on beneficial insects. The alternative insecticides used were Bt (Dipel®), chlorfluazuron (Helix®) and thiodicarb (Larvin®). Bt is regarded as particularly soft on beneficial insects. For example, Bellows and Morse (1993) showed it had little direct toxicity and zero to little residual impact on a parasitoid (*Aphytis melinus* Debatch, Hymenoptera: Aphelinidae) and a predator (*Rhizobus lophanthae* (Blaisd.), Coleoptera: Coccinellidae). Chlorfluazuron is a chiton inhibitor which is aquired via ingestion. This route of entry could be expected to select for herbivorous arthropods which are therefore probably the target pests. However, the limited available information suggests that insects which prey on effected herbivores may not be so safe. Mendal *et al.* (1994) has found that egg hatch was disrupted in Coccinella sp. by ingestion of or contact with chlorfluazuron. It would also be reasonable to assume that predatory species which occasionally feed on plant tissue would directly consume this insecticide, this would include several hemipterans found in Australian cotton crops, for example geocorids, mirids and nabids. If beneficial insects are effected by chlorfluazuron a further concern would be the long persistence (in the order of months) of this chemical.

The choice of thiodicarb to replace endosulfan is probably the most debatable substitution in regard to softness for beneficial insects. Although thiodicarb is predominently a stomach poison and therefore commonly, but mistakenly (for the reasons presented in the preceeding paragraph) expected not to effect predatory species, it has been described as having moderate contact activity (Sousa *et al.* 1977). Furthermore, predators which consume affected herbivores may also be affected by thiodicarb. For example, Bellows and Morse (1993) found that it was toxic to a coccinellid (*Rhizobius lophanthae* (Blaisd.)), particularly at the recommended field application rate. Osman *et al.* (1985) demonstrated that thiodicarb was particularly toxic to several entomophagous insects in large field trials on cotton. Endosulfan, on the other hand, has been shown to have relatively low toxicity on two Australian coccinellids, despite being a contact toxin (*Coccinella repanda* Thunberg and *Harmonia octomaculata* (Fabricus)) (Broadley 1983). Wilson (1993) ranked insecticides which provoked mite outbreaks in Australian cotton. Based on the assumption that mite flare is induced by the removal of mite predators, many of which are the same as *Helicoverpa* spp. predators, this ranking indicates the relative softness these insecticides. His ranking from hardest to softest on beneficial insects is: i) thiodicarb ii) chlofluazuron iii) endosulfan and, iv) Bt.

'Midkin' 1993/4

Fields 3 and 4 were half treated with conventional pest management and the other half treated with the soft-option insecticides. The rules for applying treatments in 1993/4 were the same as those in 1992/3. However, the actual number and time of insecticide applications differed because of differences in pest abundance between the two years. This year was drought affected and pest pressure was low, which resulted in fewer applications of insecticides. As in 1992/3 all treatments at Midkin received infurrow application of aldercarb (Temik®) at sowing for thrip control.

'Alcheringa' 1993/4

Field 5 consisted of 240 hectares of irrigated cotton. It was grown organically with 16 metre wide strips of sorghum every 200 rows (200 meters) of cotton. A 16 row strip (16meters) of cotton plants along one end of the field received no direct applications of insecticides, and was used as a control plot. This was also adjacent to a 16 row strip crop of sorghum. The organic treatments involved a total 48 sprays, applied on 22 occasions. The most commonly used compounds for *Helicoverpa* spp. control were Bt (17 applications), garlic (10 applications) and natural pyrethrum (3 applications).

The exact treatments used at this site were considered commercially sensitive by the growers and some information was not released to the author, but the available details of the treatments are contained in Table 5.3 showing product, application rate and time.

There were two inundative releases of Trichogramma (*Trichogramma* sp. nr. *brassicae* (Bezdenko)) at 'Alcheringa' but none at 'Wilby'. The Trichogramma were released at a rate of 159,000 per hectare over the entire area. There were also two releases of green lacewing (*Mallada signata*) larvae at both 'Wilby' and 'Alcheringa', but these were released only over the sorghum strips at a rate of 1880 per hectare, considering the area of the sorghum only.

'Wilby' 1993/4

Field 6 consisted of 145 hectares of raingrown cotton. As with 'Alcheringa', this field had 16 meter wide strips of sorghum every 200 rows of cotton. The organic treatments comprised a total of 27 sprays, applied on 11 occasions. The most commonly used compounds used for *Helicoverpa* spp. control were Bt (9 applications), garlic (9 applications) and natural pyrethrum (1 application). Again, a 16 row strip (16 metres) of cotton plants, along one end of the field and adjacent to a sorghum strip , received no direct applications of insecticides and was used as a control plot. As at 'Alcheringa, some details of the organic treatments were considered confidential by the grower, but available details are given in Table 5.4.

Sampling and Replication

'Midkin' in 1992/93 was the most thoroughly sampled site. A rectangular subplot of approximately 0.5 hectares was established in the four corners of each field (8 subplots). The long side of each subplot was 100 meters long, parallel to the cotton rows and 100 meters away from the edge of the field. The shorter side of the subplot was 50 rows wide and 100 meters from the tail drain or head ditch depending on which end of the field it was located (Figure 3.3 in Chapter 3). Four suction samples were collected twice weekly from each subplot from October 1992 to March 1993, encompassing the majority of the cotton growing season.

Initially, while the cotton was at the seedling stage, visual sampling was carried out because the suction samplers collected too much soil. These visual samples involved inspections of four randomly selected one meter sections of cotton row in each subplot. When the plants were larger, a small electric powered suction sampler was used (the Elecvac, refer to Chapter 3 for details). On the 26/11/92 the sample interval was increased to 10 meters to increase the size of the catches. The early visual samples and the one metre suction samples are not reported because they encountered too few insects. The large D-vac style machine, the Bigvac (Chapter 3) was introduced on 22/12/92 and formed the basis of the survey sampling from then on.

At 'Midkin' in 1993/4, a subplot of 0.5 hectares was established in each treatment area with a 100m border to the edge of the field (Figure 3.4 in Chapter 3). Four suction samples were collected from each subplot on a weekly basis using the Bigvac, following the methods described in Chapter 3.

At 'Alcheringa' and 'Wilby' in 1993/4 two 0.5 hectare subplots were established in each of the fields, one in the control plot and the other amongst the organically treated cotton. A 100 meter buffering distance was maintained from the end of the field, but the position and size of the control plots did not allow greater than a 16 meter side buffer region (Figures 3.5 and 3.6 in Chapter 3). Four suction samples were taken using the Bigvac and five using the Macvac from each of the four subplots on each sampling date. Macvac samples were collected weekly but Bigvac samples were collected every second week.

The cotton crops grown during the 1992/3 season at Midkin were more typical of a normal year than the following season, which was affected by drought. This site was also the most thoroughly sampled, both more regularly and with more replications. Therefore greater emphasis is put on the results of this year throughout the discussion.

Midkin: Field 1 (1992/3) Soft-Option Insecticides					Midkin: Field 2 (1992/3) Conventional Insecticides				
Date	**Insecticide**	**Trade Name**	**Rate (l/ha)**	**Time of Application**	**Date**	**Insecticide**	**Trade Name**	**Rate (l/ha)**	**Time of Application**
22-Dec	Bt	Dipel®	1	12.00 noon	22-Dec	Endosulfan		2.1	12.00 noon
22-Dec	Thiodicarb	Larvin®	1	12.00 noon					
7-Jan	Chlorfluazuron	Helix®	2.5	10.00pm	31-Dec	Endosulfan		2.1	10.00pm
18-Jan	Bt	Dipel®	1	9.00pm	8-Jan	Endosulfan		3.0	10.00pm
22-Jan	Thiodicarb	Larvin®	1	10.00pm	15-Jan	Endosulfan		3.0	10.00pm
29-Jan	Bt	Dipel®	1	10.00pm					
29-Jan	Thiodicarb	Larvin®	1	10.00pm	21-Jan	Synthetic pyrethroid	Decis®	3.0	10.00pm
6-Feb	Chlorfluazuron	Helix®	2.5	8.00pm	29-Jan	Synthetic pyrethroid	Decis®	3.0	7.00pm
10-Feb		Pirimor®	0.5kg/ha	10.00pm	12-Feb	Synthetic pyrethroid	Karate ®	420ml/ha	10.00pm
					12-Feb	Dimethoate	Rogor®	500ml/ha	10.00pm
25-Feb	Chlorfluazuron	Helix®	2.5	10.00pm	25-Feb	Chlorfluazuron	Helix®	2.5	10.00pm
					12-Mar	Dimethoate	Rogor®	500ml/ha	10.00pm

Table 5.1 The insecticide application schedule for the soft-option and conventional insecticide treatments imposed at **Midkin** over the **1992/3** cotton growing season (i.e. Fields 1 and 2). These applications are included as markers above the data in the charts of the arthropod abundance throughout chapters 5 and 6. Bt is a formulation of a toxin derived from *Bacillus thuringiensis*.

Midkin: Field 3 (1993/4) Soft-Option Insecticides					Midkin: Field 4 (1993/4) Conventional Insecticides				
Date	**Insecticide**	**Trade Name**	**Rate (l/ha)**	**Time of Application**	**Date**	**Insecticide**	**Trade Name**	**Rate (l/ha)**	**Time of Application**
15 Dec	Bt	Dipel®	1	10:00	13 Dec	Endosulfan		2.1	22:00
15 Dec	Thiodicarb	Larvin®	1	10:00					
23 Dec	Bt	Dipel®	1	10:00	23 Dec	Endosulfan		2.1	10:00
23 Dec	Thiodicarb	Larvin®	1	10:00					
31 Dec	Bt	Dipel®	1	22:00	30 Dec	Endosulfan		2.1	22:00
31 Dec	Thiodicarb	Larvin®	1	22:00					
25 Jan	Chlorfluazuron	Helix®	2.5	22:00	15 Jan	Synthetic Pyrethroid	Decis®	3	10:00
					4 Feb	Bt	Dipel®	1	22:00
					4 Feb	Synthetic Pyrethroid	Karate®	3	22:00
25 Feb	Dimethoate	Rogor®	0.45	22:00	25 Feb	Dimethoate	Rogor®	0.45	22:00

Table 5.2 The insecticide application schedule for the soft-option and conventional insecticide treatments imposed at **Midkin** over the **1993/4** cotton growing season (i.e. Fields 3 and 4). These applications are included as markers above the data in the arthropod abundance charts throughout chapters 5 and 6. Bt is a formulation of a toxin derived from *Bacillus thuringiensis*.

Date of Application	Substance applied or natural enemy release (Application Rate in litres/hectare)				Method of Application
17/12/93	Garlic (0.5)		Delfin OF (2)		Aerial
19/12/93	Symspray (0.4)				Ground rig
23/12/93			Dipel LS (3)		Aerial
27/12/93	Garlic (0.5)			Puresugar (4)	Aerial
28/12/93			Delfin OF (3)	Lacewing larvae[1] (1880/ha)	Aerial
31/12/93	Garlic (0.5)		Dipel LS (3)		Aerial
6/1/94				Trichogramma[2] (159000/ha)	Aerial
7/1/94			Delfin OF (3)		Aerial
13/1/94				Trichogramma (159000/ha)	Aerial
14/1/94		Natural Pyrethrum (0.1)	Dipel LS (3)		Aerial
19/1/94		Natural Pyrethrum (0.1)	Dipel LS (3) DC Tron (2)		Aerial
21/1/94			Delfin OF (2)		Aerial
26/1/94			Dipel LS (2)		Aerial
28/1/94	Garlic (0.5)				Aerial
9/2/94			Dipel LS (2.5)	Pure Sugar (5.5)	Aerial
14/2/94			Dipel LS (2.5)		Aerial
16/2/94	Garlic (1.2)	Natural Pyrethrum (0.1)	Dipel LS (2)		Aerial
21/2/94			Delfin OF (3)	Pure Sugar (4)	Aerial
25/2/94	Garlic (1)	Natural Pyrethrum (0.13)		Natrakelp (1)	Aerial
10/3/94			DC Tron (2)	Natrasoap(2)	Aerial

Table 5.3 ***Alcheringa 1993/4*** Treatments applied to the organic areas of cotton grown at Alcheringa in the 1993/4 cotton growing season (ie. Field 5). Only those organic treatments or substances aimed at effecting the survival or behaviour of arthropods are listed.

Date of Application	Substance applied or natural enemy release (Application Rate in litres/hectare)				Method of Application
2/12/93	Garlic(0.5)	Delfin WDG (1)	Codacide Oil (0.25)		Ground rig
10/12/93	Garlic (0.75)	Dipel LS (3)	Codacide Oil (0.25)		Ground rig
21/12/93	Garlic (0.5)	Delfin OF (3)	Natrakelp (0.5)		Ground rig
27/12/93	Garlic (0.2)	Delfin OF (3)	Codacide Oil (0.25)		Ground rig
28/12/93				Lacewing larvae (1880/ha)	Aerial
30/12/93	Natural Pyrethum (0.1)	Dipel LS (1.5)			Aerial
9/1/94				Lacewing larvae (1880/ha)	Aerial
27/1/94	Garlic (0.5)	Delfin OF (3)	Codacide Oil (0.25)		Aerial
21/2/94		Dipel LS (2)			

Table 5.4 ***Wilby 1993/4*** Treatments applied to the organic areas of cotton grown at Wilby in the 1993/4 cotton growing season (ie. Field 6). Only those organic treatments or substances aimed at effecting the survival or behaviour of arthropods are listed. *Some details of the many products and treatments used at the organic sites were considered commercially sensitive by the growers and therefore information is limited to that above, that is, general product names, application rate and time.*

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[1] The lacewing larvae were eggs to 3rd instar *Mallada signata* (Neuroptera: Chrysopidae) and were only released over the relatively small area of sorghum strip crops. Refer to Figures 3.5 for 'Alcheringa' and 3.6 for 'Wilby' for the layout of the strip crops.

[2] The Trichogramma were *Trichogramma* nr. *brassicae*.

5.3 Results and Discussion

The raw counts from the arthropod survey at each site are presented on the computer disc inside the back cover of this thesis under the following file names:

1) **Stanley\appen5.xls** worksheet 'Appendix 5.2':
Corresponds to counts from 'Midkin' in 1992/3

2) **Stanley\appen5.xls** worksheet 'Appendix 5.3':
Corresponds to counts from 'Midkin' in 1993/4

3) **Stanley\appen5.xls** worksheet 'Appendix 5.4':
Corresponds to counts from 'Alcheringa' and 'Wilby' in 1993/4

Species

The same general suite of predatory arthropods species was recovered throughout the areas surveyed in this study. Furthermore, the types of generalist predators (Chapter 3) were similar to those reported from throughout the temperate to subtropical regions of the world in herbaceous crops such as soybeans and cotton (Denkins *et al.* 1970a and 1970b, Shepard *et al.* 1974, Byerly *et al.* 1978, Room 1979a and 1979b, Evans 1985, O'Neil and Wiedenmann 1987, Pyke and Brown 1996).

Abundance

Appendix 5.1 presents rankings of the total number and the average daily maximums for each predator at each site. The arthropod density is given as the number in a 10 metre suction sample unless otherwise stated. There were 10 treatments overall at the 4 sites in the two years. These treatments were surveyed with different frequencies, so the total catches over the season cannot be directly compared. However, within each site and treatment, the rankings are based on the totals. The average daily maximums are useful to gauge population size and variability. For example, a high average daily maximum with low totals indicates a sporadically appearing predator, whereas the reverse shows a persistent predator which does not reach high abundance at any time.

Appendix 5.1 has been summarised in Tables 5.5 and 5.6 for an overall evaluation of relative abundance. Table 5.5 shows the relative abundance of the adult predators and Table 5.6 shows the same analysis for juvenile predators and small spiders. The maximum daily average over all the sites is also shown to indicate the maximum density recorded under these treatments and the site where that maximum occurred is also shown.

Although abundance was quite variable, several species were consistently more abundant than others, even when viewed across the different insecticide regimes. These were *Dicranolaius bellulus,* Formicidae, *Oxyopes* spp., *Nabis kinbergii, Coccinella transversalis* and *Diomus notescens* (Table 5.5). Formicidae included several species and therefore may have gained a high ranking due to a pooling effect. Likewise *Oxyopes* spp. represents at least three species. The abundant predators which were identified to single species groups were therefore *D. bellulus*, *N. kinbergii, C. transversalis* and *D. notescens*. All these species have been shown to predate on *Helicoverpa* spp. in laboratory studies (Room 1979a). Therefore they became the focus of further investigations into predator-prey relationships.

Table 5.6 shows the dominant abundance of small spiders over other juvenile arthropod predators. The dominance is so overwhelming that the pooling effect which biases against those sorted to species is unlikely to have seriously affected this conclusion. However, suction sampling is considered to be particularly poor for collecting the juvenile stages of many predatory species (Gonzalez *et al.* 1977, Byerly *et al.* 1978). The five least abundant species were represented so poorly compared to the abundance of their respective adults that sampling inefficiency is likely to have been a problem. Although adult totals may be large if they are generally more persistent, periods of very high juvenile abundance could be expected to yield larger total catches than those shown in Table 5.6.

The abundance of particular predatory species, or groups of species, in each site and year, is presented graphically in Figures 5.2 to 5.48. The species which are examined individually in this way are *Dicranolaius bellulus, Nabis kinbergii, Coccinella transversalis, Diomus notescens, Geocoris* sp., *Germalus* sp., *Oechalia schellenbergii, Mallada signata,* large and small spiders, and Formicidae.

Adult Predators and Large Spiders	Overall Ranking on Grand Total	Frequency Ranked 1st to 5th	Frequency Ranked 6th to 10th	Frequency Ranked above 10th	Grand Total of all sites	Max Daily Average	Site of the Max Daily Average
Campylomma spp.	1	10	0	0	2234	41.83	Alcheringa Control
Dicranolaius bellulus	2	5	5	0	1585	28.5	Alcheringa Control
Formicidae	3	6	4	0	1163	32.75	Alcheringa Control
Oxyopes spp.	4	6	4	0	1143	19.75	Midkin Soft 93/4
Nabis kinbergii	5	5	4	1	944	9.33	Alcheringa Control
Coccinella transversalis	6	8	1	1	677	9	Wilby Organic
Diomus notescens	7	5	2	3	575	23.75	Wilby Control
Creontiades dilutus	8	3	5	2	493	13.67	Alcheringa Control
Orius spp.	9	1	3	6	294	4.25	Alcheringa Control
Geocoris spp.	10	1	1	8	252	2	Midkin Soft 93/4
Chiracanthium spp.	11	0	8	2	190	5.5	Wilby Control
Other Spiders	12	0	7	3	162	2.75	Wilby Control
Salticidae	13	0	2	8	121	2	Midkin Soft 93/4
Germalus spp.	14	0	0	10	29	0.63	Midkin Conventional 92/3
Oechalia schellenbergii	15	0	1	9	27	0.83	Alcheringa Control
Harmonia conformis	16	0	0	10	16	0.75	Midkin Soft 92/3
Mictolestodes macleayi	17	0	0	10	9	0.5	Wilby Control
Microspis frenata.	18	0	0	10	3	0.06	Midkin Soft 92/3

Table 5.5 The ranking of abundance of the adult predators over all the treatments surveyed during this study. The total catch of each predator throughout the cotton growing season was ranked within each treatment. The frequency rankings are the number of times the predator ranked within the High (1st to5th inclusive) Medium (6th to10th inclusive) or Low (11th to 15th inclusive) categories of the total collected at each site. Maximum daily averages were based on the 10 meter Bigvac suction sampling method.

Juvenile Predators and Small Spiders	Overall Ranking on Grand Total	Frequency Ranked 1st to 5th	Frequency Ranked 6th to 10th	Grand Total over all Sites	Max Daily Average	Site of the Max Daily Average
Oxyopes spp.	1	10	0	7523	93	Midkin Soft 93/4
Other Spiders	2	9	1	3180	20	Midkin Conventional 92/3
Creontiades dilutus	3	8	2	382	16	Alcheringa Control
Salticidae	4	6	4	366	3.06	Midkin Soft 92/3
Campylomma spp.	5	3	7	236	20	Alcheringa Control
Chiracanthium spp.	6	6	4	163	5.5	Wilby Control
Mallada signata	7	4	6	159	2.5	Alcheringa Control
Geocoris spp.	8	1	9	82	3	Midkin Soft 93/4
Nabis kinbergii	9	2	8	52	1.25	Midkin Soft 93/4
Coccinella transversalis	10	1	9	47	4.33	Alcheringa Control
Oechalia schellenbergii	11	0	10	37	2.75	Midkin Soft 93/4
Orius spp.	12	0	10	15	2.5	Alcheringa Control

Table 5.6 The ranking of abundance of the juvenile insects or small spiders over all the treatments surveyed during this study.
The total suction catch of each predator over the cotton growing season was ranked for each treatment. The frequency rankings are the number of times the predator ranked within the High (1st to 4th inclusive) or Low (5th to 8th inclusive) categories of the total collected at each site. Maximum daily averages were based on the 10 meter Bigvac suction sampling method.
Small spiders are those with a head width of < 1mm.

5.3.1 *Campylomma* spp. (including *Campylomma liebknechti*, the Apple Dimpling Bug)

Although generally considered a pest of cotton and included in the sucking pest group when monitoring for pest management, *Campylomma* spp. are predatory as well as phytophagous. They have been included in the analysis of predators because the most commonly collected species, *Campylomma liebknechti* exhibited high consumption rates on *Helicoverpa* spp. eggs (3.9 eggs per predator per day in petri dish trials, Room 1979a), and are often highly abundant. The nymphs are also predatory and are included with the adults in the charts of the seasonal abundance of this species (Figures 5.2 to 5.5). At most sites this was the most abundant predator inhabiting the cotton, and the presence of many juveniles indicates it can reproduce in cotton fields (Table 5.5).

At 'Midkin' in 1992/3, the soft-option treatments had greater numbers of this species. However, the application of Chlorfluazuron on 7/1/93 appears to have caused very high mortality up to 12/1/93. Mortality might be expected since juveniles are included in these data, and Chlorfluazuron is a chitin inhibitor (completion of moults may be affected). There also appear to have been declines in abundance associated with the application of thiodicarb on a number of occasions. *Campylomma* spp. were consistently lower in abundance under the soft-option sprays, but the conventional field appears to have harboured lower populations from the start of the season, even before any insecticides were applied.

At 'Midkin' in 1993/4 the soft-option and conventional areas had similar populations of *Campylomma* spp. to the 1992/3 season but this was sustained in the soft-option field for longer. The peak abundance of 17 per 10m sample in 1992/3 was also not reached. This may have been due to the generally drier conditions of the crop in 1993/4, which received no irrigations and appears to have reduced predator populations generally, judging by the maximum daily averages produced at each site in those years (Appendix 5.1). Thiodicarb and chlorfluazuron were not implicated in any obvious population declines in this year.

The effect of endosulfan on *Campylomma* spp. abundance was inconsistent. In the 1992/3 season the first application (13/12/93) appears to have reduced the populations considerably whereas the following two applications had no effect. Synthetic pyrethroids clearly have a strong effect, reducing populations to near zero in both years.

The unsprayed plots at 'Alcheringa' in 1993/4 (Figure 5.4) produced much higher populations of *Campylomma* spp. (maximum daily average of 60/10m suction sample) than any other treatment. They appeared between late December and late February, peaking in late January at this plot, which provides the best estimate of their potential seasonal abundance in irrigated cotton. At the 'Wilby' unsprayed site where no irrigations were applied the populations declined a month earlier. Conditions were particularly dry over January, but significant rain fell in early February, which may explain a resurgence at this site in late February. All the sites indicate a similar seasonality, that is, maximum abundance in mid December through to mid February, except where conventional insecticides curtailed their presence, particularly the synthetic pyrethroids applied at 'Midkin' in both seasons.

There is evidence that organic treatments also reduced populations of *Campylomma* spp. at 'Alcheringa' and 'Wilby'. Garlic and/or codacide oil are implicated by the difference in the abundance between sprayed and control areas on the last sampling data at 'Wilby'. The reductions at 'Alcheringa' cannot be easily attributed to any particular insecticide because of the number of sprays, the mixtures used and the frequency of application compared to the sampling frequency, but the effect of synthetic pyrethroids at 'Midkin' would suggest that natural pyrethrum may be effective on *Campylomma* spp., and this product may have reduced their numbers. The organic areas at 'Wilby' and 'Alcheringa' were both treated with natural pyrethrum at some stage.

5.3.2 *Dicranolaius bellulus* (The Red and Blue Beetle)

On many occasions during this study this species was the most abundant predator collected from cotton. The prey range of *Dicranolaius bellulus* encompasses *Helicoverpa* spp. eggs and early instar larvae (Room 1979a). *D. bellulus* were also observed to feed on *Aphis gossypii*. They may also feed on cicadellids, because they were abundant on flowering pasture grasses infested with cicadellid nymphs at the 'Midkin' site in 1993. These cicadellids were overwhelmingly *Austroasca viridigrisea*, the same species which is common in cotton.

In contrast to the above observations, which suggest that *D. bellulus* is a predator of soft-bodied insects including *Helicoverpa* eggs and larvae, it was regarded as a pollen feeder by Schicha (1974) who studied it on rice in the Murrumbidgee Irrigation Area (on the

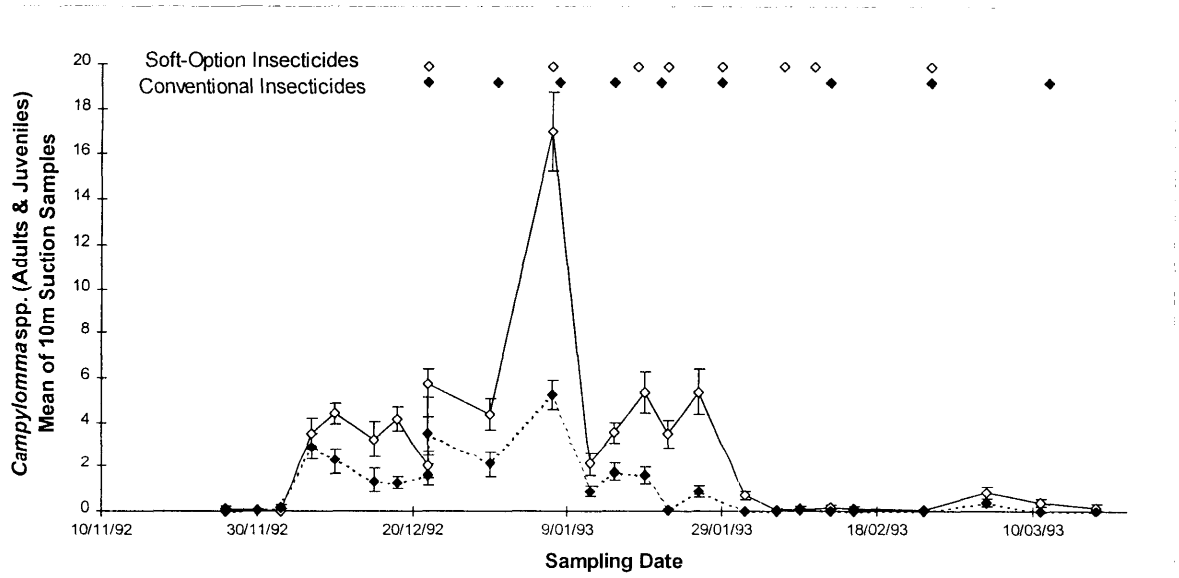

Figure 5.2 ***Campylomma* spp. (Adults and Juveniles), 'Midkin' 1992/3:** The abundance of *Campylomma* spp. recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

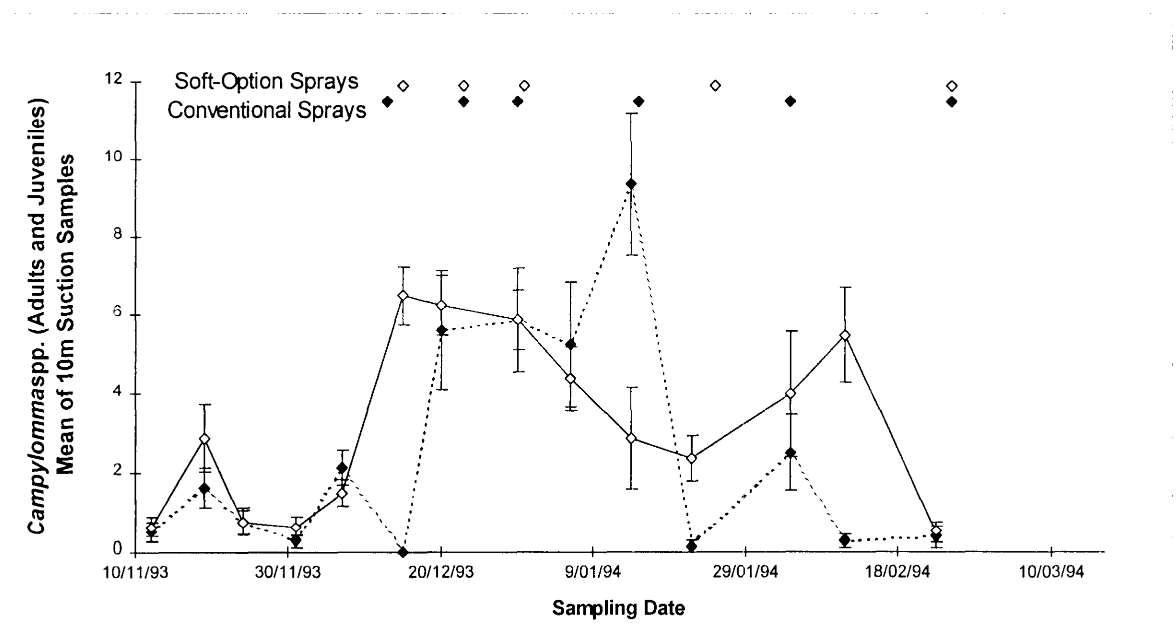

Figure 5.3 ***Campylomma* spp. (Adult and Juveniles), 'Midkin' 1993/4:** The abundance of *Campylomma* spp. recorded by 10m suction samples from cotton fields 3 and 4 treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was used after 19-11-93.

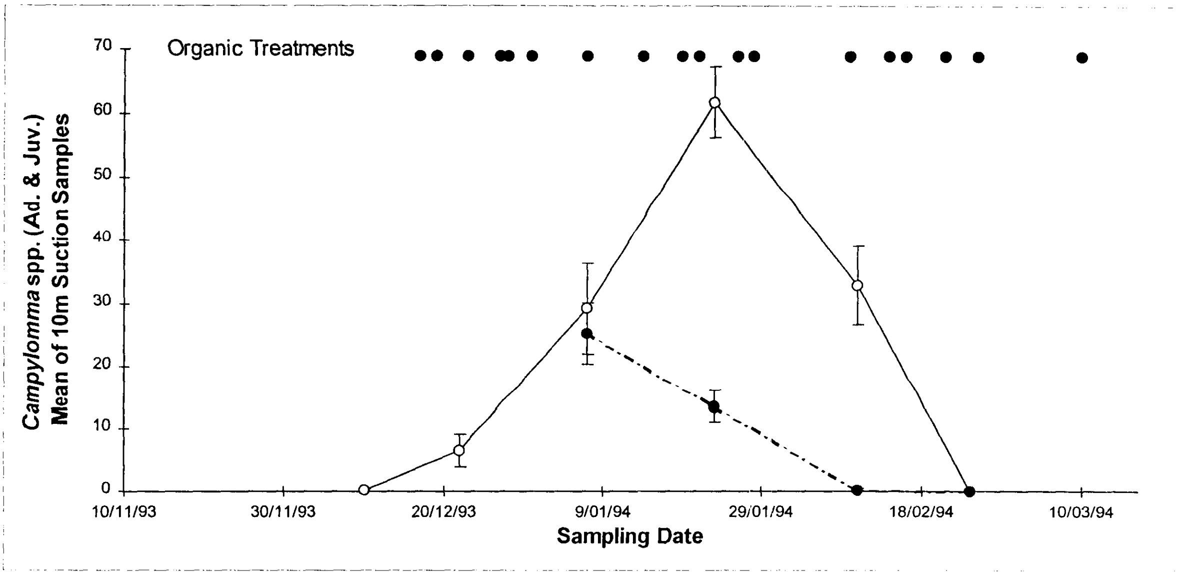

Figure 5.4 ***Campylomma*** **spp. (Adults and Juveniles), 'Alcheringa' 1993/4:** The abundance of *Campylomma* spp. recorded by **Bigvac** 10m suction samples from cotton field 5 treated with no insecticides (-O-) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

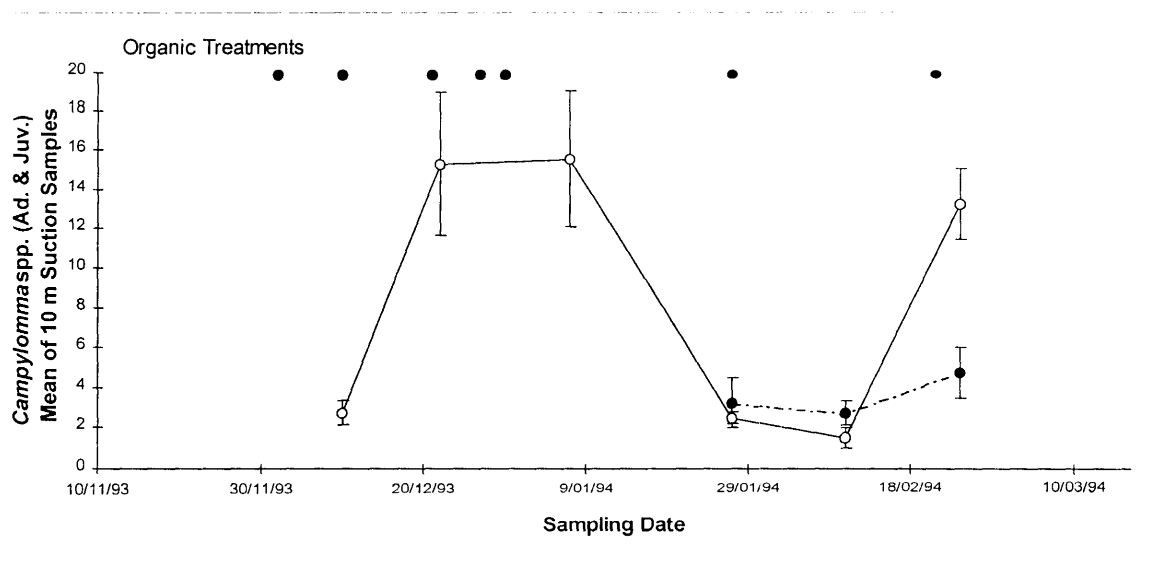

Figure 5.5 ***Campylomma*** **spp. (Adults and Juveniles), 'Wilby' 1993/4:** The abundance of *Campylomma* spp. recorded by **Bigvac** 10m suction samples from cotton field 6 treated with no insecticides (-O-) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars represent the standard error of the mean (n=4).

NSW/Victoria border). Adults readily fed on cotton anthers when offered, without an alternative, in petri dishes under standard laboratory conditions but were not observed to do this in the field at any time during the visual sampling conducted during this thesis.

'Midkin' 1992/3

There were substantial numbers of *D. bellulus* present under both insecticide regimes (Figure 5.6). *D. bellulus* were commonly caught in numbers of 2 to 4 per 10m in suction samples and reached a maximum of 14 per 10m under the soft-option insecticides. Evaluation of the suction sampling efficiency (Chapter 4) suggested that this represented about 54% of the insects which were actually present. Therefore numbers of 0.5 to 1.0 *D. bellulus* per meter were common in cotton under the soft-option insecticides and at least in the early half of the season under the conventional regime. This level of persistent abundance, especially for a predator known to be capable of feeding on considerable numbers of *Helicoverpa* eggs and larvae, establishes it as a potentially important predator on *Helicoverpa* spp. in cotton.

Both fields reached a similar level of *D. bellulus* by the first insecticide applications on 22/12/92. Over the following month, four endosulfan sprays were applied to the conventional field (Field 2) while two Bt, a thiodicarb and a chlorfluazuron were applied to the soft-option field (Field 1). The result was quite unexpected, with *D. bellulus* populations consistently higher under the conventional treatment. This indicates that the soft option, or some component of it, is probably not as soft as originally expected, or that endosulfan is not so detrimental. The idea that endosulfan might not be hard for this species is supported by Cox (1981) who found a tolerance by *D. bellulus* for this insecticide.

The most likely component of the soft-option treatment to be detrimental to *D. bellulus* is thiodicarb (Larvin®) because Bt is known to be highly specific to Lepidoptera and chlorfluazuron, being a chitin inhibitor, does not affect adult insects. Furthermore recent insecticide trials have shown that Larvin® is detrimental to predators of mites (*Tetranychus* spp.), especially predatory beetles (L.J. Wilson pers. comm. 1995). The possibility that the "soft option" insecticides were not particularly soft, compared to the early season conventional treatments (essentially endosulfan) masks the potential abundance of this predator under a truly soft option regime. Another explanation for the difference between conventional and soft-option fields might be that naturally higher populations occurred in the conventional field, with little influence of insecticides. This is supported by the higher levels of *D. bellulus* recorded in this field during the early season using the Elecvac.

The choice and times of application of the insecticides in each treatment were under the control of the growers. The soft options treatments therefore reflected a primary aim of the growers to produce high yields without endosulfan and synthetic pyrethroids. Although the desire to choose truly soft options was implicit in a strategy to increase the mortality of *Helicoverpa* spp. by natural enemies, the selection of these products was based on the limited scientific information at the time, and probably influenced by advertising material as well as the cost and availability of the various alternatives. Consequently, the softness of some chemicals was possibly overestimated at the beginning of this study.

At the time pyrethroids were being introduced on the conventional field, *D. bellulus* numbers in the soft-option treatment continued to increase to a maximum of 8 per 10m before declining in late January and early February. In the conventional field, there was a smaller peak and a more prolonged reduction. The pyrethroids directly reduced the numbers of this predator in the conventional field but also appeared to affect the numbers in the soft option field. This could possibly be explained by spray drift or to a general depletion of regional populations. The regional synchrony of spray formulations means that over this four week period virtually all cotton crops in the district would be treated with pyrethroids. Either lack of replacement individuals or the death of those which venture far enough to contact treated crops could explain a general decline in the abundance. Late in the season the *D. bellulus* numbers were again greater under the soft-option treatment and the recovery in the conventionally treated field probably reflected the decreasing residual effects of the synthetic pyrethroid applications.

Larvae of *D. bellulus* were observed in the soil beneath the 'Midkin' 1992/3 crop, however the peak in adult abundance recorded on 30/1/93 was presumed to be immigration because the regular irrigations could be expected to disrupt the development of the egg, larval and pupal stages, all of which occur in the soil.

'Midkin' 1993/4

The pattern of abundance recorded for *D. bellulus* in 1993/4 at 'Midkin' (Figure 5.7) was similar to that in 1992/3, but the results are less confounded by the possibility of

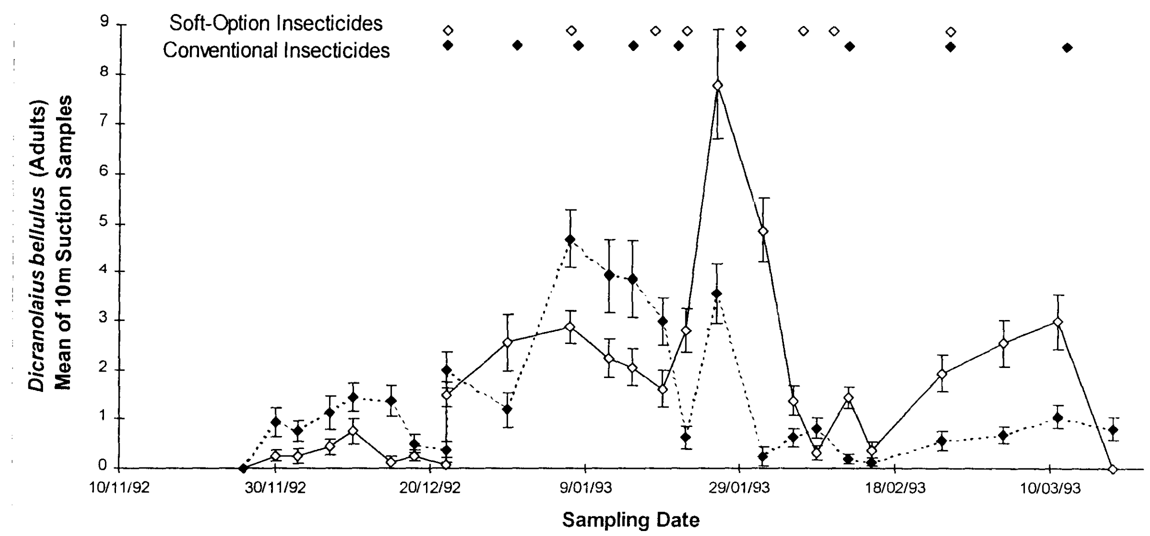

Figure 5.6 ***Dicranolaius bellulus*** **(Adult), 'Midkin' 1992/3:** The abundance of *D. bellulus*. recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

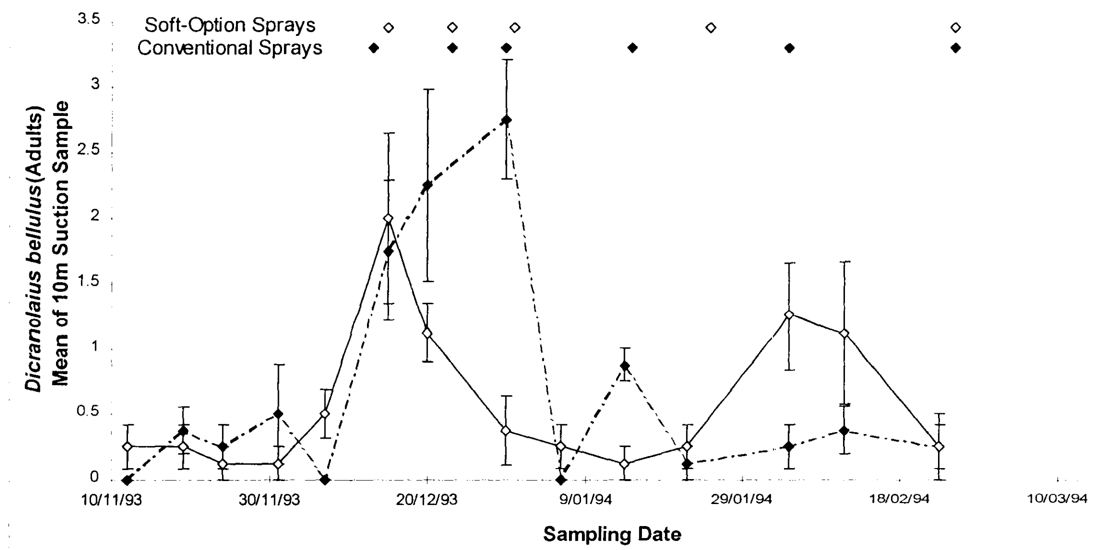

Figure 5.7 ***Dicranolaius bellulus*** **(Adult), 'Midkin' 1993/4:** The abundance of *D. bellulus* recorded by 10m suction samples from cotton fields 3 and 4 treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

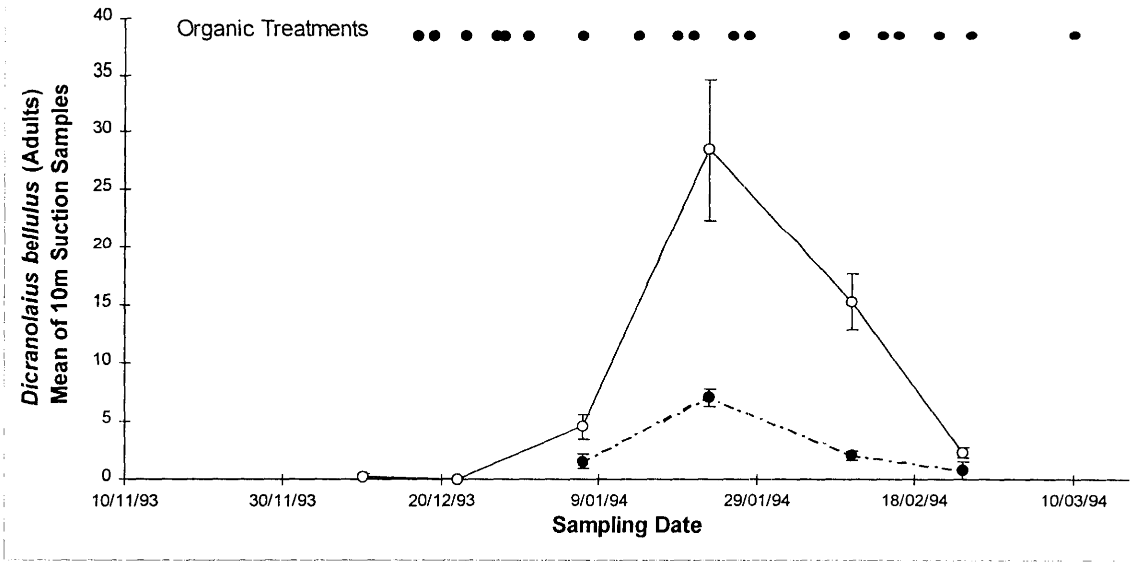

Figure 5.8 ***Dicranolaius bellulus*** **(Adult), 'Alcheringa' 1993/4:** The abundance of *D.bellulus* recorded by **Bigvac** 10m suction samples from cotton field 5 treated with no insecticides (—o—) or organic treatments (--•--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

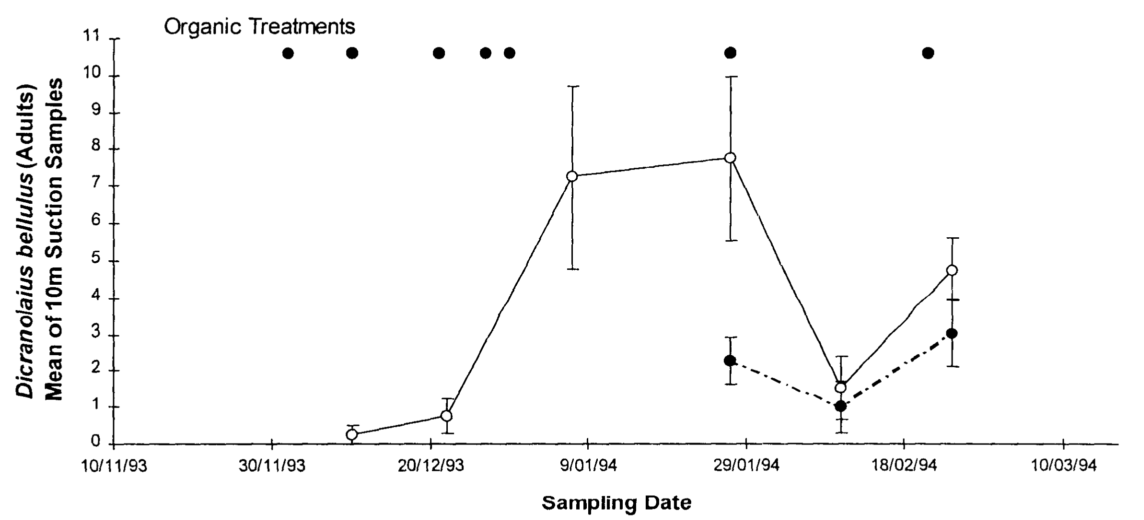

Figure 5.9 ***Dicranolaius bellulus*** **(Adult), 'Wilby' 1993/4:** The abundance of *D. bellulus* recorded by **Bigvac** 10m suction samples from cotton field 6 treated with no insecticides (—o—) or organic treatments (--•--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars represent the standard error of the mean (n=4).

intrinsic field differences because replication within crop management units was achieved (Figure 5.1). The initial build up of the population occurred in a similar way to the first year with the conventional field appearing to have larger numbers of predators, although the difference was not statistically significant until late December- early January.

In 1993/4 at 'Midkin' the 'softer-option' insecticides appeared to cause a greater reduction to *D. bellulus* than the endosulfan applications of the conventional treatment. In fact the densities of *D. bellulus* increased in the presence of endosulfan while three consecutive thiodicarb sprays in mid to late December apparently reduced this predator. It appears that endosulfan was the softer-option in this case.

The disappearance of *D. bellulus* between the 30/12/93 and 6/1/94 is difficult to explain without invoking spray drift from the other fields. There were no distinctively destructive weather events, such as storms, in this period which might explain such a high mortality. This decline occurred for many species of predator (evident by the decline in the total predator chart, Figure 5.48) but generally not to the extent recorded for this beetle. A higher rate of endosulfan may have been inadvertently applied but *D. bellulus* is relatively tolerant of endosulfan and numbers would therefore not be expected to have fallen to this level. Mortality of this severity in the previous year was generally associated with the application of synthetic pyrethroids and although these were not deliberately applied to this field or even the adjacent conventionally treated areas at this time, regional use of pyrethroids had begun, so spray drift is a possibility.

Several species of predator suffered a major collapse in early January of 1994. The insecticide schedule adopted by the industry for the application of pyrethroids was adjusted in this year so that on a regional basis general pyrethroid treatments began on the 1st of January. This again raises the possibility that reductions in predator numbers may have been effected in one of three ways; i) the general reduction in source areas which may be necessary to maintain predator numbers in a cotton field, ii) via spray drift, or iii) via the movement of predators into nearby treated fields where they contacted the chemical.

That populations of predators persisted at 'Alcheringa' and 'Wilby' throughout the pyrethroid 'window' supports the idea of regional spraying affecting predator populations because these sites were relatively isolated compared to the proximity of treated areas at 'Midkin'. Drought is again a possibility because this is the period where the weather generally begins to become very hot (Appendix 5.5). The recovery of *D. bellulus* populations once the insecticide program had ended confirmed the conclusion from the previous year that higher densities could be expected to persist throughout the year in the absence of synthetic pyrethroids and thiodicarb applications.

'Alcheringa' 1993/4

D. bellulus reached much higher densities in the unsprayed controls at Alcheringa than in either the soft-option or conventional treatments at Midkin (Figure 5.8). This may be a regional difference, since the sites were 100 km apart. However, there were no obvious differences in the climate, surrounding vegetation, or general suite of insect fauna; therefore it seems more likely that both insecticide programs at 'Midkin' reduced *D. bellulus* abundance.

The organically treated area harboured much lower densities of this predator, which indicates that some component of the spray program was detrimental. Natural pyrethrum is implicated since the synthetic pyrethroids were so effective at reducing abundance at 'Midkin'. This is consistent with the limited abundance recorded on 23/1/94 in the organic plot at 'Alcheringa' following applications of pyrethrum on the 14/1/94.

The reduced frequency and period of sampling with the Bigvac at these sites reduces the resolution of the effects of the frequently applied treatments. The organic sites were monitored much more frequently using the Macvac but these data were considered inferior because of the poor sampling efficiency shown for that method over the later two thirds of the season (Chapter 4).

'Wilby' 1993/4

D. bellulus did not reach the densities in the unsprayed plot at 'Wilby' that it did at 'Alcheringa' (Figure 5.9). The crop at 'Wilby' was a rain grown crop in a generally dry year, and produced much smaller plants. This habitat may not have been as suitable for herbivores in general, and in turn this may explain the lower densities of this predator. The decline after the application of garlic and Codacide oil on 29/1/94 implies that one of these components might have affected *D. bellulus*. However, there was considerable rainfall on 7/2/94 (21 mm within a three hour period), which may also have influenced predator abundance.

5.3.3 *Creontiades dilutus* (Green Mirid)

Like *Campylomma* spp., this species is mainly considered a sucking pest on cotton, but it is also predatory. It is often referred to as an early season pest because the damage it causes is mainly restricted to the destruction of early developing cotton squares (Pyke & Brown 1996). The abundance profiles under the different treatments (Figures 5.10 to 5.13) were also similar to those for *Campylomma* spp. Chlorfluazuron appeared to have a large impact on this species ('Midkin' 1992/3, Figure 5.10). Data for the conventional field at this time suggest that endosulfan steadily reduced this species with repeated applications. The effect of endosulfan was less clear at 'Midkin' in 1993/4, where there was a decline following the first application of endosulfan on 13/12/93, but the two later applications (23/12/93 and 30/12/93) were followed by an increase in numbers. However, comparisons with the unsprayed treatments of 'Alcheringa' and 'Wilby' (Figures 5.12 and 5.13) suggest that populations might have increased to even greater levels if not for the endosulfan applications.

Thiodicarb also apparently reduced the abundance of *C. dilutus* and, along with chlorfluazuron applications, may explain the absence of this insect at 'Midkin' after 15/1/93. Drought is also a possible explanation for the decline over this period. Although these fields received several irrigations, regionally there would have been very few source areas due to the very dry conditions.

The general pattern for seasonal abundance of *C. dilutus* was similar to that for *Campylomma* spp. The data for the unsprayed plots at 'Alcheringa' indicate that it can be present from mid January to late February. The 'Midkin' data in both years show that they can be present much earlier than this, as early as November. The records at 'Alcheringa' generally show that the decline mid season at 'Midkin' in 1992/3 was probably due to insecticides, but the similarity between the declines at 'Wilby' and 'Midkin' in 1993/4 suggests that unsuitable factors related to drought in the rain grown environment may be important. The organic treatments caused considerable reductions and again the synthetic pyrethroids were clearly devastating to the populations of this species.

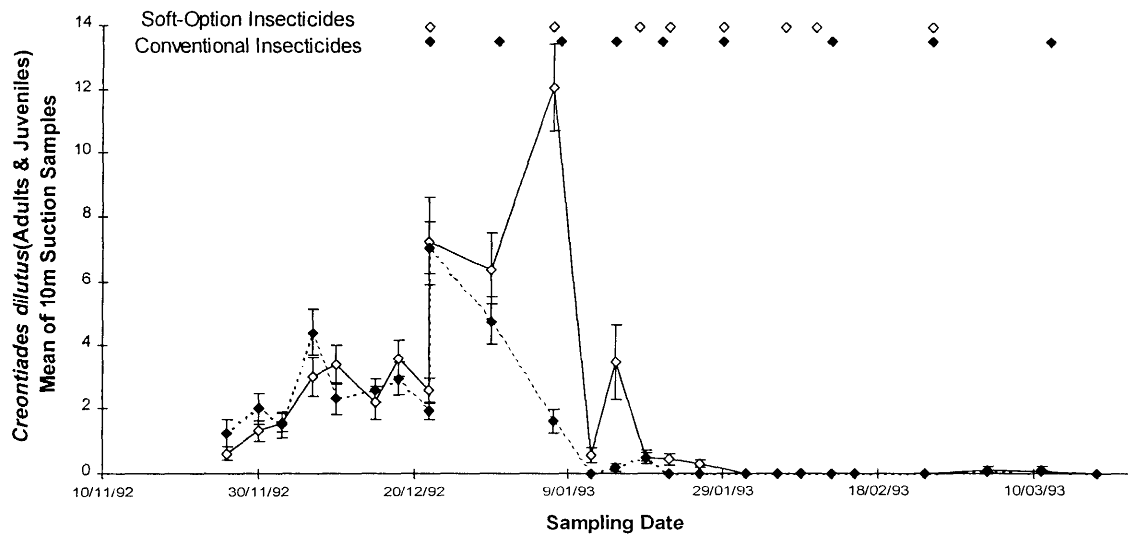

Figure 5.10 ***Creontiades dilutus*** **(Adults and Juveniles), 'Midkin' 1992/3:** The abundance of *Creontiades dilutus* recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.1. The error bars represent the Standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

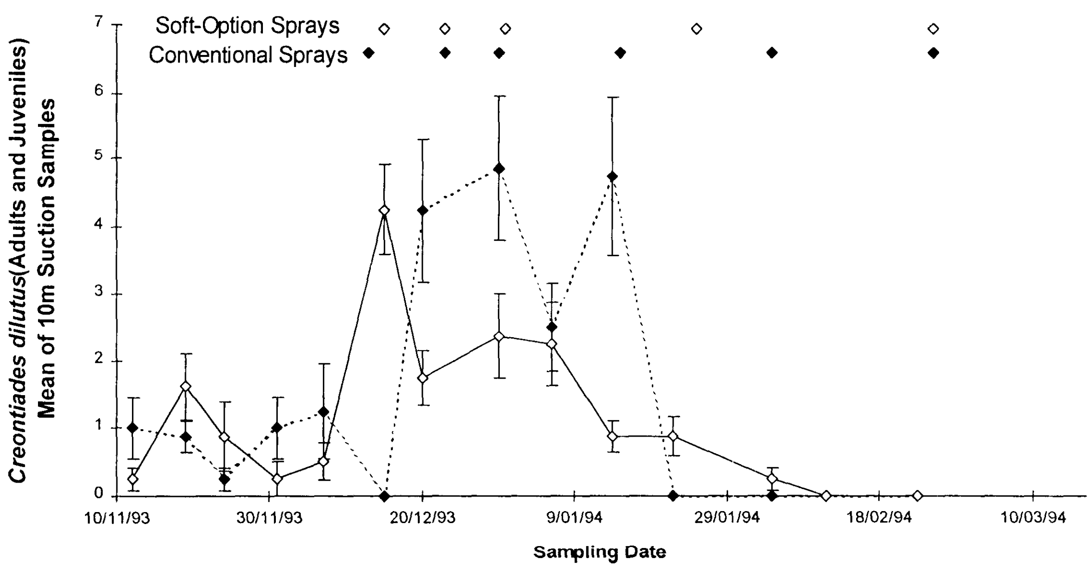

Figure 5.11 ***Creontiades dilutus*** **(Adults and Juveniles), 'Midkin' 1993/4:** The abundance of *Creontiades dilutus* recorded by 10m suction samples from cotton fields 3 and 4 treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

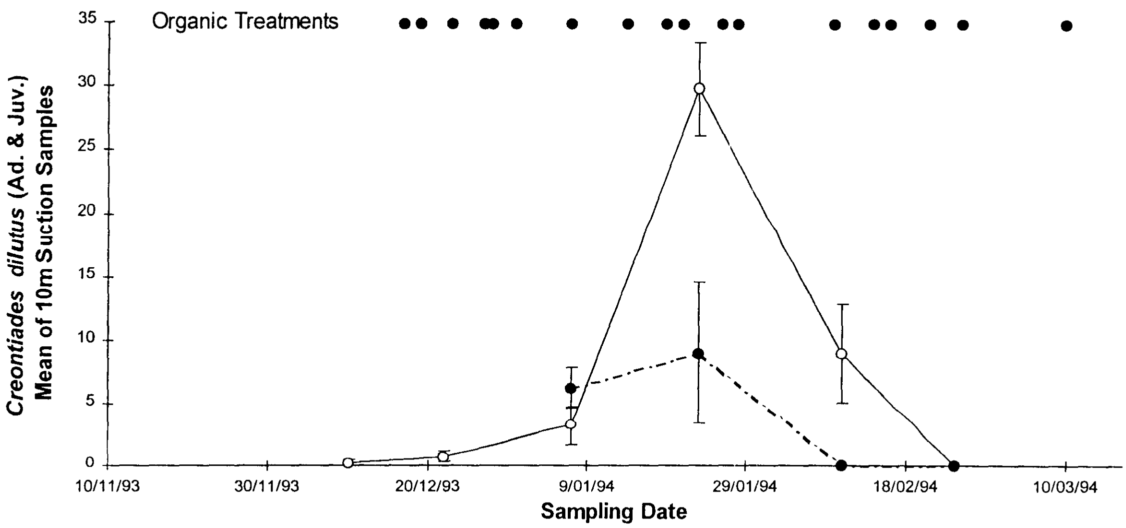

Figure 5.12 ***Creontiades dilutus*** **(Adults and Juveniles), 'Alcheringa' 1993/4:** The abundance of *Creontiades dilutus* recorded by **Bigvac** 10m suction samples from cotton field 5 treated with no insecticides (—o—) or organic treatments (--•--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

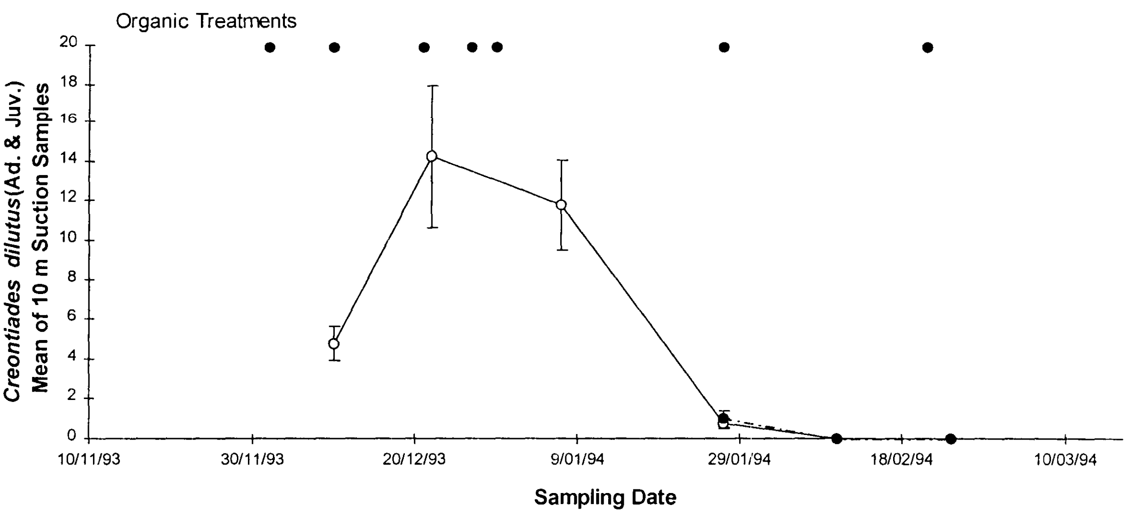

Figure 5.13 ***Creontiades dilutus*** **(Adults and Juveniles), 'Wilby' 1993/4:** The abundance of *Creontiades dilutus* recorded by **Bigvac** 10m suction samples from cotton field 6 treated with no insecticides (—o—) or organic treatments (--•--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars represent the standard error of the mean (n=4).

5.3.4 *Nabis kinbergii* (Pacific Damsel Bug)

Nabis kinbergii (Hemiptera: Nabidae) was one of the most abundant species of predators in Australian cotton fields (Table 5.5). A maximum daily average of 8 per 10m in soft option cotton at 'Midkin' in 1992/3 was the highest abundance recorded. This probably corresponds to about 80% of the actual abundance judging by the suction efficiency tests presented in Chapter 4. Very few nymphs were collected but reproduction was obviously occurring within the field. Byerly *et al.* (1978), demonstrated that suction methods are very inefficient at collecting juveniles of *Nabis* spp. so much larger populations were probably developing than is indicated here.

Room (1979a) showed that adult *N. kinbergii* consumed 3.8-4.0 eggs per day; 2.4 very small (up to 3 mm) larvae per day or 0.9 small (3 to 7 mm) larvae per day in petri dish trials. The juvenile instars of this genus are also predatory and capable of consuming *Helicoverpa* eggs, and larvae. Consumption rates of a similar species were shown to depend on size, such that 1st and 2nd instar *Tropiconabis nigrolineatus* Dist. could cope with only 1st instar *H. punctigera* whereas 3rd and 4th instar predators could also predate 2nd instar *H. punctigera* (Awan 1990). Adult *T. nigrolineatus* are capable of predating up to 3rd instar *H. punctigera* larvae (Awan 1990).

At 'Midkin' in 1992/3, conventional insecticide treatments led to reduced *N. kinbergii* numbers compared to the soft-option or unsprayed areas. The reduction in numbers in early January (Figure 5.14) in the soft-option field was also likely to be due to insecticides because of the partial recovery of the population once the insecticide program had ended. Systemic seed treatments with insecticide have been shown by Ridgway *et al.* (1967) to affect predatory bug numbers, possibly via plant feeding (Stoner 1972) although accessing the toxin via feeding on poisoned prey is also possible. This might explain a slower general colonisation by this predator relative to the predatory beetle populations which were more abundant almost a month earlier. However several explanations are possible including that *N. kinbergii* may have higher development temperature thresholds or a stronger diapause, or simply that they arrived in greater numbers later than the beetles.

At 'Midkin' in 1992/3 (Figure 5.14) the decline in the soft-option plot after the 8/1/93 insecticide treatment is difficult to interpret. It may be that both Chlorfluazuron and

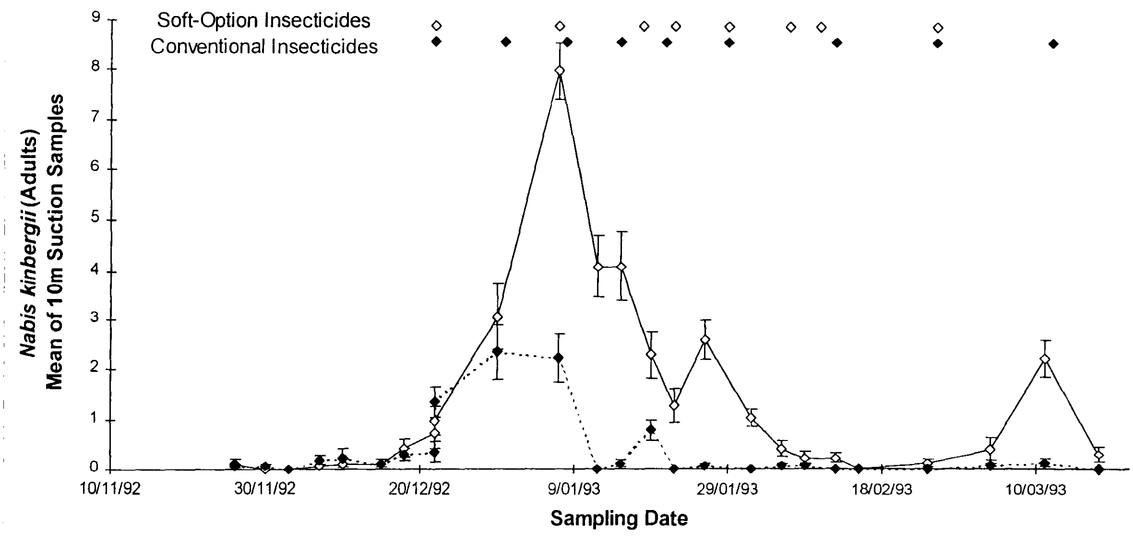

Figure 5.14 ***Nabis kinbergii*** **(Adults), 'Midkin' 1992/3:** The abundance of *Nabis kinbergii* recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

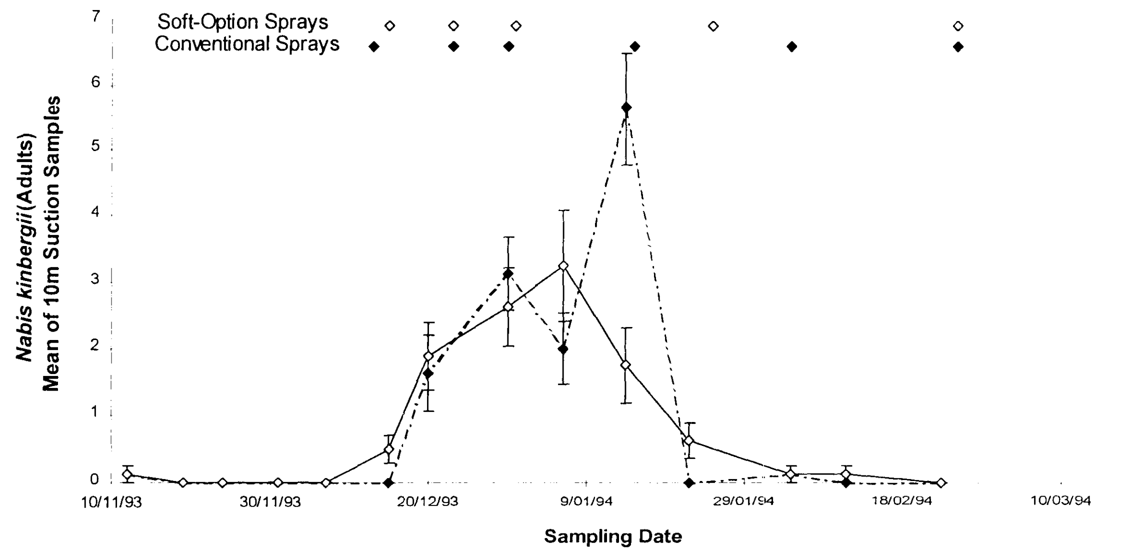

Figure 5.15 ***Nabis kinbergii*** **(Adult), 'Midkin' 1993/4:** The abundance of *Nabis kinbergii* recorded by 10m suction samples from cotton fields 3 and 4 treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

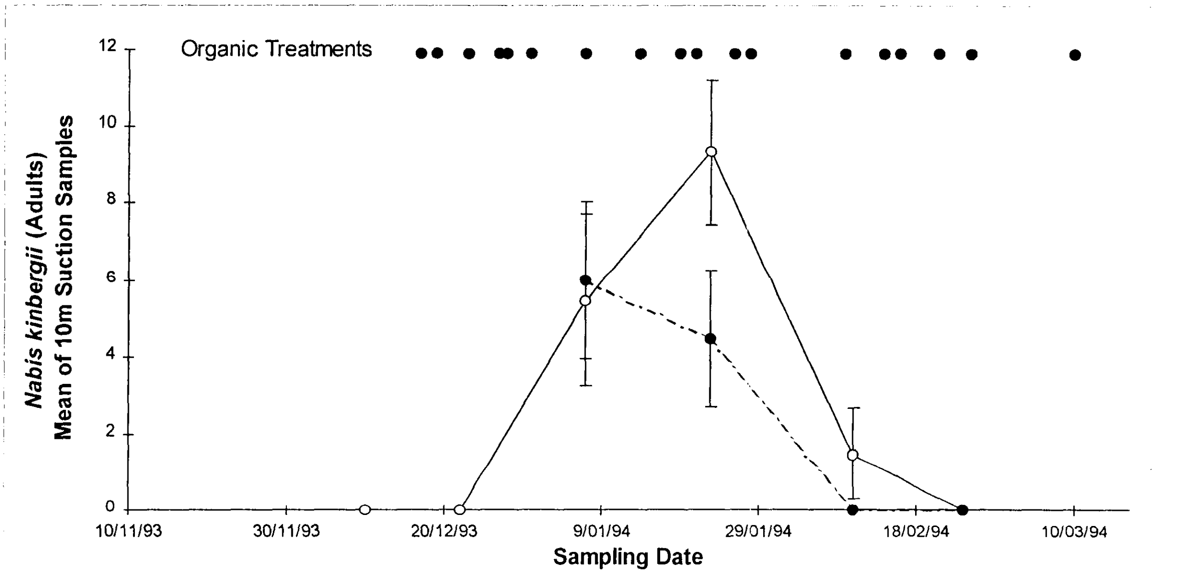

Figure 5.16 ***Nabis kinbergii*** **(Adult), 'Alcheringa' 1993/4:** The abundance of *Nabis kinbergii* recorded by **Bigvac** 10m suction samples from cotton field 5 treated with no insecticides (–○–) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

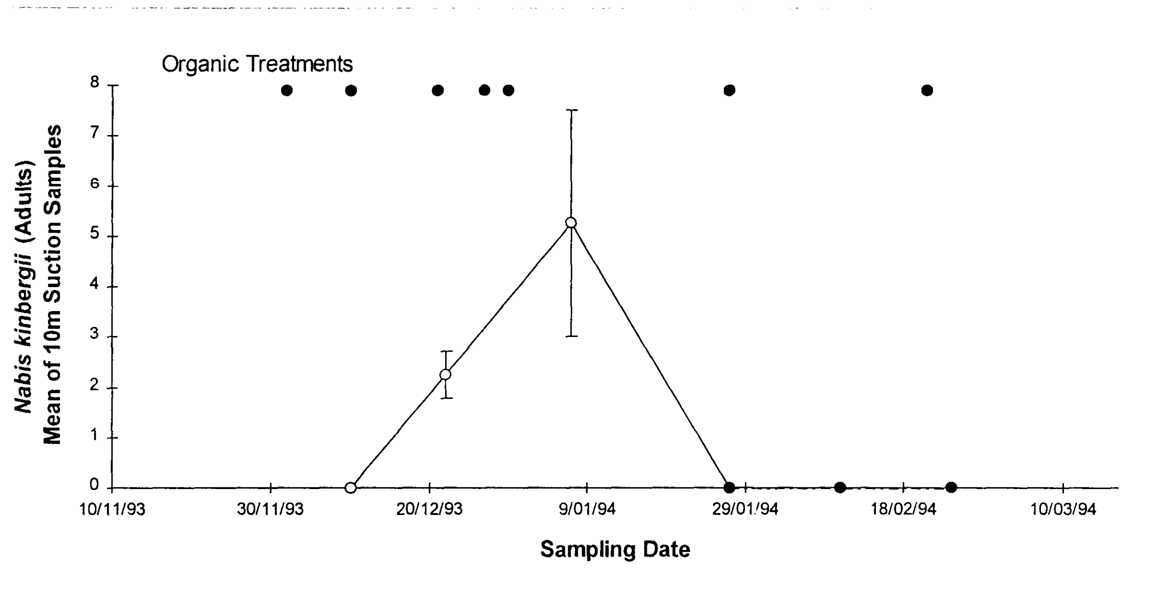

Figure 5.17 ***Nabis kinbergii*** **(Adult), 'Wilby' 1993/4:** The abundance of *Nabis kinbergii* recorded by **Bigvac** 10m suction samples from cotton field 6 treated with no insecticides (–○–) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart(•). The details of the insecticide treatments are in Table 5.4. The error bars represent the standard error of the mean (n=4).

endosulfan had a similarly detrimental effect or that there was some inadvertent spray drift of endosulfan onto the soft-option field. However, if spray drift had occurred the effect would be expected to diminish in the more distant plots, especially since the effect was only partial. The plots were in fact very similar across the soft option field.

This could instead, be explained by pyrethroid drift. The reduction was similar but delayed in the soft-option field over the pyrethroid period suggesting a common effect. The effect of pyrethroids might be general because most fields in the area are being sprayed and source areas might be lost. There is a possibility that these predators roam into nearby treated fields, as previously discussed with *D. bellulus.*

The endosulfan treatments clearly had a detrimental effect on the abundance of *N.kinbergii*, but the synthetic pyrethroids and organophosphate treatments from 21/1/93 onward removed them altogether. If the increases in *N. kinbergii* from late December 1992 were mainly due to immigration, the effect of endosulfan has been underestimated, that is, the records of *N. kinbergii* collected in the conventionally treated field may reflect recent immigration. The recovery of populations in the soft-option field after regional pyrethroid and organophosphate applications had ceased again shows the potential for these predators to remain over the entire season if these insecticides were not used.

The effect of endosulfan in the following season at 'Midkin' (1993/4) was not evident (Figure 5.15). The *N. kinbergii* populations were able to increase in the conventionally treated field until the synthetic pyrethroid was applied. Populations steadily declined in the soft-option areas but insecticides were not implicated. The same seasonal pattern of abundance was exhibited at the 'Wilby' unsprayed area in the same year, so this decline might reflect the seasonal abundance of this species under the drier conditions late in the season of a rain grown cotton crop. The 'Alcheringa' unsprayed area showed a similar appearance of *N. kinbergii* in late January, with an earlier decline in the organically treated area.

The seasonal abundance profiles from all the sites indicate that *N. kinbergii* are most abundant in January. They occurred later in the year at 'Alcheringa' which suggests that irrigation may prolong the suitability of conditions for this species. Similar profile under the soft-option regimes implies that these insecticides were not particularly detrimental, however evidence of a recovery at 'Midkin' in March 1993 suggests otherwise.

5.3.5 *Coccinella transversalis* (Transverse Ladybird)

This species was observed to be abundant on pasture grasses feeding on *A. viridigrisea* nymphs (the same cicadellid species as commonly collected from the cotton). The suitability of this prey was indicated by the presence of many juvenile *C. transversalis*. However, juveniles of *C. transversalis* were only abundant in cotton when aphids were abundant (either early or late in the cotton growing season) and were generally rare at other times even if cicadellids were abundant (Appendix 5.2 to 5.4 on computer disc in file Stanley\appen5.xls). A parasitoid (*Dinocampus coccinellae* (Schrank) Braconidae: Euphorinae) was discovered to be quite active in the cotton crops with parasitism rates of 30% being recorded on *C. transversalis* collected for cultures from 'Midkin' in 1992/3 during this study.

The decline in numbers through December 1992 at 'Midkin,' before any insecticides were applied, was probably due to the poor sampling efficiency with the Elecvac as the cotton plants became larger. Therefore the high abundance recorded for *C. transversalis* once the Bigvac was employed probably confirms (as in the early Elecvac samples) that the conventional field harboured a greater number of this species up to this point. Sampling on 22nd December preceded the insecticide application, therefore the subsequent declines implicate both endosulfan and thiodicarb as detrimental to *C. transversalis* (Figure 5.18). However, *C. transversalis* abundance in the conventional treatment remained relatively constant throughout the following endosulfan applications (31/12/92, 8/1/93 and 15/1/93), while the next thiodicarb treatment was again associated with a reduction. If so, it is likely that thiodicarb is more detrimental to this predator than endosulfan. This suggestion is reinforced by the events of the following year, when the first thiodicarb application on 15/12/93 virtually removed *C. transversalis* from the soft-option field, and subsequent application (23/12/93 and 31/12/93) appear to have kept it that way. The Bt which accompanied thiodicarb in each of the applications in the soft-option treatment is not implicated because it is known to be specific to lepidopterans. Chlorfluazuron may also be damaging to *C. transversalis*, as indicated by a decline in their numbers immediately after applications to the soft-option plot on the 7/1/93 at 'Midkin' in 1992/3 (Figure 5.18).

A consistent pattern emerged in the following year at 'Midkin'(1993/4) where *C. transversalis* disappear from the soft-option treatment after the first thiodicarb spray on 15/12/93 and from the conventional treatment after the regional use of synthetic pyrethroids starting on 1/1/94 (Figure 5.19).

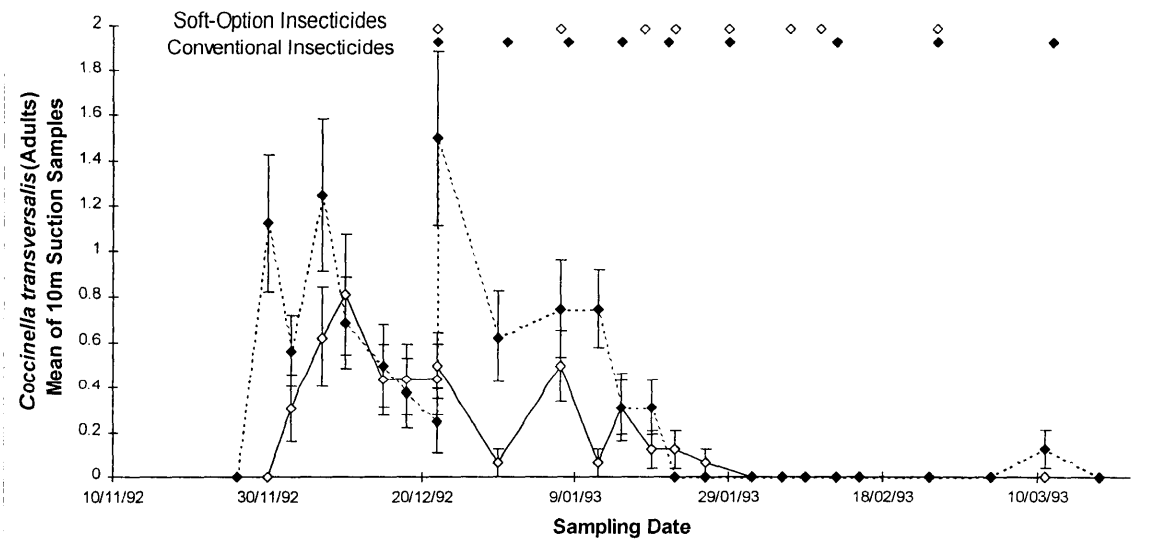

Figure 5.18 ***Coccinella transversalis*****, 'Midkin' 1992/3:** The abundance of *Coccinella transversalis* recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

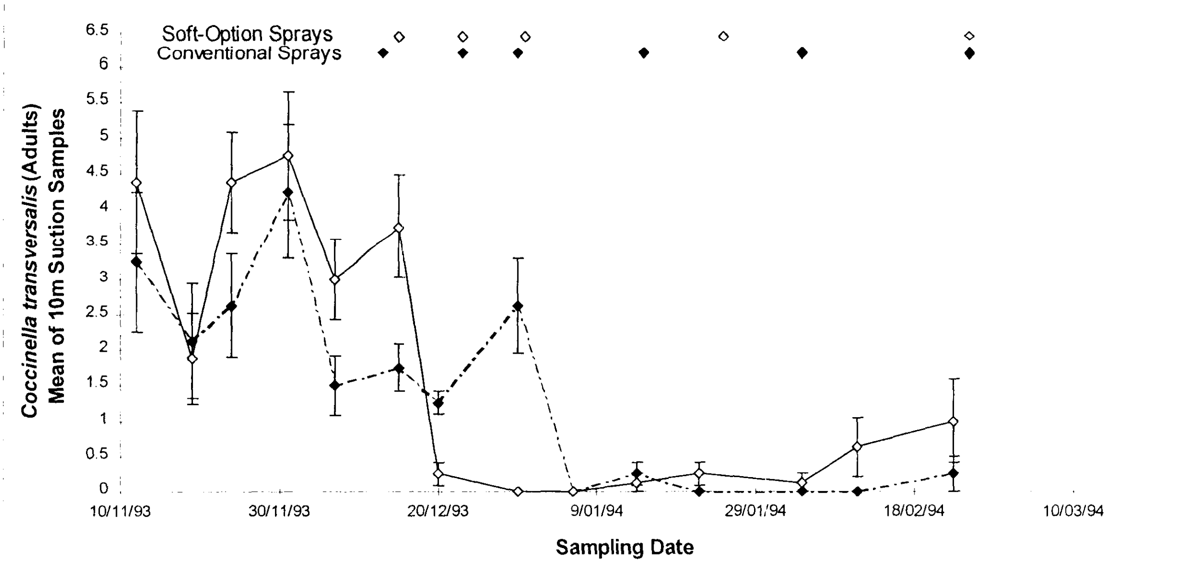

Figure 5.19 ***Coccinella transversalis*****, 'Midkin' 1993/4:** The abundance of *Coccinella transversalis* recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

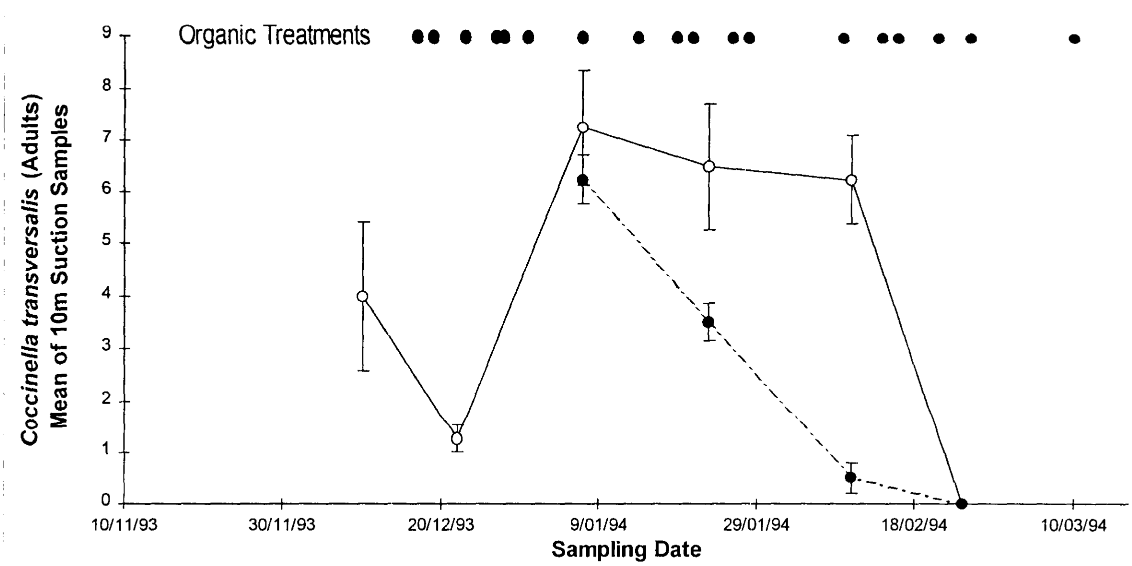

Figure 5.20 ***Coccinella transversalis*** **(Adult), 'Alcheringa' 1993/4:** The abundance of *Coccinella transversalis* recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

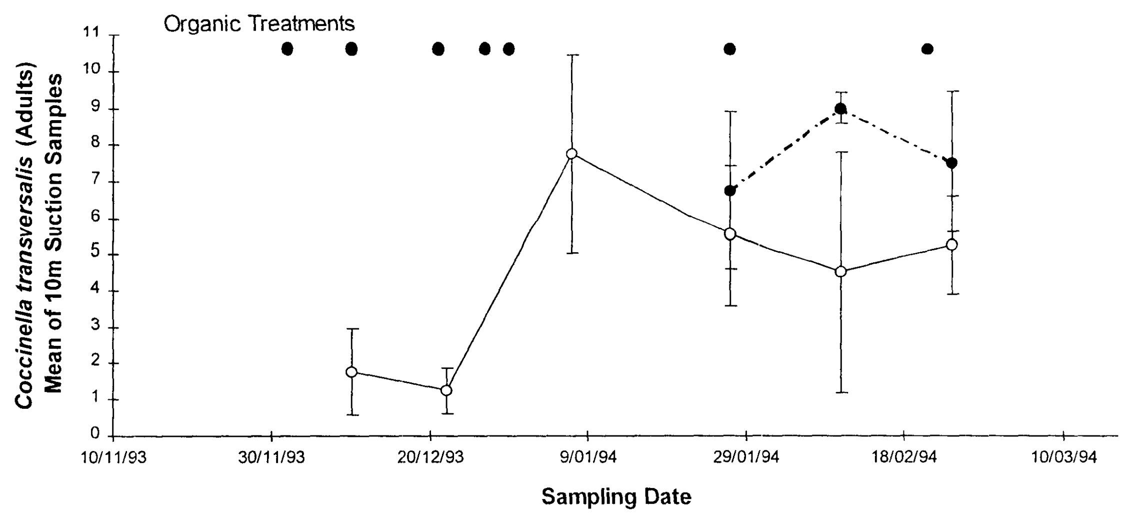

Figure 5.21 ***Coccinella transversalis*** **(Adult), 'Wilby' 1993/4:** The abundance of *Coccinella transversalis* recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

Consideration of the data from 'Midkin' in both seasons would imply that *C. transversalis* is an early season predator, but the records from 'Alcheringa' and 'Wilby' strongly suggest that this abundance profile was considerably modified by insecticides. At both localities, *C. transversalis* persisted in substantial numbers well into February, a time when they were quite rare at 'Midkin'. It appears that high numbers of this predator can persist throughout the cotton season in the absence of the insecticides which reduced its numbers at 'Midkin' (thiodicarb, chlorfluazuron and the synthetic pyrethroids). The organic treatments also reduced the abundance of *C. transversalis* at 'Alcheringa' (Figure 5.20), and this did not occur until natural pyrethroids were applied from 14/1/94 onwards.

The populations of this beetle were considerably greater at all sites in 1993/4 compared to 'Midkin' in 1992/3, probably because aphids were much more abundant in the spring of 1993.

5.3.6 *Diomus notescens* (Two spotted ladybird)

Diomus notescens is a small coccinellid which was present at all the survey sites. It did not reach appreciable abundance at 'Midkin' in 1992/3 which may simply reflect an unsuitable year for this species (Figure 5.22). Therefore the fluctuations in the abundance offer little evidence of an insecticide effect on their own. However the larger populations present at the beginning of the 1993/4 season (Figure 5.23) appear to have been severely reduced by thiodicarb. This was also evident in the 1992/3 abundance profile along with a reduction associated with endosulfan, however the latter was not repeated in 1993/4. The 1992/3 profile may also suggest an effect of chlorfluazuron. Both the 'Midkin' insecticide regimes reduced the potential of this species, because the unsprayed plots indicate that *D. notescens* can persist throughout the season.

Both unsprayed plots at 'Wilby' and 'Alcheringa' (Figures 5.24 and 5.25) indicated that the peak abundance of *D. notescens* occurred in early January and that in the absence of insecticides populations of up to 24 per 10 m ('Wilby') were possible. Comparison of the organically treated areas with the unsprayed areas at both sites (Figures 5.24 and 5.25) suggests that some component of the organic treatments was detrimental to *D. notescens*; natural pyrethrum, again, being the most likely candidate.

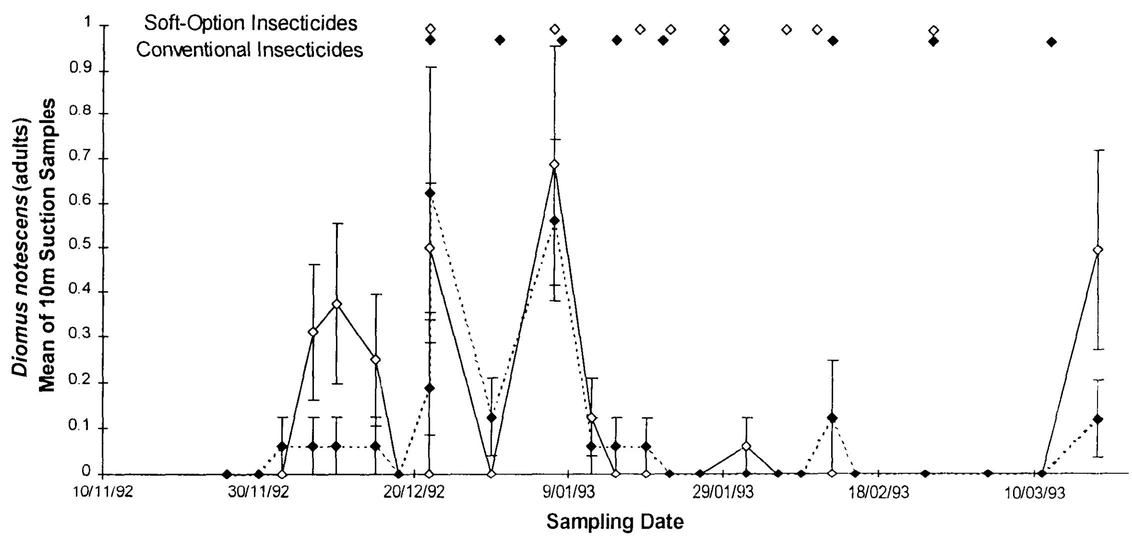

Figure 5.22 ***Diomus notescens*****, 'Midkin' 1992/3:** The abundance of *Diomus notescens* recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

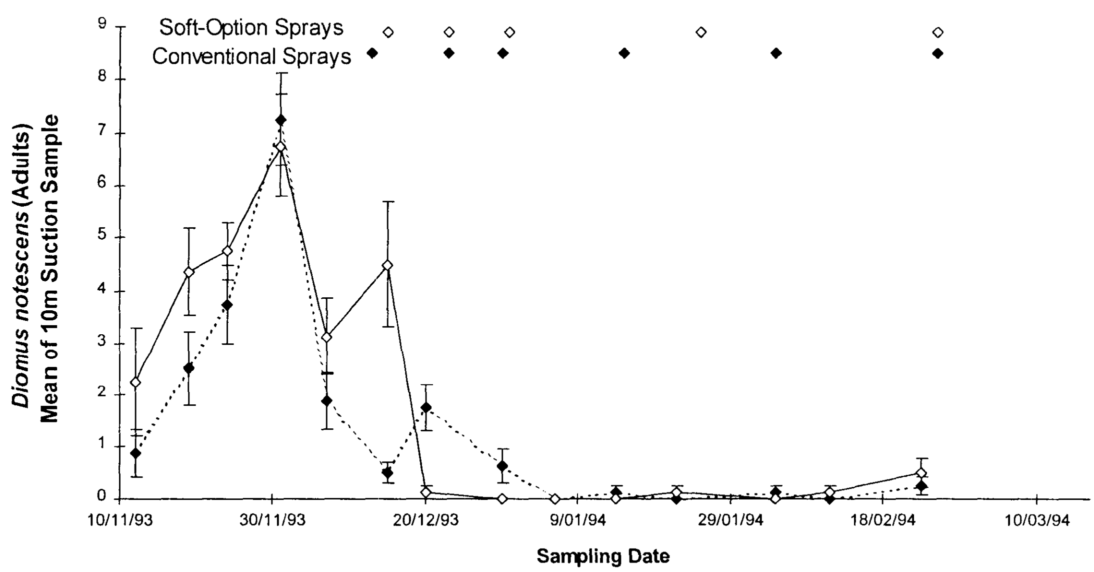

Figure 5.23 ***Diomus notescens*****, 'Midkin' 1993/4:** The abundance of *Diomus notescens* recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

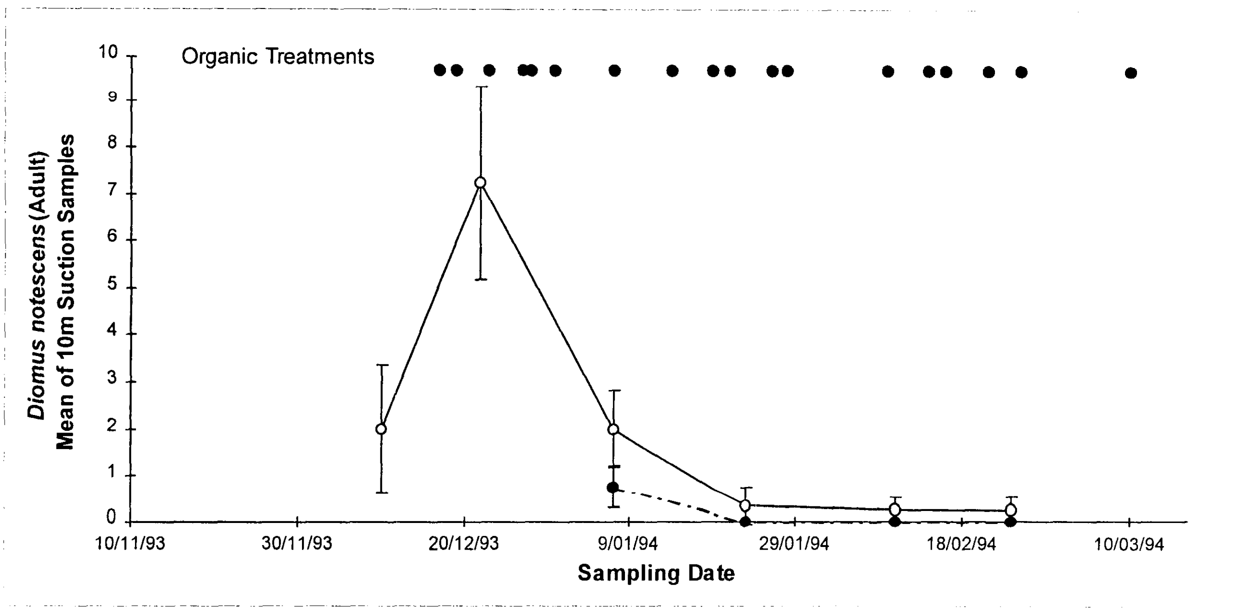

Figure 5.24 ***Diomus notescens*** **(Adult), 'Alcheringa' 1993/4:** The abundance of *Diomus notescens* recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (—o—) or organic treatments (--•--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

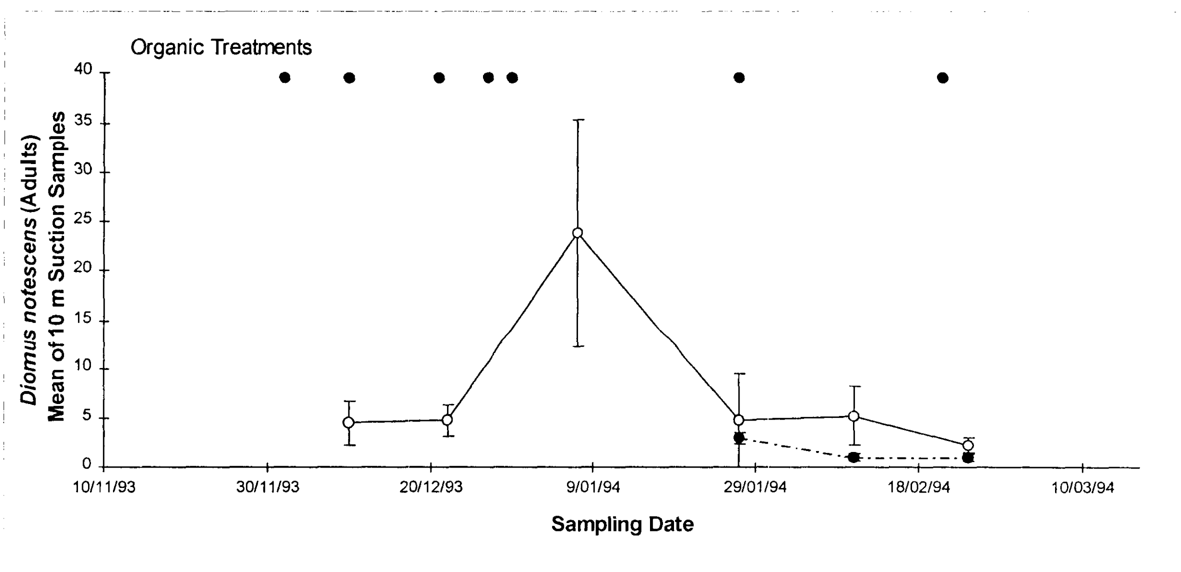

Figure 5.25 ***Diomus notescens*** **(Adult), 'Wilby' 1993/4:** The abundance of *Diomus notescens* recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (—o—) or organic treatments (--•--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

5.3.7 *Geocoris* spp.

The initial pattern of colonisation for this species at 'Midkin' in 1992/3 (Figure 5.26) was similar to that of *Nabis* spp, another predatory bug. As with that species the use of endosulfan on 22/12/92 and 31/12/92 appears to have greatly reduced its abundance. The persistence of *Geocoris* spp. throughout the synthetic pyrethroid period, but only in the soft-option field, strongly suggests that spray drift was not a problem during these trials and therefore represents circumstantial evidence that the gradual decline of some predatory species might be due to greater mobility, taking them into nearby treated fields.

Both thiodicarb and endosulfan may be damaging to populations of geocorids, since their numbers declined immediately after these insecticides were applied in their respective fields (Figure 5.26 and 5.27). The devastating effect of synthetic pyrethroids is again evident by the total lack of *Geocoris* spp. for about a month after the first use of these insecticides on 21/1/93, The rapid recovery in the post insecticide period and the season long presence in the soft-option field strongly suggests that this predator would remain in the absence of insecticides. Irrigated cotton appears to harbour greater populations than the rain grown crops during these drier than usual years.

Numbers were generally low and variation was high at 'Alcheringa' and 'Wilby' (Figures 5.28 and 5.29). They were lower here than at 'Midkin' which is inconsistent with the general trends for most of the predators. Although the areas were separated by nearly 100 km, it is unlikely that these areas differed climatically. In the relative isolation from insecticides it is possible that the natural enemies of the geocorids were more abundant at 'Wilby' and 'Alcheringa'.

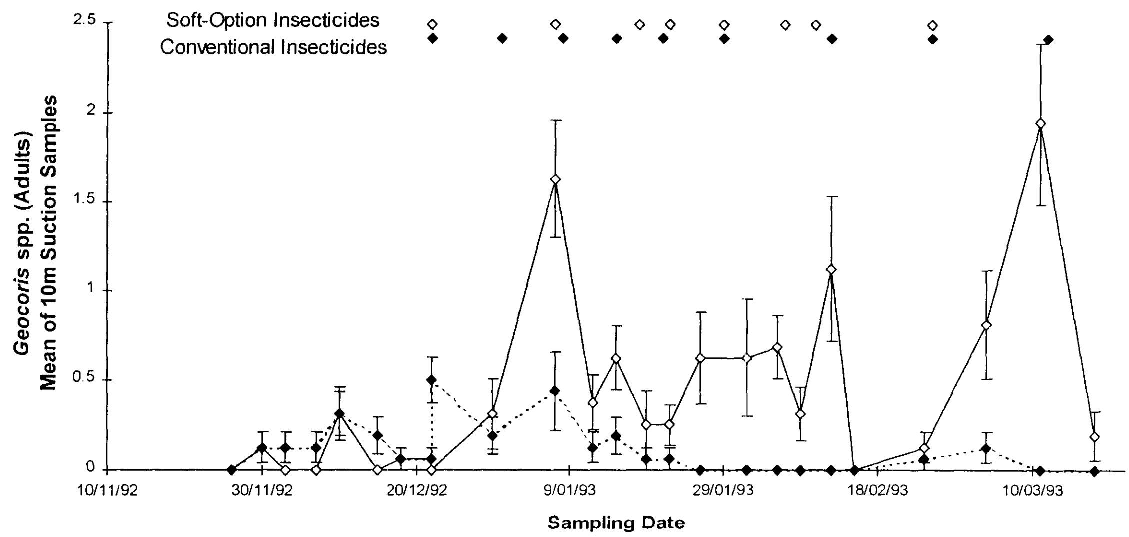

Figure 5.26 ***Geocoris* spp., 'Midkin' 1992/3:** The abundance of *Geocoris* spp. recorded by 10 meter suction samples from cotton (Fields 1 and 2, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

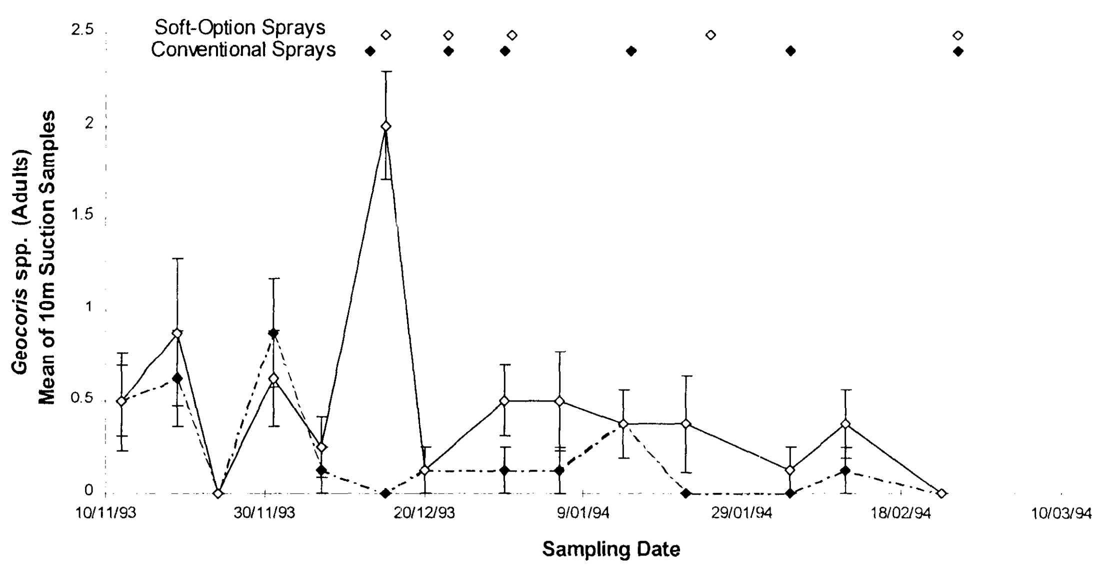

Figure 5.27 ***Geocoris* spp., 'Midkin' 1993/4:** The abundance of *Geocoris* spp. recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93 the **Bigvac** was used from 24-11-93 onwards.

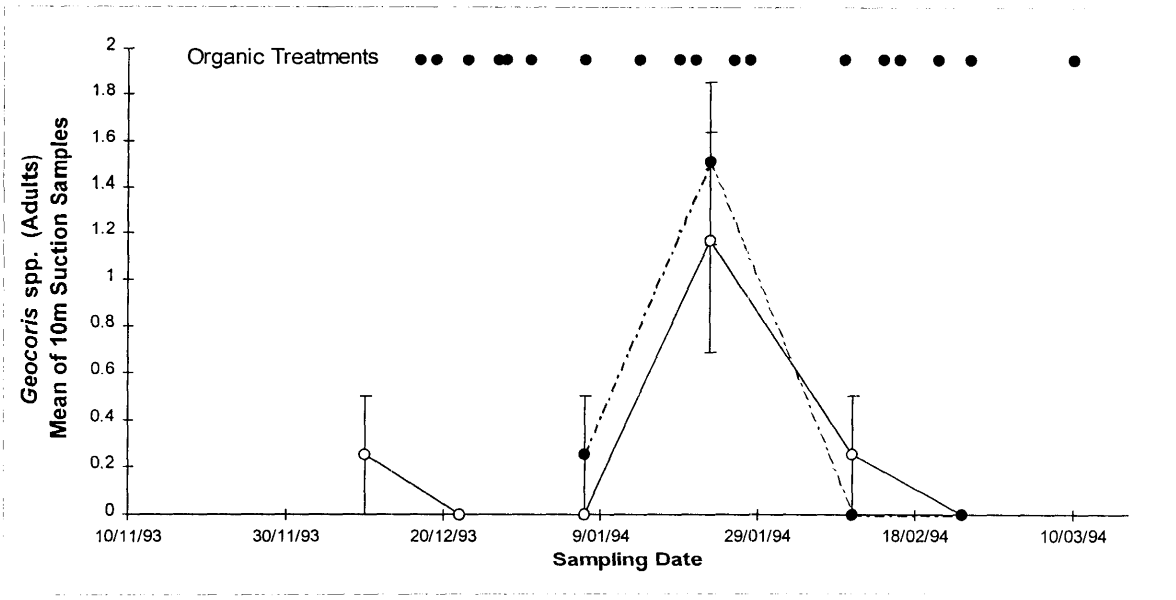

Figure 5.28 ***Geocoris*** **spp., 'Alcheringa' 1993/4:** The abundance of *Geocoris* spp. recorded by **Big vac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (‑o‑) or organic treatments (‑‑•‑‑) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

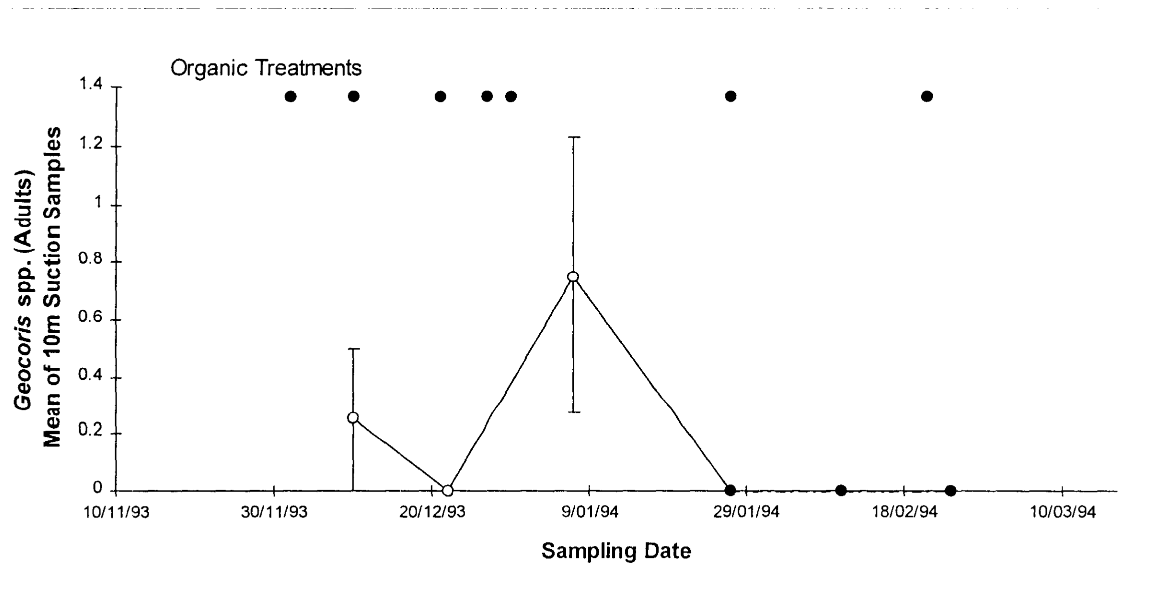

Figure 5.29 ***Geocoris*** **spp., 'Wilby' 1993/4:** The abundance of *Geocoris* spp. recorded by **Big vac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (‑o‑) or organic treatments (‑‑•‑‑) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

5.3.8 *Orius* Spp. (Minute Pirate Bugs)

Orius spp. are a very small predatory bug species which has been associated with prey of the size of thrips. *Orius* species, in other countries, have been implicated as good predators of *Helicoverpa* spp. eggs (van den Berg and Cock 1995) but the Australian species were in such low numbers at 'Midkin' that the potential of this predator may have been obscured (Figures 5.30 and 5.31). This predator was one of the few omitted by Room (1979a) in petri-dish predation trials, possibly indicating that this species was not very abundant at the time those trials were conducted.

The nymphs of this species are also predatory and were often found on the cotton plants during the visual searches and occasionally in suction samples. This indicated that reproduction was occurring within the crop canopy, but the importance of this, relative to immigration, on the population variation is unknown.

Orius spp. were absent from samples until January at Midkin in both growing seasons (Figures 5.30 & 5.31). This probably indicates that these species have a later seasonal occurrence rather than a persistent effect of insecticides because the same seasonal pattern appears in the unsprayed control plot at 'Alcheringa' (Figures 5.32). Synthetic pyrethroids appear to have delayed the establishment of *Orius* spp. under the conventional treatment at 'Midkin' 1992/3 (Figure 5.30). The dimethoate applications which follow on the 12/2/93 and 12/3/93, at this site, also appear to have greatly reduced the density of this predator. Other reductions coincided with particular insecticide applications, for example immediately after the chlorfluazuron spray on 25/2/93 ('Midkin', Figure 5.30) but these were not repeated at other applications of the same chemicals.

Overall the conventional program consistently registered lower densities of *Orius* spp. than the soft-option treatment. However, the soft-option insecticides may also have been limiting the densities of this predator because the maximum in the control plots at 'Alcheringa' was twice that of the maximum under the soft-option treatment at 'Midkin'.

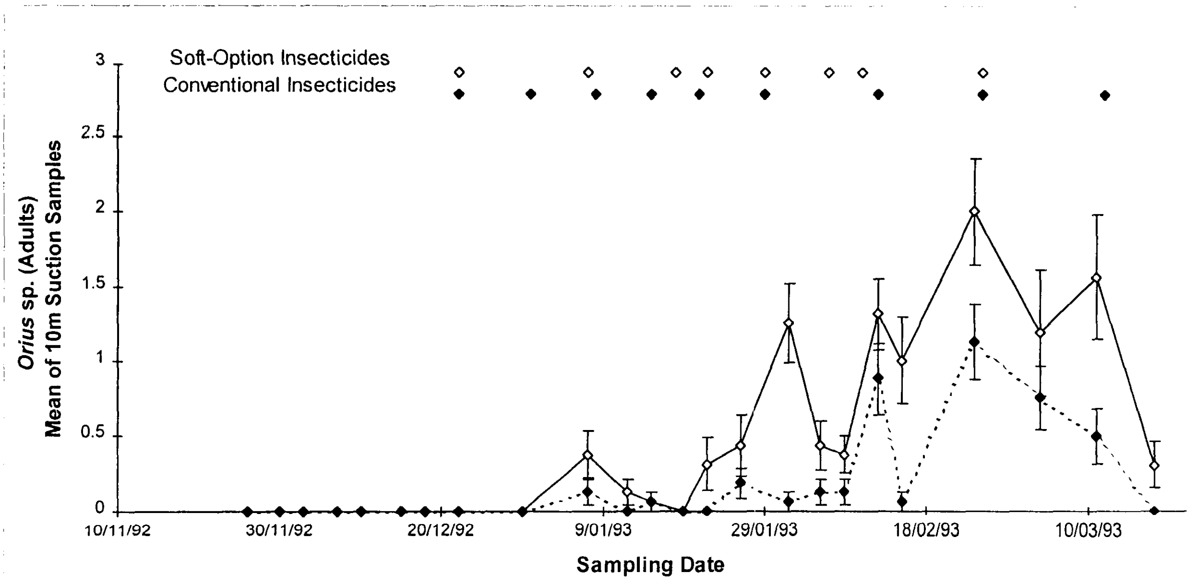

Figure 5.30 ***Orius* spp., 'Midkin' 1992/3:** The abundance of *Orius* spp. recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

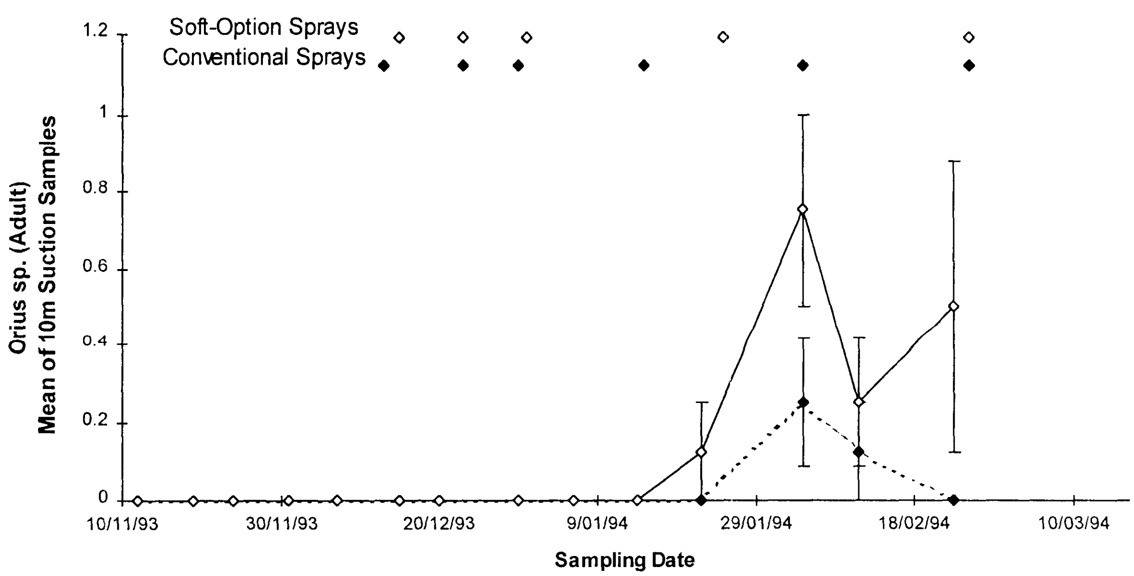

Figure 5.31 ***Orius* spp., 'Midkin' 1993/4:** The abundance of *Orius* spp. recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

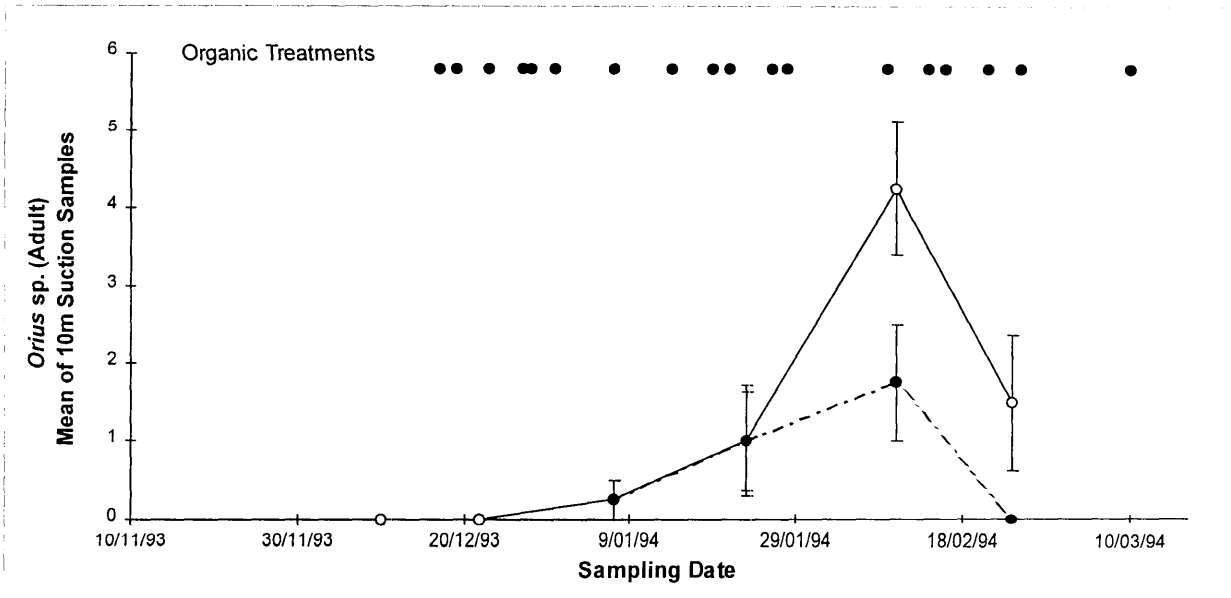

Figure 5.32 ***Orius* spp. (Adult), 'Alcheringa' 1993/4:** The abundance of *Orius* spp. recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (—○—) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

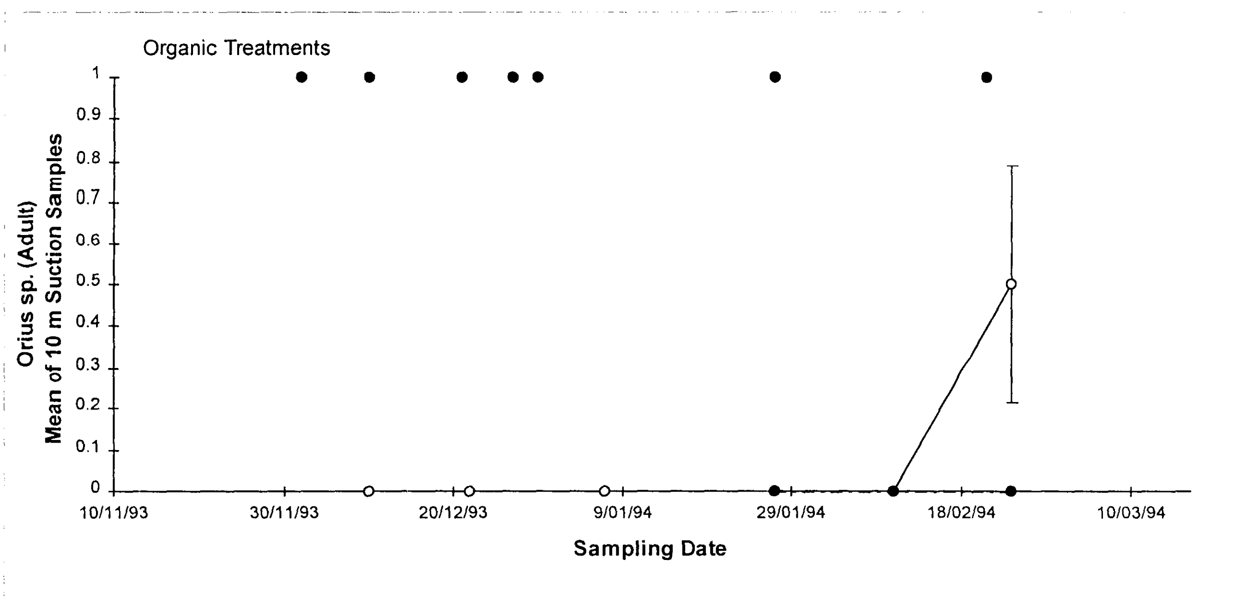

Figure 5.33 ***Orius* spp. (Adult), 'Wilby' 1993/4:** The abundance of *Orius* spp. recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (—○—) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

5.3.9 *Germalus* sp.

No literature was located for this species, and it was presumed to be predatory based solely on its close taxonomic relationship to *Geocoris* spp., which are known to be predatory. *Germalus* sp. was so poorly represented that only one chart is presented for this species, at 'Midkin' in 1992/3 (Figure 5.34). This species was present mainly before insecticides were used, and remained virtually undetectable throughout the insecticide program before increasing again late in the season . This suggests that it is highly sensitive to insecticides. If this is so, it could persist in the absence of insecticides. Some evidence for this is provided by suction sampling of up to 24 per 10 row-m from unsprayed cotton at the I. A Watson Wheat Research Station 2 km north of Narrabri (NSW) (see Appendix 5.4 on computer disc in file Stanley\appen5.xls).

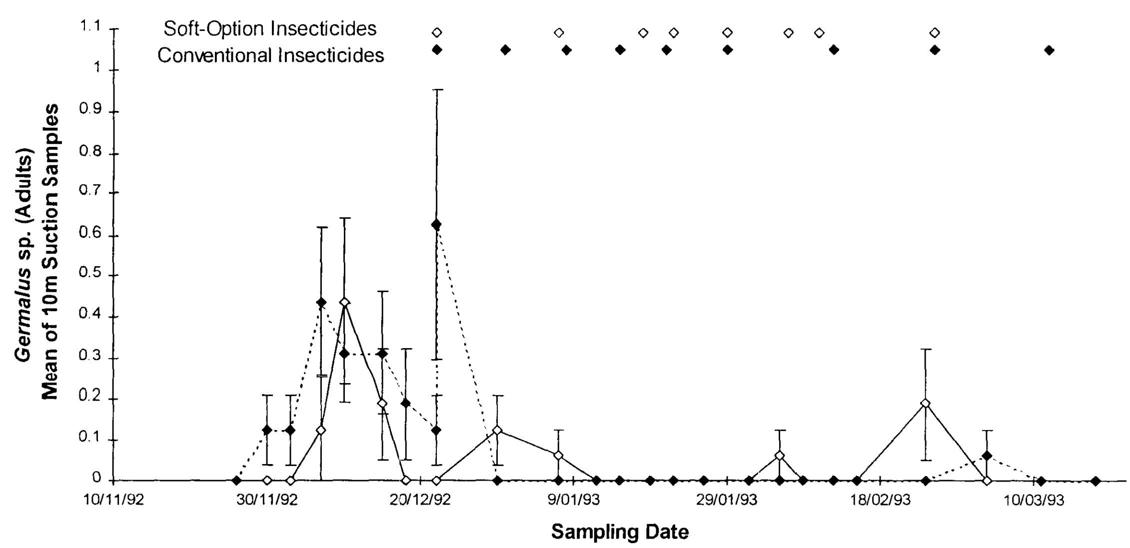

Figure 5.34 *Germalus* sp., 'Midkin' 1992/3: The abundance of *Germalus sp.* recorded by 10 meter suction samples from cotton(Fields 1 and 2, refer to figure 5.1) treated with soft-option (–◇–) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

5.3.10 Oechalia schellenbergii

Oechalia schellenbergii (Hemiptera: Pentatomidae) is potentially an effective predator because it is large and capable of feeding on 2nd to 5th instar *Helicoverpa* larvae (Awan 1985). It did not, however reach appreciable population levels at any of the sites covered by this survey, and only the data for 'Midkin' in 1992/3 are presented here (Figure 5.35). *O. schellenbergii* has been commonly associated with the presence of abundant lepidopteran larvae, and responds to *H. punctigera* frass as an aid to prey location (Awan *et al.* 1989). Its ability to reproduce in cotton was clearly demonstrated by the presence of several egg rafts and nymphs. The influence of the insecticide treatments probably limited their potential to develop substantial populations since the presence of lepidopteran larvae also initiated insecticide applications.

At 'Midkin' only 13 adults of this predator were collected during the 1992/3 survey and only 16 in the following year. This might indicate a low potential for *O. schellenbergii* to contribute to *Helicoverpa* spp. control, but it may also show that this species was particularly poorly sampled by the suction method.

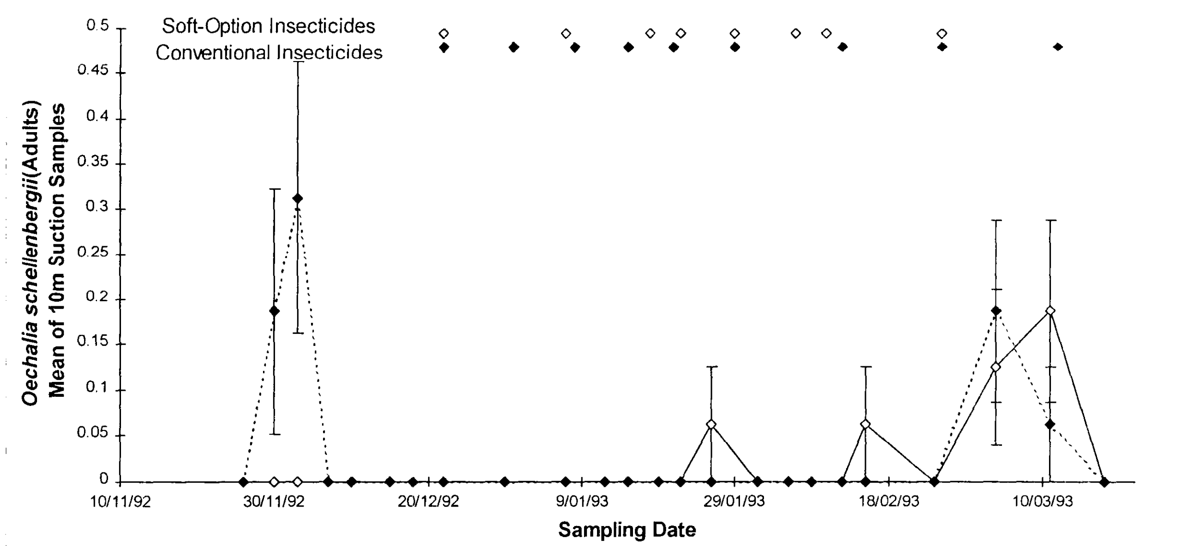

Figure 5.35 ***Oechalia schellenbergii*** **'Midkin' 1992/3:** The abundance of *Oechalia schellenbergii* recorded by 10 meter suction samples from cotton(Fields 1 and 2, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◊) and conventional insecticide applications (♦). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

5.3.11 *Mallada signata* (Green lacewing)

Only the larval stage of this species is predatory, so the abundance of adults, although recorded (Appendix 5.2 to 5.4, on computer disc in file Stanley\appen5.xls), is not presented graphically. Its counterpart in the USA (*Chrysoperla carnea*) was considered to be a very effective predator of *Heliothis* spp. (Ridgway and Jones 1967 and 1968), and therefore the endemic abundance of the Australian species was of considerable interest. Unfortunately it was very poorly represented in the suction samples and so only data from the site where it reached the greatest abundance ('Alcheringa' in 1993/4) are presented (Figure 5.36). The low numbers at 'Midkin' occurred despite the observation of large numbers of adults and eggs at 'Midkin' from an area of unsprayed raingrown cotton in January 1994. These samples were collected within the crop being used for the cage trials (Chapter 3, Figure 3.4). On that occasion 26 *M. signata* eggs were collected for observation of which eight (31%) were parasitised by an unidentified *Telenomus* sp. This observation may help to explain the low number of larvae recorded. However, lacewing larvae, along with other juvenile predators, are not believed to be sampled very effectively by the suction methods (Byerly *et al.* 1978).

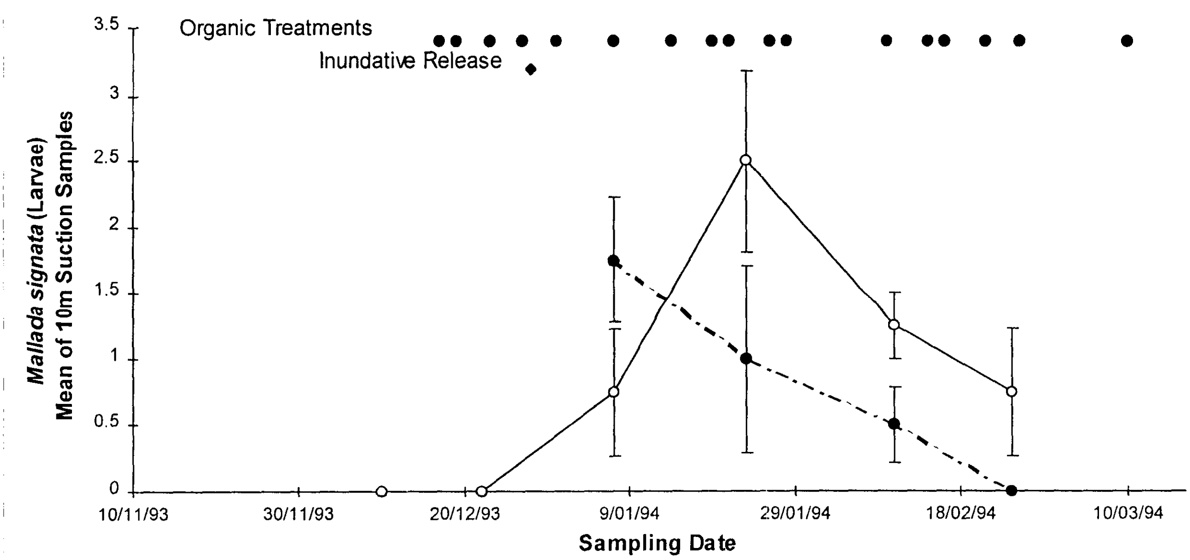

Figure 5.36 ***Mallada signata*** **(larvae), 'Alcheringa' 1993/4:** The abundance of *Mallada signata* recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (—o—) or organic treatments (--•--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4). An inundative release of *M. signata* eggs and early instar larvae was made over the sorghum strips on 28/12/93 (♦) at a rate of 1880/ha of sorghum.

At 'Alcheringa' where the greatest abundance was recorded, the organic treatments appear to have reduced the abundance of *M. signata* larvae, compared to the unsprayed control. However, there was an inundative release of these larvae at this site onto the sorghum strips bordering the unsprayed plot (Section 5.2 'Alcheringa'). Therefore the higher abundance in the unsprayed area may simply reflect the nearby source. Note, however that the date of the inundative release, highlighted on the chart, was much earlier than the period where the difference between the treatments arose.

5.3.12 Spiders

These were arbitrarily divided into small and large spiders according to head capsule size (less than or greater than 1mm across the head). This was done to delineate the larger spiders probably capable of taking *Helicoverpa* spp. larvae from the tiny spiderlings which probably could not. A large lynx spider (Oxyopidae) was observed carrying away a 3rd instar *Helicoverpa* larva in the field.

Small spiders, particularly Oxyopidae, readily colonised the cotton fields at all the sites in both years (Figures 5.37 to 5.40). Their abundance was greatest during the mid season (throughout January) in areas without insecticides or those under reduced insecticide applications. This included the conventionally treated areas at 'Midkin' in 1993/4 (Figure 5.38), where high numbers of spiders were found after the intensity of spraying was reduced due to low yield expectations following the drought.

At 'Midkin' in 1992/3 endosulfan appears to have suppressed the growth of the small spider population, because the peak on 7/1/93 in the conventional field, where this chemical had been used, was lower than that in the soft option field where it had not. At the same time that populations were doubling under thiodicarb applications, there was almost no increase in the conventional field. This suggests that spiders may be an exception to the general trend of more deleterious effects of thiodicarb compared to endosulfan on predators. The first insecticide to clearly show a strongly detrimental effect on spiders was chlorfluazuron in the soft option field on 7 /1/93, and this effect was repeated with the following application of this insecticide on 6/2/93. The synthetic pyrethroids applied to the conventional field between

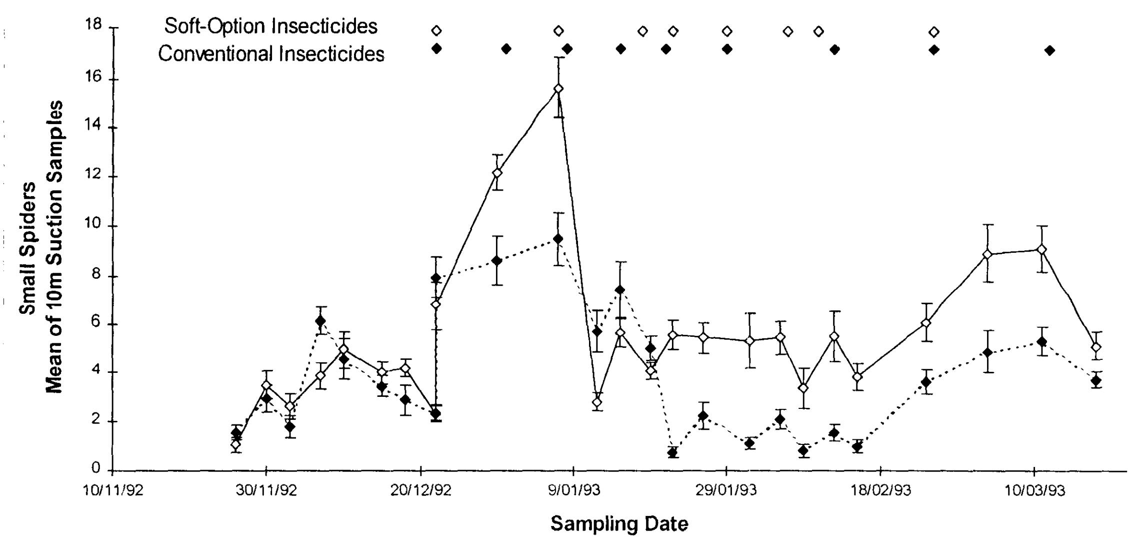

Figure 5.37 Total Small Spiders (head< 1mm wide), predominently Salticidae, Oxyopidae Chiracanthium spp., Thredidae, Aranea and Diea, 'Midkin' 1992/3: The abundance of total small spiders recorded by 10 meter suction samples from cotton(Fields 1 and 2, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

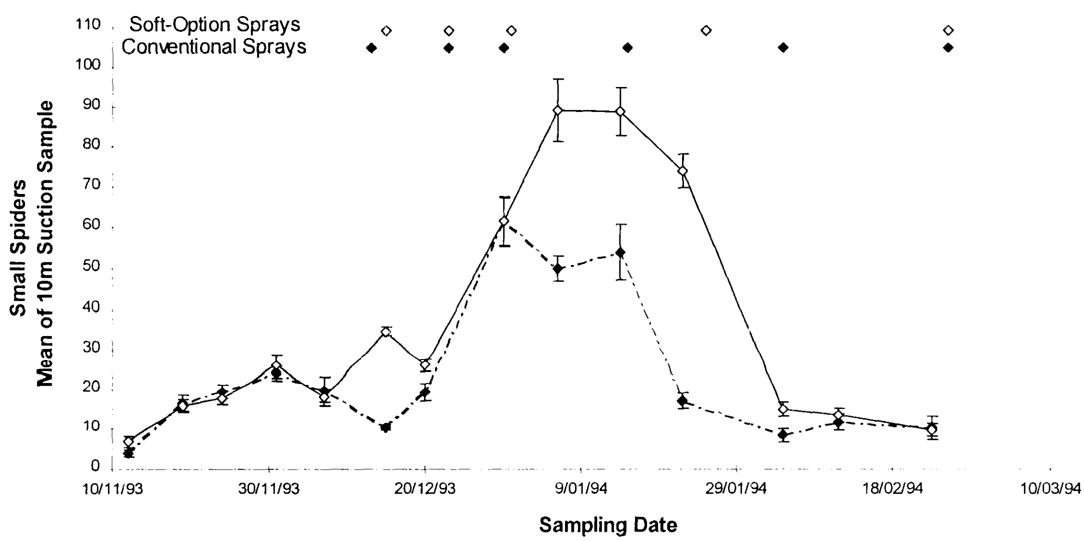

Figure 5.38 Total Small Spiders (head <1mm wide), predominently Salticidae, Oxyopidae and *Chiracanthium* spp., 'Midkin' 1993/4: The abundance of total small spiders recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93 the **Bigvac** was used from 24-11-93 onwards.

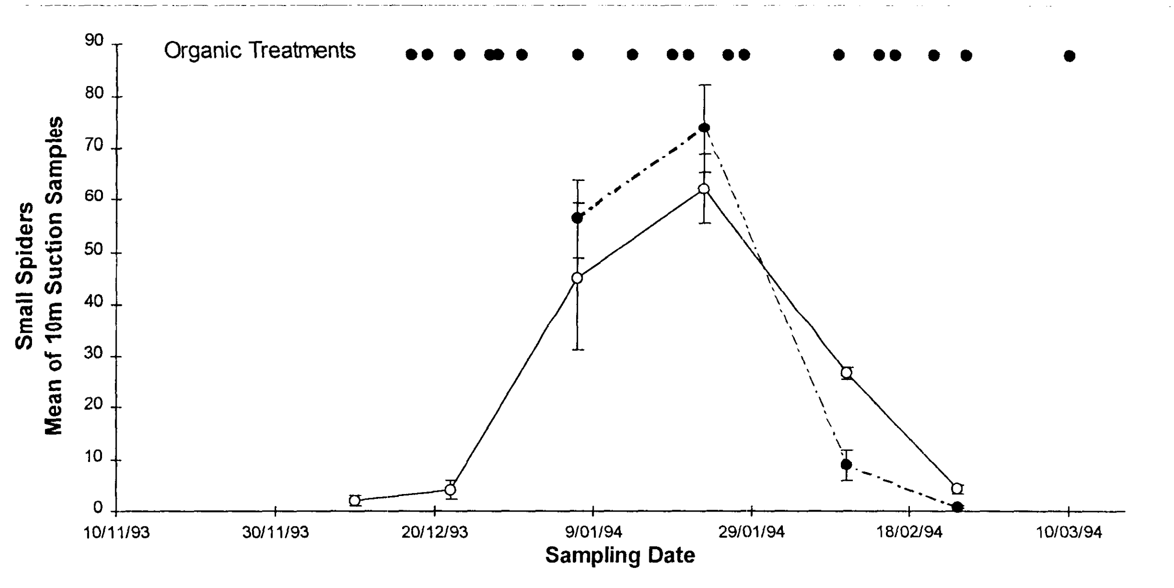

Figure 5.39 Total Small Spiders (<1mm across head), 'Alcheringa' 1993/4: The abundance of total small spiders recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

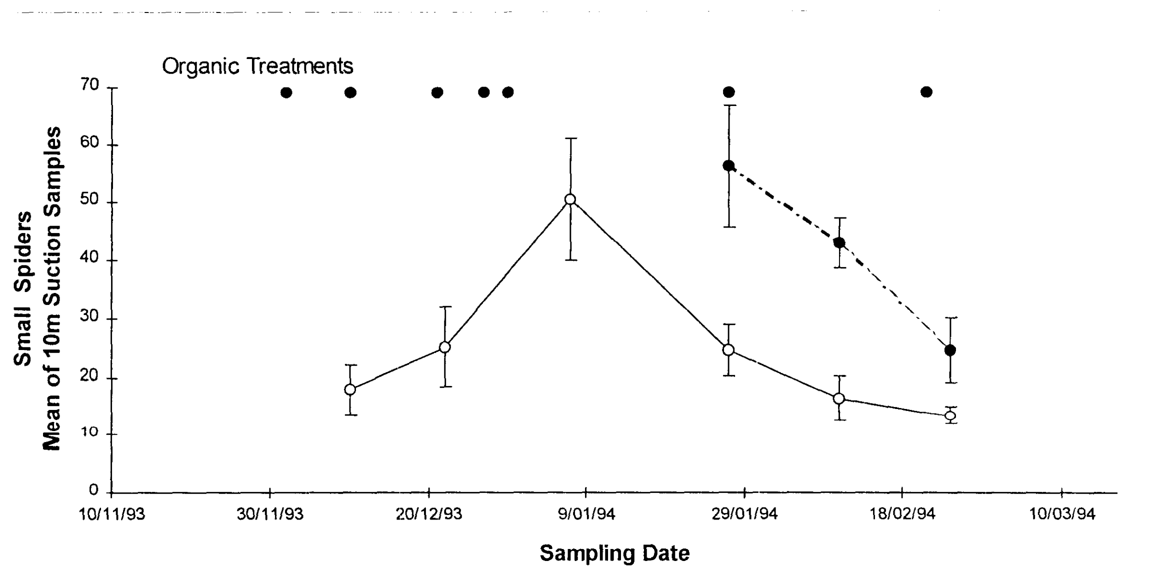

Figure 5.40 Total Small Spiders (<1mm across head), 'Wilby' 1993/4: The abundance of total small spiders recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart(•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

21/1/93 and 12/2/93 had a severe effect, but not so severe as observed with other species of predator, especially the predatory bugs (*Nabis* and *Geocoris* spp.). Possibly, a constant recolonisation of tiny spiders from surrounding areas was maintaining abundance over the pyrethroid period.

'Midkin' in 1993/4 harboured greater numbers of spiders throughout the season than the previous year, probably due to the reduced frequency of insecticide applications. The conclusions reached on the effects of the particular insecticides in 1992/3 are supported by the events of 1993/4 (Figure 5.38). In particular, the relative softness of thiodicarb and the damaging effects of pyrethroids were clearly evident.

Data from the unsprayed plots of 'Alcheringa' and 'Wilby' (Figure 5.39 and 5.40) show that large numbers of small spiders can be present for most of the season, and that the organic treatments had little effect on their numbers.

The results for large spiders (Figures 5.41 to 5.44) were similar to those for the small spiders. As the distinction made during counting does not necessarily mean a change from juvenile to adult, this trend could be expected. However this division does produce abundance curves which reflect the transition of a population from juveniles to adults. That is, as the small spider populations decreased in the unsprayed plots the large spider populations increased. This helps to elucidate the detrimental effect of chlorfluazuron, because the declines of small spiders in the unsprayed plots at 'Alcheringa' and 'Wilby' (Figures 5.39 & 5.40) were followed by increases in the large spider populations (Figures 5.43 & 5.44). However, the large spider abundance in soft option fields at 'Midkin' in both years declined markedly after the application of chlorfluazuron. However, this decline also coincides with the use of pyrethroids in the conventional field in both years. The potential of pyrethroids to affect spiders is evident by the difference between the sprayed and unsprayed areas at 'Alcheringa' when natural pyrethrum was used. Endosulfan and synthetic pyrethroids had similar effects to those shown for small spiders, that is, both were apparently damaging. The steady increases in the large spider populations at 'Midkin' in 1993/4 following repeated thiodicarb applications between 15/12/93 and 31/12/93 again suggests that this chemical is relatively soft on spiders.

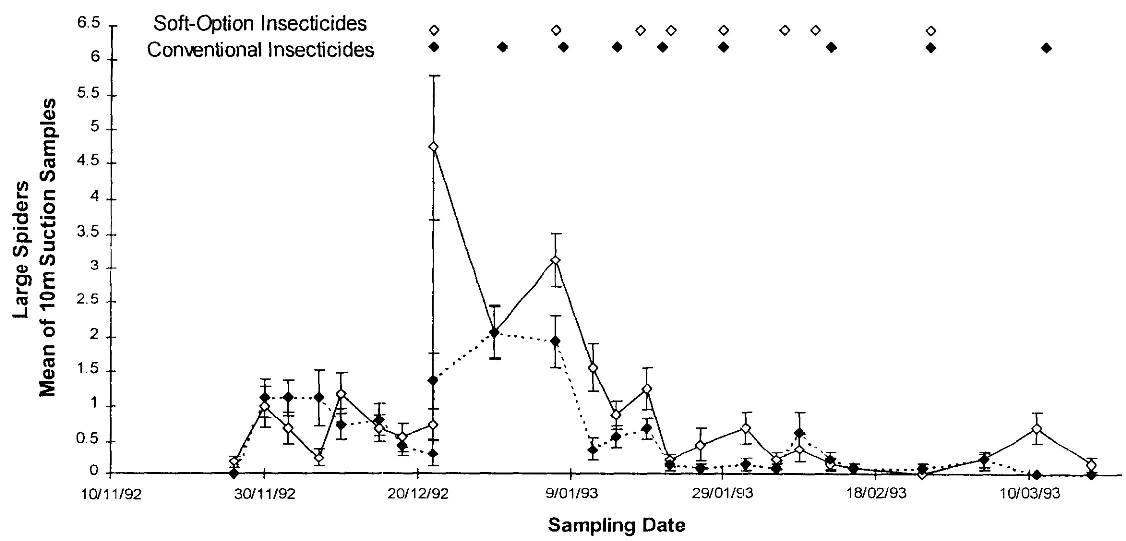

Figure 5.41 Total Large Spiders (head >1mm wide), predominently Salticidae, Oxyopidae and *Chiracanthium* spp. 'Midkin' 1992/3: The abundance of total large spiders recorded by 10 meter suction samples from cotton(Fields 1 and 2, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

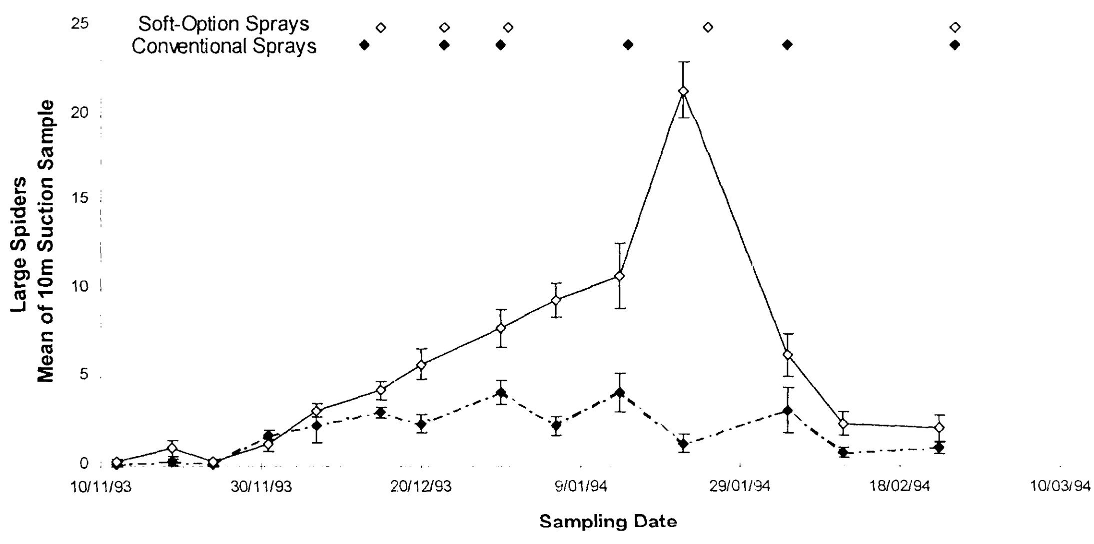

Figure 5.42 Total Large Spiders (head >1mm wide), predominently Salticidae, Oxyopidae and *Chiracanthium* spp., 'Midkin' 1993/4: The abundance of total large spiders recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93 the **Bigvac** was used from 24-11-93 onwards.

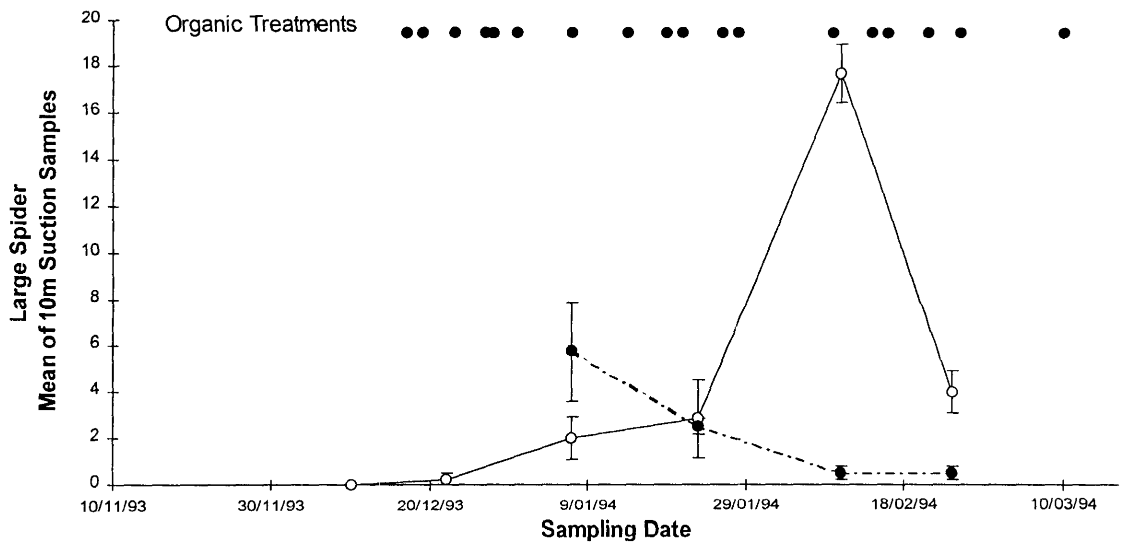

Figure 5.43 Total Large Spiders, 'Alcheringa' 1993/4: The abundance of total large spiders recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

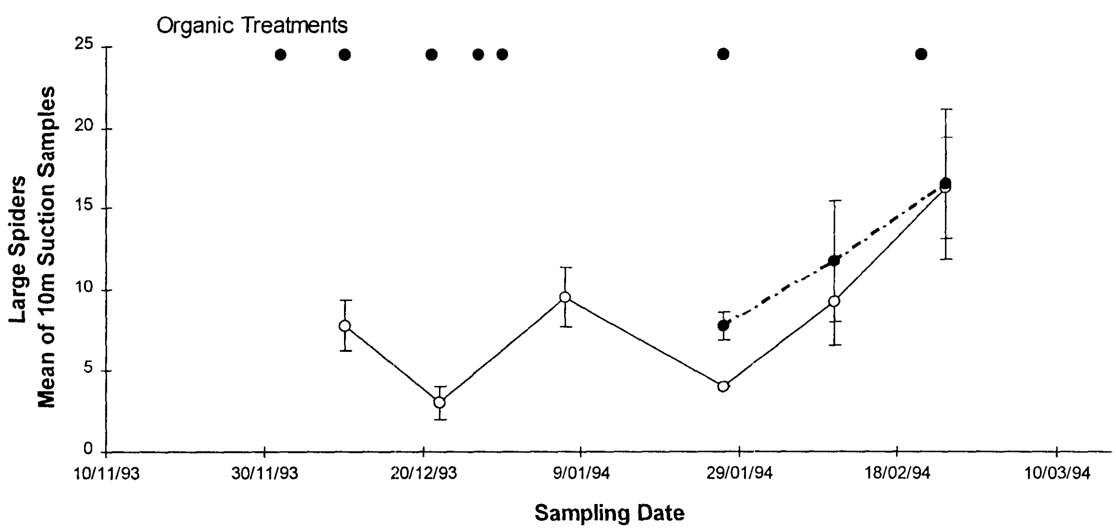

Figure 5.44 Total Large Spiders, 'Wilby' 1993/4: The abundance of total large spiders recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart(•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

5.3.13 Formicidae (ants)

A cotton field might not be considered a particularly hospitable environment for ants, because the soil where many ants form nests is frequently cultivated and flood irrigated during the year. Therefore it is not surprising that Formicidae were not abundant at 'Midkin' in either season (Figures 5.45 and 5.46). The standard errors were often very high, reflecting erratic catches with the Bigvac, which may be associated with clumped spatial distributions resulting from the social nature of these insects. With such variation, no differences were discernible between the insecticide treatments.

The unsprayed control area at 'Alcheringa' (Figure 5.47) may show the effect of irrigations on ant populations (Figure 5.47). The organic treatment at 'Wilby' , which was without irrigations, maintained high populations of ants throughout the latter half of the season. The organic treatments appear to have reduced numbers considerably, particularly at 'Wilby'. However this may reflect the position of the control plots, rather than the effects of the organic treatments. The unsprayed control plots were adjacent to a 16 row border of sorghum at the end of the field (Chapter 3, Figures 3.5 & 3.6) compared to the organic plot which was well within the cotton crop. The ants collected from the control may have been foraging from nearby nests built in less disturbed areas in the sorghum or even outside the crop area, whereas the sampling within the organic plot was possibly too remote from these sources. 'Wilby' also had a more friable soil type which might be expected to be more conducive to ants than the clay at 'Alcheringa'.

The possible influence of irrigations and the importance of the proximity of the sampling position to the edge of the fields makes identification of insecticide effects even more difficult with this order. However the most consistent period of reduction of Formicidae at 'Midkin' appears to coincide with the main period of pyrethroid use on a regional scale.

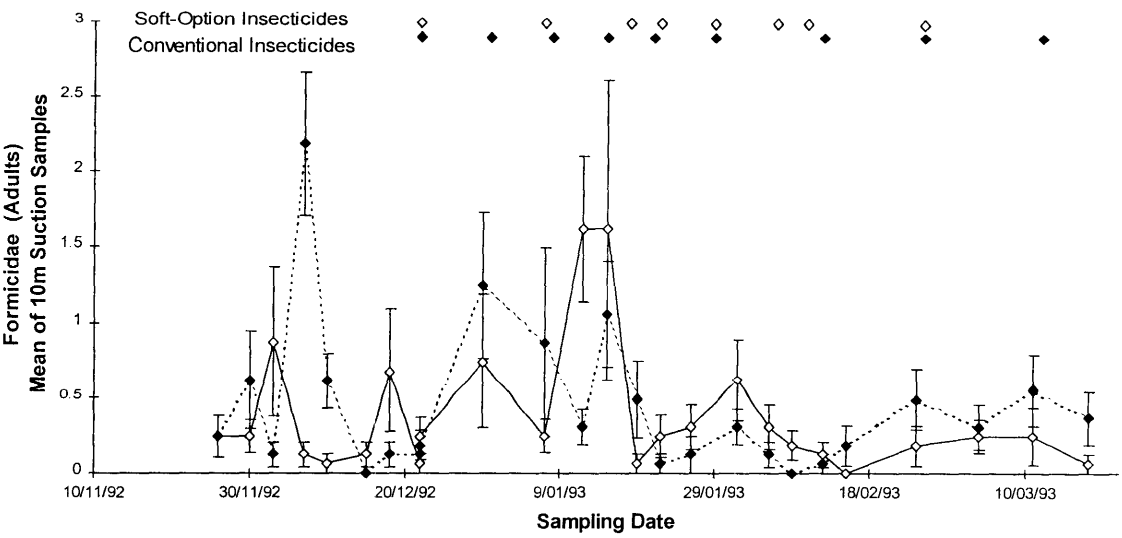

Figure 5.45 Formicidae, 'Midkin' 1992/3: The abundance of Formicidae recorded by 10 meter suction samples from cotton (Fields 1 and 2, refer to figure 5.1) treated with soft-option (–◇–) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

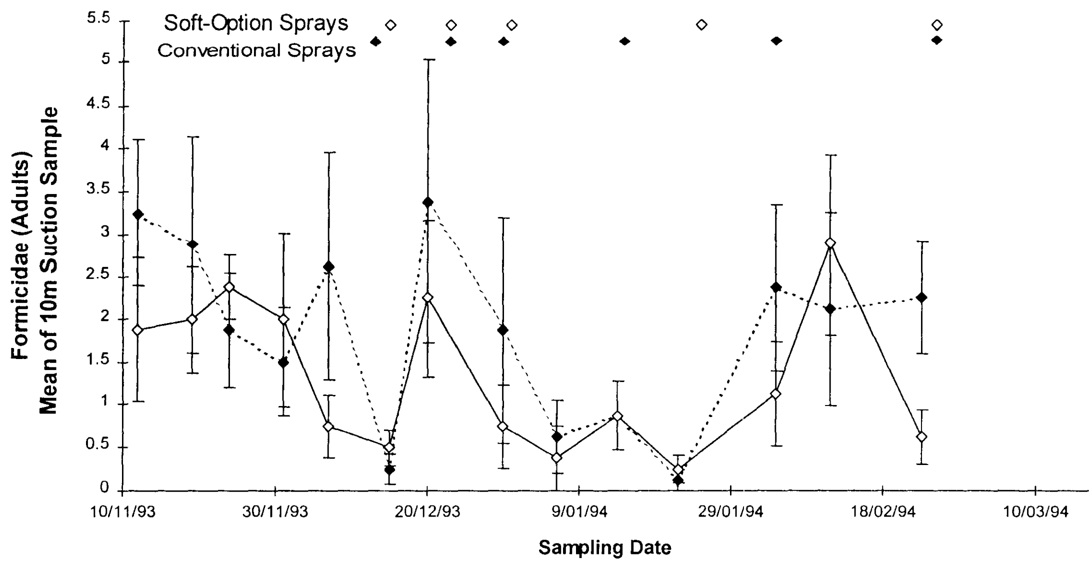

Figure 5.46 Formicidae, 'Midkin' 1993/4: The abundance of Formicidae recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (–◇–) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93 the **Bigvac** was used from 24-11-93 onwards.

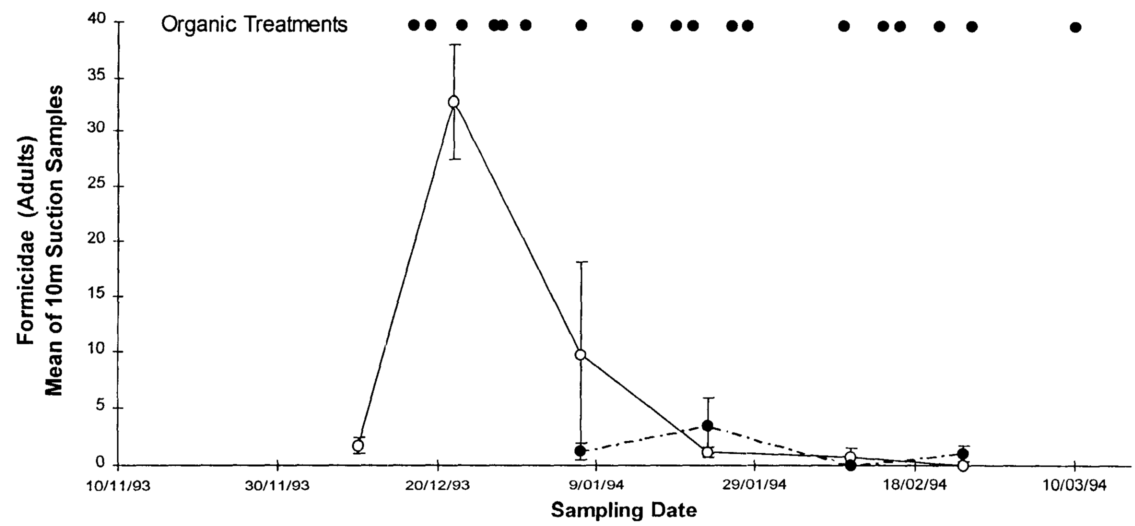

Figure 5.47 Formicidae, 'Alcheringa' 1993/4: The abundance of Formicidae recorded by **Big vac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (–o–) or organic treatments (--•--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

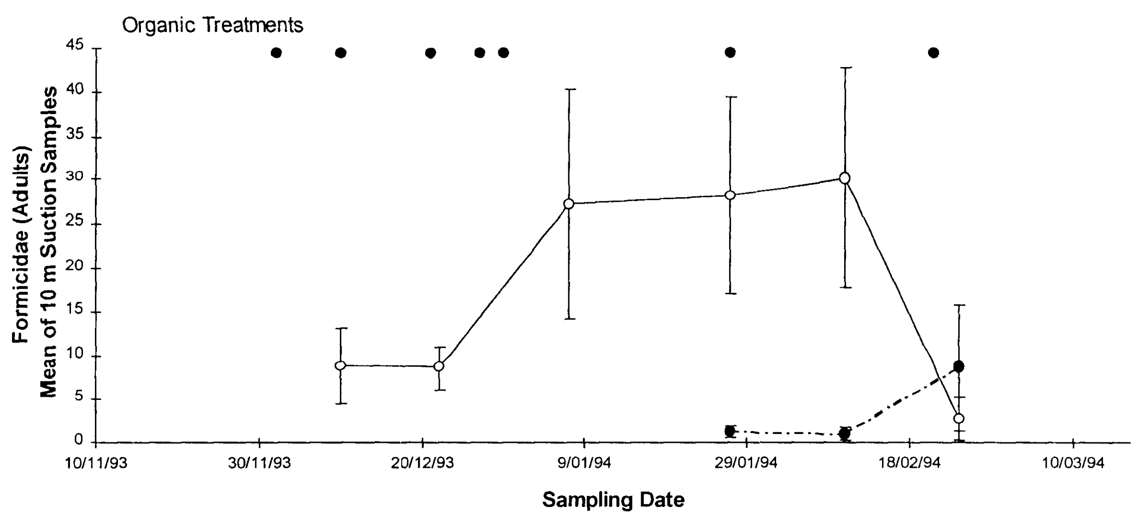

Figure 5.48 Formicidae, 'Wilby' 1993/4: The abundance of Formicidae recorded by **Big vac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (–o–) or organic treatments (--•--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

5.3.14 Total Predators

The overall abundance of the predators as a group is shown by Figures 5.49 to 5.52 for each site and treatment. In the absence of detailed information about the effectiveness of particular species of predators, cotton pest management in Australia frequently relies on counts of total predators. The implicit assumption of combining predators is that all species are equally effective. While this is almost certainly quite wrong, the widespread use of total predator counts in the field suggested that analysis of the results of these surveys in terms of total predators would be useful. In any case, the farmers and consultants often lack the time and expertise to make counts of separate predators.

Predators (whether at genus or species level) were included in the total predator profiles if they had been implicated by laboratory or field trials as consuming *Helicoverpa* eggs or larvae, or had a prey size range which would imply that they may do so (Room 1979a, McDaniel & Sterling 1979, Ridgway *et al.* 1967). In practice this effectively excluded only tiny predators such as predatory mites (which were probably present but not recorded), Empedidae (which were on occasions abundant but not separated from other Diptera for counting) and small spiders. Small spiders (< 1mm across the head) were not included in Figures 5.49 to 5.52. Also, only those species caught in a predatory life stage were included. For example, Neuropteran larvae were included, but not Neuropteran adults. Therefore, the 'total predator' group included the following species or groups of species, as either adults (Ad) or juveniles (jv): *Coccinella transversalis* (Ad. & jv), *Harmonia conformis* (Ad. & jv), *Micraspis frenata* (Ad. & jv), *Diomus notescens* (Ad.), *Dicranolaius bellulus* (Ad.), *Mictolestodes macleayi* (Ad.), *Campylomma* spp. (Ad & jv), *Creontiades dilutus* (Ad & jv), *Geocoris* spp. (Ad.&jv.), *Germalus spp.*(Ad.), *Nabis kinbergii* (Ad.& jv.), *Oechalia schellenbergii* (Ad.& jv.), *Orius* spp., Formicidae (Ad.), Salticidae (Large), *Oxyopes* spp. (Large), *Chiracanthium sp.* (Large), *Other Spiders* (Large) and *Mallada signata* (jv.).

Overall, predatory arthropods increased in abundance until mid season in the cotton crops at all sites. Any annual crop, where the habitat is removed each year, would be expected to exhibit this profile because the crop canopy, starting from nothing, would grow to provide a larger and larger area suitable for herbivores and, in turn, predatory species to

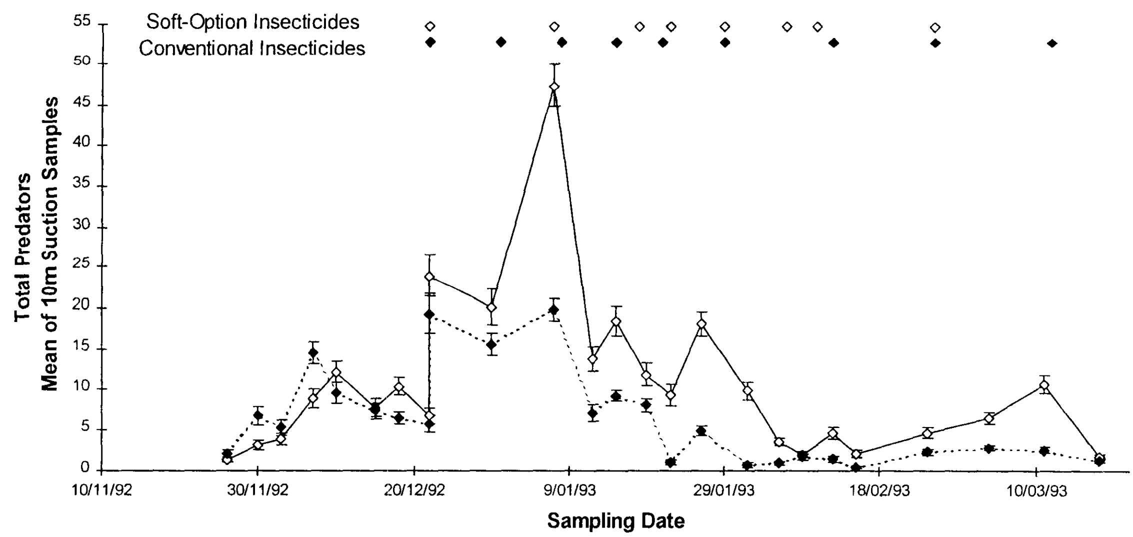

Figure 5.49 Total Predators, 'Midkin' 1992/3: (not including small spiders). The abundance of arthropod predators recorded by 10m suction samples from cotton fields 1 and 2, treated with soft-option insecticides (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the Standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

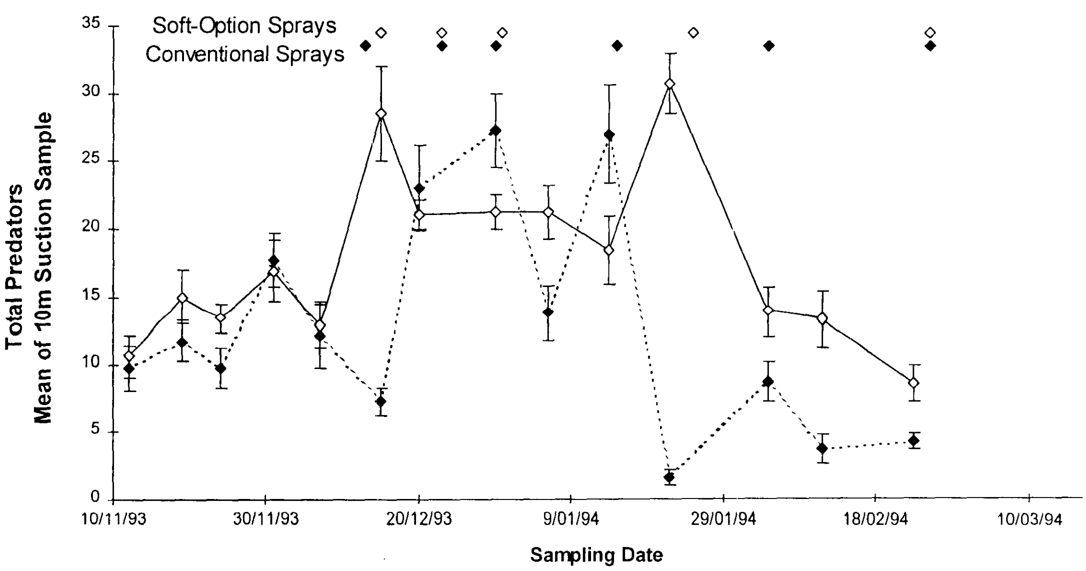

Figure 5.50 Total Predators, 'Midkin' 1993/4: (not including small spiders). The abundance of Arthropod Predators recorded by 10m suction samples from cotton fields 3 and 4 treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the Standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93; the **Bigvac** was after 19-11-93.

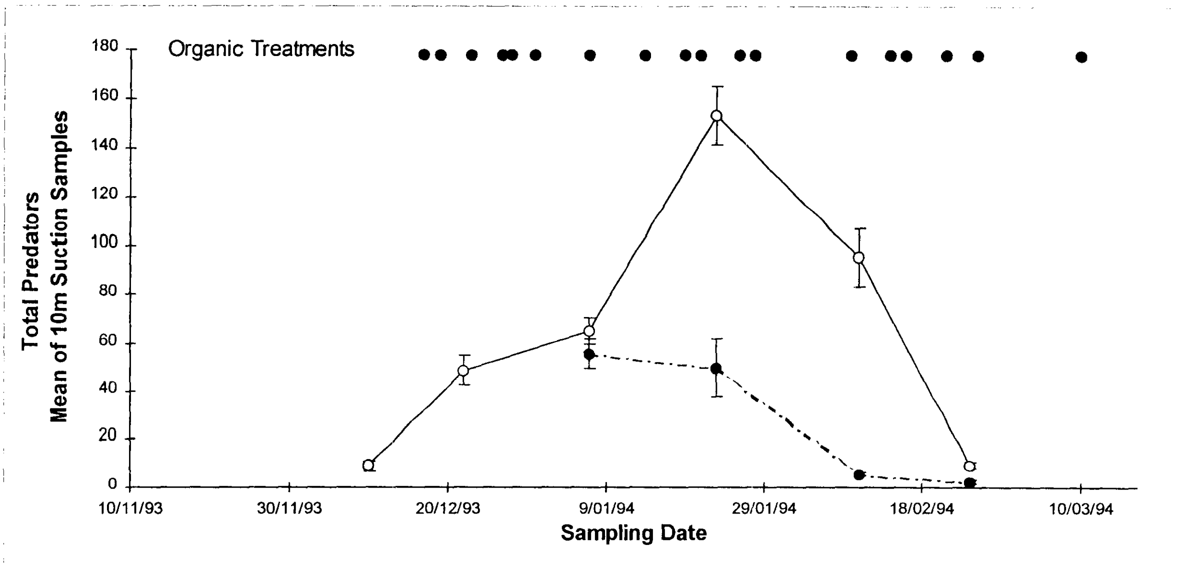

Figure 5.51 Total Predators, 'Alcheringa' 1993/4: (not including small spiders). The abundance of Arthropod Predators recorded by **Bigvac** 10m suction samples from cotton field 5 treated with no insecticides (‒○‒) or organic treatments (‐‐●‐‐) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

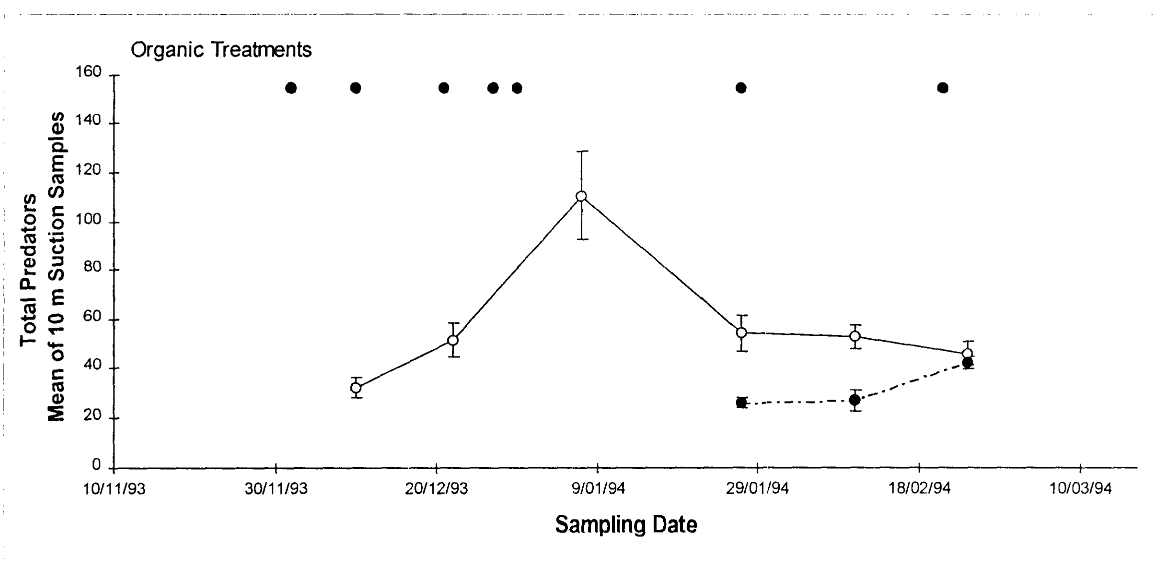

Figure 5.52 Total predators, 'Wilby' 1993/4: (not including small spiders). The abundance of Arthropod Predators recorded by **Bigvac** 10m suction samples from cotton field 6 treated with no insecticides (‒○‒) or organic treatments (‐‐●‐‐) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars represent the standard error of the mean (n=4).

survive and reproduce. Up until late December in each season the major determinant of population increase would be intrinsic species factors such as immigration behaviour and potential rates of increase within habitat and climate constraints. In this period, while suction sampling is efficient and before the start of insecticide schedules, the major factors which could cause marked decreases in populations are therefore likely to be seasonal. The increases over this period were relatively steady.

However, the marked decreases in January at 'Midkin' in 1992/3 (Figure 5.49) and again in 1993/4 (Figure 5.50) may be due to three main effects; climatic or seasonal phenology effects, a sudden reduction in sampling efficiency, or the effect of insecticides. Evidence against seasonal effects is that most of the species contributing to the total count were present for most of the season in all surveys and were particularly abundant at this time of year in the unsprayed control plots at 'Alcheringa' and 'Wilby'. There was also an absence of particularly detrimental weather events which might have provided alternative explanations (Appendix 5.5). A reduction in sampling efficiency has been associated with a steady decline in predator numbers in surveys using the Macvac (Chapter 4). This is unlikely in this survey because the method using the Bigvac covers a much larger area of the canopy and increases with the crop as it grows (Chapter 4). The samples from 'Alcheringa' also indicate that larger numbers of predators can be caught by this method on large plants later in the season (Figure 5.51).

These features strongly suggest that the reduction recorded in mid January is linked to the application of insecticides. The partial recovery of most species after the period of intensive insecticide use also supports the theory that insecticides had a major effect. In the conventional field (Field 2) the direct application of endosulfan either had no effect or at least a similar effect to that of the soft-option sprays. The introduction of synthetic pyrethroids clearly reduced the predators and all other species to near zero abundance. A small peak in abundance was evident after the first synthetic pyrethroid spray. This was largely comprised of *D. bellulus*. However the following pyrethroid spray returned this field to the previous low counts. In the soft-option field the main peak in abundance was largely a result of the build up of *Campylomma* spp. and *Creontiades dilutus* and their subsequent destruction by chlorfluazuron.

The declines in predator abundance throughout the mid to late season under soft-option and conventional insecticide management offer further evidence that insecticides were the main influence on predators in these fields. The declines often coincided with the application of particular insecticides while unsprayed sites at 'Wilby' and 'Alcheringa' show predator populations were considerably higher or even increasing. The tendency for predator densities to increase after the spray program was completed at 'Midkin' 1992/3 is also evidence of a strong influence of insecticides.

Insecticide Effects

At 'Midkin' the soft option field consistently harboured greater numbers of arthropod predators than the conventionally treated field. This difference was least noticeable early in the season, suggesting that the endosulfan sprays (22/12/92 to 20/1/93) of the conventional insecticide treatment were only marginally more destructive to the predatory species than the soft-option insecticides (thiodicarb/Bt mix) overall. However, this difference varied between different predatory groups. Coleopteran predators appeared to be tolerant of endosulfan whereas predatory hemipterans were susceptible.

When they were introduced later in the season, the synthetic pyrethroids were particularly severe on predators, producing a period where very few insects, predatory or otherwise, were collected (from 22/1 to 15/2/93 in the conventional treatment).

There was also a considerable difference between the treatments in the recovery of predator populations late in the season. Under the organophosphate treatments (from 20/2 /93 onwards in the conventional field), there were far fewer predators than occurred during the same period in the soft-option field, which was predominantly treated with chlorfluazuron over this period.

5.4 General Predator Conclusions

As with many records of the seasonal abundance of generalist predators in field crops (eg. Shepard *et al.* 1974), the predator populations in this study began low from the seedling stage and steadily increased over the first two months. The common families and genera are represented, with Coleoptera, Miridae, *Nabis*, *Geocoris*, *Orius*, Neuroptera and *Oxyopes* predominating. For all of these there was good evidence for reproductive increases within the crop, in the form of immatures. However, the possibility of immigration and poor sampling techniques for juveniles confounds estimations of the relative importance of intracrop reproduction versus movement as contributors to predator densities.

The predator populations were much lower than reported by other investigators in unsprayed plots in America (Table 5.7). The reasons for these differences are not clear, but the almost synchronised use of certain insecticide groups over a regional scale could be expected to be a major contributor. Table 5.7 summarises the records from four studies of the most commonly encountered predatory genera. The entries are the daily maximums gained using a variety of the most thorough sampling methods found, in different areas and crops, roughly transformed to a common sampling area (1 row-m) to allow more convenient comparisons. The differences in sampling technique and area prevent precise analysis but the discrepancy between these general population levels and those found during this study are clear. These data are for unsprayed crops and clearly show that at least in some time in the season the predator numbers are considerably higher than those recorded under the insecticide treated plots in this study.

Neuropteran larvae are highly abundant in some areas of the USA with populations reaching levels of around 1 to 3 per row-m as adults and 10 to 20 per row-m as juveniles in unsprayed crops (Shepard *et al.* 1974). These authors report that predatory species were most abundant when the populations of the pest species of Lepidoptera were highest. This appears to be in contrast to the situation in Australia, however they also conclude that the wide variety of prey makes discerning particular predatory relationships difficult. Leigh *et al.* (1974), Byerly *et al.* (1978) and Gonzalez *et al.* (1977) recorded *Nabis*, *Orius* and *Geocoris* spp. as the most abundant species of predators under unsprayed conditions. The maximum of 41 *Geocoris* spp. per row-m (Leigh *et al.* 1974) is much higher than any recorded in this Australian study.

Although the unsprayed plots at 'Alcheringa' and 'Wilby' go some of the way to showing the potential densities of predators, none of these sites were far removed from the effects of insecticides, whether they be organic or otherwise. The influence of insecticides on the possible source areas of predators even beyond the farm boundaries cannot be realised in districts where spraying is so common that the entire region might be affected. Therefore one can only guess at their potential abundance if insecticides are not so broadly used. The indications of the work described in this thesis are that they would be greatly increased.

Reference	Sampling method	Place	*Geocoris*	*Nabis*	*Orius*	Neuroptera	Coccinellidae	Coleoptera Others	Spiders
[1] Smith *et al.* (1976)	Suction of an enclosed section of Row	Mississippi Delta USA	0.3A	na.	2.2C	0.1A 0.6J	4A	2.3A	5.5C
[2] Gonzalez *et al.* (1977)	Whole section of row bagging	California USA	14.4A 9.5J	6.5A 11.5J	11.5A 18.5J	4.0A 7J	na.	27A	4C
[3] Bryerly *et al.* (1978)	Whole plant bagging	California USA	16.0A 30J	4A 4.0J	10.5A 9.5J	1.4A 20J	na.	5.6A	10C
[4] Stanley (this thesis)	10 meter suctions with adjustment	NSW Australia	0.2A 0.3J	1A 0.1J	0.4A 2.5J	0.2A 0.3J	8A 1J	7.5A	~20C

Table 5.7 The approximate abundance reached (maximum daily average) by predatory insects and spiders reported from cotton crops using sampling methods which give the best available indication of absolute population densities. A=adult, J=juvenile and C= combined adults and juveniles.
The calculations required to give the abundances in estimates of individuals per row-m and the actual species referred to by each author is presented in the foot notes. These data are only approximate and were calculated using broad assumptions of plant densities and the efficiency of the various sampling procedures.

[1] Smith *et al.* (1976) data read from graphs of means per acre. These were divided by 4080 to give approximate abundance per row-m. Included Species: *Geocoris* spp., mostly *Orius insidiosus* (Say), *Chrysoperla carnea* Stephens, mostly *Coleomegilla maculata* (DeGeer) & *Hippodamia convergens* (Guérin), mostly *Oxyopidae salticus* Hentz.

[2] Gonzalez *et al.* (1977) data from tables of means per 5 plants. These were multiplied by 2 to give approximate number per row-m. (that is assuming an average density of 10 plants per meter). Included Species: *Geocoris punctipes* (Say) and *G. pallens* (Stal), mostly *Nabis americoferus* Carayan, *Orius tristicolor* (White), mostly *Chrysoperla carnea* Stephens and *Notoxus calcaratus* Horn

[3] Byerly *et al.* (1978) data read from graphs of means per 50 plants and divided by 5 to give approximate abundance per row-m. (that is assuming an average density of 10 plants per meter). Included Species: *Geocoris punctipes* (Say) and *G. pallens* (Stal), mostly *Nabis americoferus* Carayan, *Orius tristicolor* (White), *Chrysoperla carnea* Stephens and *Notoxus calcaratus* Horn

[4] Stanley (this thesis) Maximum recorded collection from any treatment sampled in this study. Bigvac samples divided by 10 and multiplied by 2.5 to give absolute abundance per row-m. (that is assuming an average efficiency of 40% suggested by the suction sampling efficiency experiments in chapter 4). Included Species: *Geocoris* spp., *Nabis kinbergii*, mostly *Orius tintillus*, Coccinellids; *Coccinella transversalis, Diomus notescens, Harmonia conformis, Micraspis frenata,* Other Coleoptera; *Dicranolaius bellulus and Spiders; Oxyopes, Salticidae, Chirachanthium spp.*

5.5 Abundant Alternative Prey

Sources of alternative prey may have an important influence on the amount of predation on *Helicoverpa* spp. An abundance of alternative prey could be expected to increase the number of generalist predators, but may also distract them via prey preference or switching behaviour. The samples at all sites within this survey were, for most of the season, dominated by cicadellids (Appendix 5.2 to 5.4 on computer disc in file Stanley\appen5.xls). Furthermore, many of the parasitoid species collected in the survey and noted for identification were also found to be cicadellid parasitoids. Other arthropods which were highly abundant on occasions were thrips, aphids, and mites.

Entomophagous arthropods depend upon the presence of prey species and although some, particularly the predacious Hemipterans (such as *Geocoris, Orius* and *Nabis*) are capable of survival by feeding from plant tissue, their development and fecundity are enhanced by feeding on insects (Stoner 1970 and 1972, Kiman and Yeargan 1985, and Legaspi and O'Neil 1993). The prey are mostly phytophagous arthropods which become abundant exploiting the fertilised expanses of agricultural crops which, at least initially, are relatively devoid of natural enemies. In the case of Australian cotton crops the phytophagous arthropods are represented by thrips and aphids early in the season. These populations are low compared to the later season but as a proportion of the total arthropod population they are high.

Cicadellids were present in high numbers throughout most of the season, and mites and aphids commonly become very abundant late in the season. At all times, the numbers of one or more of these groups greatly exceeded those of *Helicoverpa* spp., and so are likely to have had a dominant influence on the general predator abundance and composition. Evidence also exists of intra-predator feeding especially within the group of predatory bugs (*Geocoris, Nabis, and Orius*), in which the smallest individual in the confrontation often becomes the prey (Atim and Graham 1984, Arditi and Akcakaya 1990).

5.5.1 Cicadellids and related insects

Generally these were highly abundant and persistent in Australian cotton crops if harder broad spectrum insecticides were not applied (Figures 5.53 and 5.56). This family was dominated by two species; *Austroasca viridigrisea* (Paoli) and *Orosius argentatus* (Evans). Over the 1992/93 season at 'Midkin' up to 510/10 meter suction sample were collected for *A. viridigrisea,* with an average of 71/10m before insecticide treatments commenced on 22/12/92). In the same season, up to 330 *O. argentatus* per 10 m sample were collected, with an average of 42/10 m before spraying commenced. Numbers of adults and nymphs combined reached 1470/10m sample with an average of 153/10m before spraying commenced. Samples from the soft option sprays and the untreated plots show that the decline from early January in the conventionally treated field was most likely due to the insecticides, especially synthetic pyrethroids which were applied from 21/1/93. Regional use of pyrethroids probably explains the reduction in cicadellids generally over the later half of the season in the soft-option field, aided by the use of chlorfluazuron and thiodicarb.

Room & Wardhaugh (1977) found both *A. viridigrisea* and *O. argentatus* in unsprayed cotton but considered that only *A. viridigrisea* was breeding successfully. Considerable numbers of *O. argentatus* nymphs were also collected over several months in this study, suggesting that these insects were also successfully breeding. However, this species appears to be affected to a greater extent by natural enemies. A broad group of parasitoids were found to be associated with *O. argentatus* including a trichogrammatid which parasitises eggs *(Aphelinoidea sp.* Girault), a dryinid, parasitising nymphs and adults *(Gonatopus sp.,* undescribed), a Dipteran (pipunculid), which emerged from adults and Strepsipterans (unidentified, but several emergence tunnels were found on adult *O. argentatus*). The dryinid larvae were only found attached to late instar nymphs and adults of *O. argentatus.* Only the adults (an ant mimicking female) of one species of Dryinid were collected throughout the survey, therefore the larvae were considered to belong to that species. The parasitic relationship between the trichogrammatid and *O. argentatus* produced a strong correlation coefficient in time series analysis (Chapter 6.4.3).

A. viridigrisea were also observed in large populations on pasture grasses at 'Midkin' in December 1992. Large numbers of *Dicranolaius bellulus* adults and *Coccinella transversalis* adults and larvae were also found throughout these grasses, probably feeding on the nymphs.

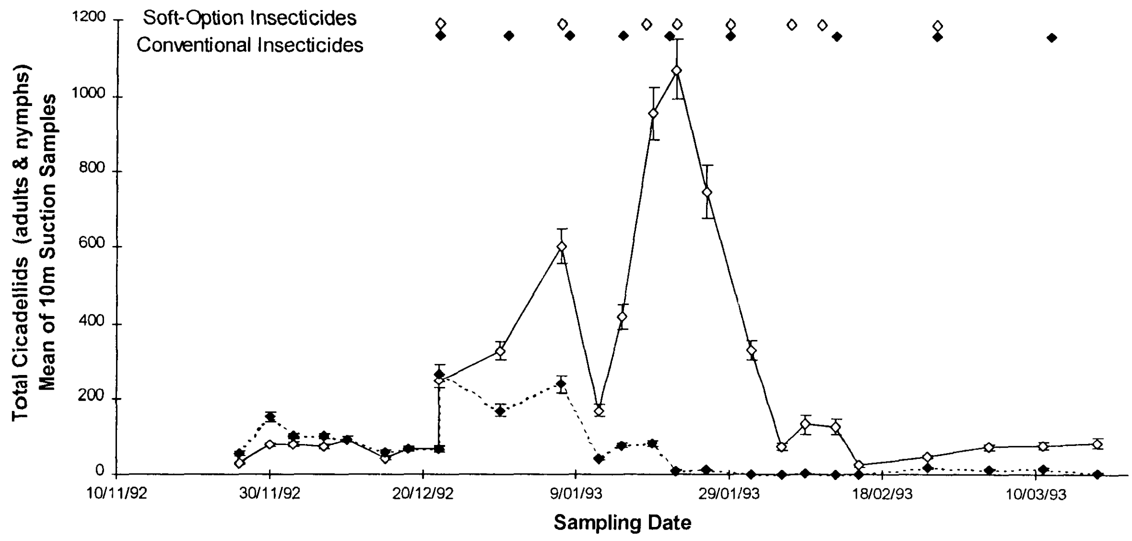

Figure 5.53 Total Cicadellids (adults & nymphs) 'Midkin' 1992/3: The abundance of total cicadellids recorded by 10 meter suction samples from cotton(Fields 1 and 2, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

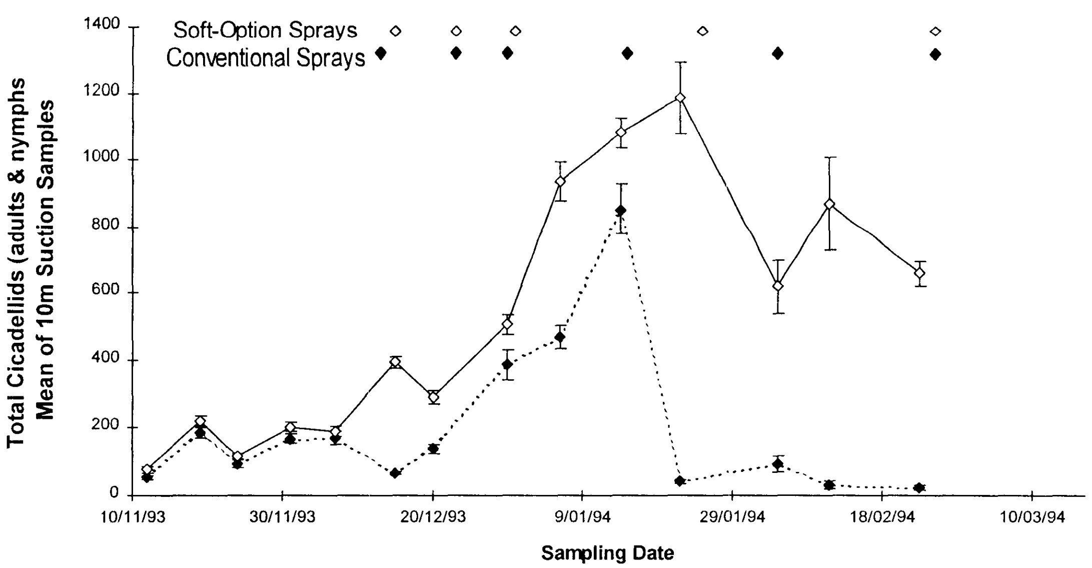

Figure 5.54 Total Cicadellids (adults & nymphs), 'Midkin' 1993/4: The abundance of total cicadellids recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93 the **Bigvac** was used from 24-11-93 onwards.

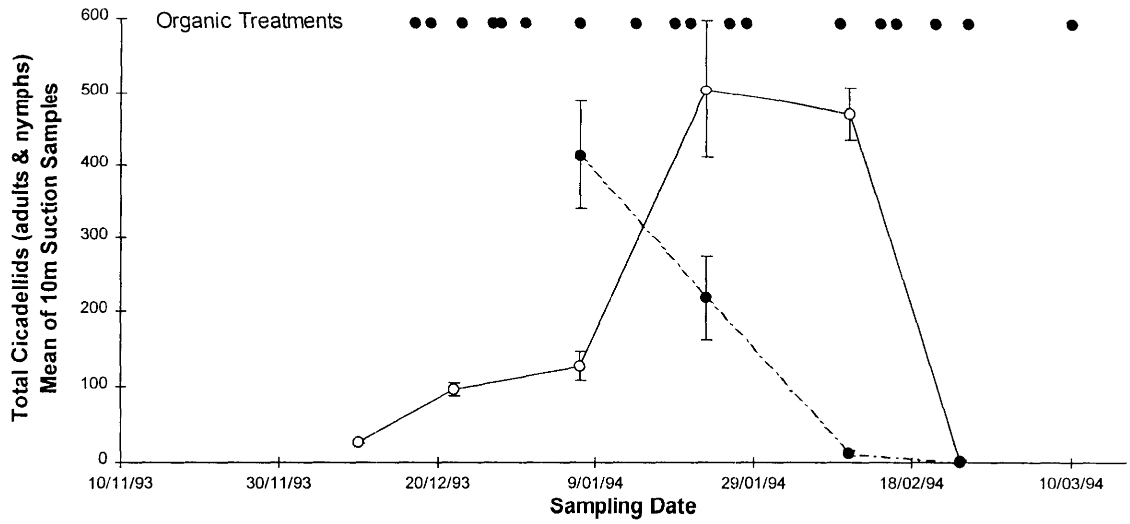

Figure 5.55 Total Cicadellids (adults & nymphs), 'Alcheringa' 1993/4: The abundance of total cicadellids recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (—o—) or organic treatments (--•--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

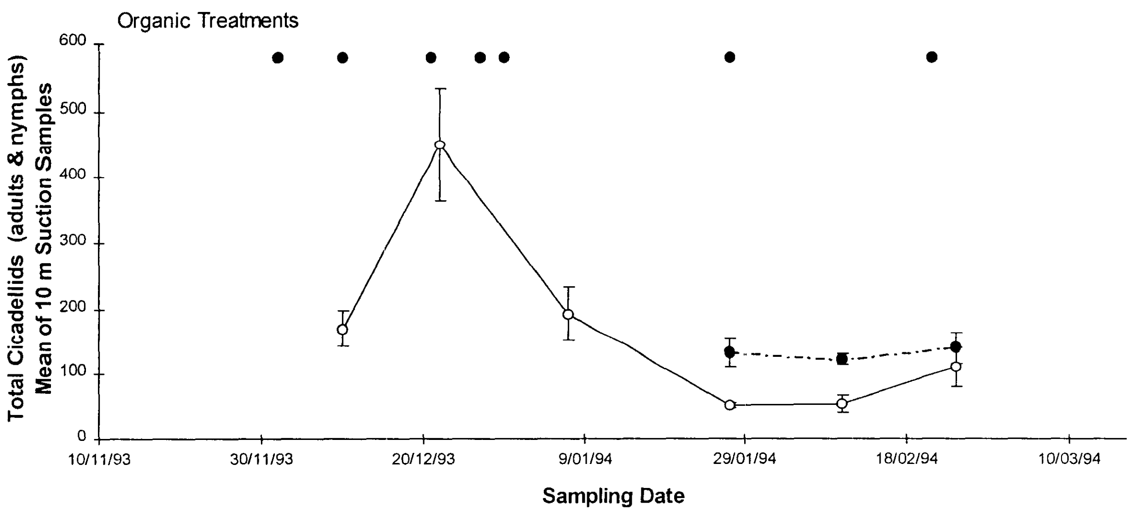

Figure 5.56 Total Cicadellids (adults & nymphs), 'Wilby' 1993/4: The abundance of total cicadellids recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (—o—) or organic treatments (--•--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

Endosulfan does not appear to have had a marked effect on *A. viridigrisea* or *O.argentatus* at 'Midkin' in either year (Figures 5.55 and 5.56). The soft option treatments of 'Midkin' in 1992/93 and the organic areas ('Wilby' and 'Alcheringa') surveyed in 1993/94, showed that these insects can remain abundant throughout the cotton growing season in the absence of insecticides.

Several other cicadellids and related insects were collected in relatively low numbers. These were included in a category of 'brown cicadellids' along with the *O. argentatus,* but they contributed a very small proportion of the counts in this category. These included , *Oliarus lubra* (Kirkaldy) (Cixiidae), *Phaconeura froggatti* (Kirkaldy) (Meenoplidae), *Batracomorphus angustatus* (Osborn) (Cicadellidae), *Balclutha rubrostriata* (Melichar) (Cicadellidae), *Zygina melanogaster* (Kirkaldy) (Cicadellidae). All are plant feeders and combined with the *A. viridigrisea* and *O. argentatus* are probably the most common prey for the generalist predators within these agricultural ecosystems.

5.5.2 Thysanoptera (thrips):

Thysanoptera appeared very early and steadily increased throughout the season at most sites (Figures 5.57 to 5.60). They were the most abundant arthropod early in the season and therefore provided the initial food source for the predator populations to build upon. All the 'Midkin' experiments used aldicarb (Temik®) added as a side dressing at sowing, and the early populations of thrips could be expected to be higher in the absence of this treatment. Nevertheless thrips were the most predominant arthropod prey at this time.

5.6 General Conclusions:

The insecticide treatments had a marked effect on the abundance of the predators, though different predator species had different levels of susceptibility to different insecticides. The most obvious was the effect of synthetic pyrethroids between 20/1/93 and 15/2/93 at 'Midkin' where the conventionally treated field at 'Midkin' in 1992/3 remained virtually devoid of all species of arthropod including predators over this three week period. The effect

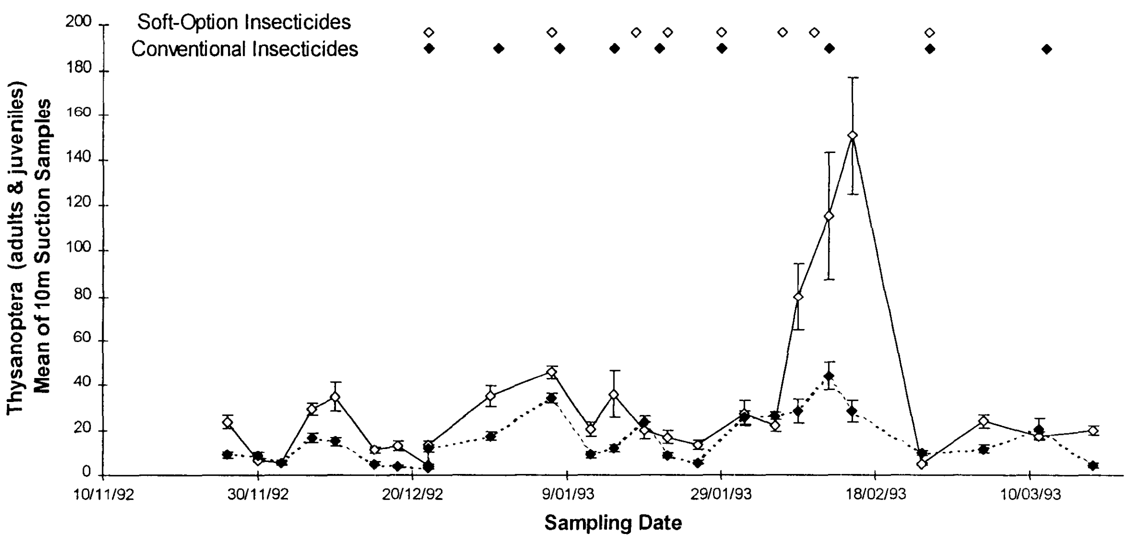

Figure 5.57 Thysanoptera (adults & nymphs) 'Midkin' 1992/3: The abundance of Thysanoptera recorded by 10 meter suction samples from cotton(Fields 1 and 2, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1992/3 cotton growing season. The timing of the insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.1. The error bars represent the standard error of the means (n=16). The **Elecvac** was used up to and including 22-12-92; the **Bigvac** was used from then on including 22-12-92.

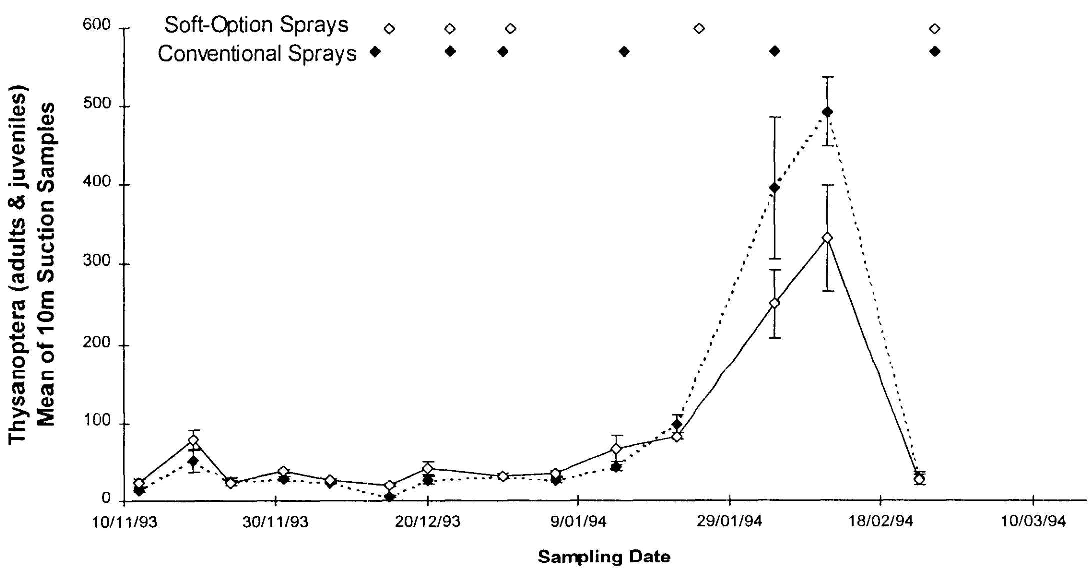

Figure 5.58 Thysanoptera (adults & nymphs), 'Midkin' 1993/4: The abundance of Thysanoptera recorded by 10 meter suction samples from cotton (Fields 3 and 4, refer to figure 5.1) treated with soft-option (—◇—) or conventional insecticides (--◆--) at 'Midkin' over the 1993/4 cotton growing season. The timing of insecticide treatments are shown above the chart; soft-option applications (◇) and conventional insecticide applications (◆). The details of the insecticide treatments are in Table 5.2. The error bars represent the standard error of the means (n=8). The **Macvac** was used up to and including 19-11-93 the **Bigvac** was used from 24-11-93 onwards.

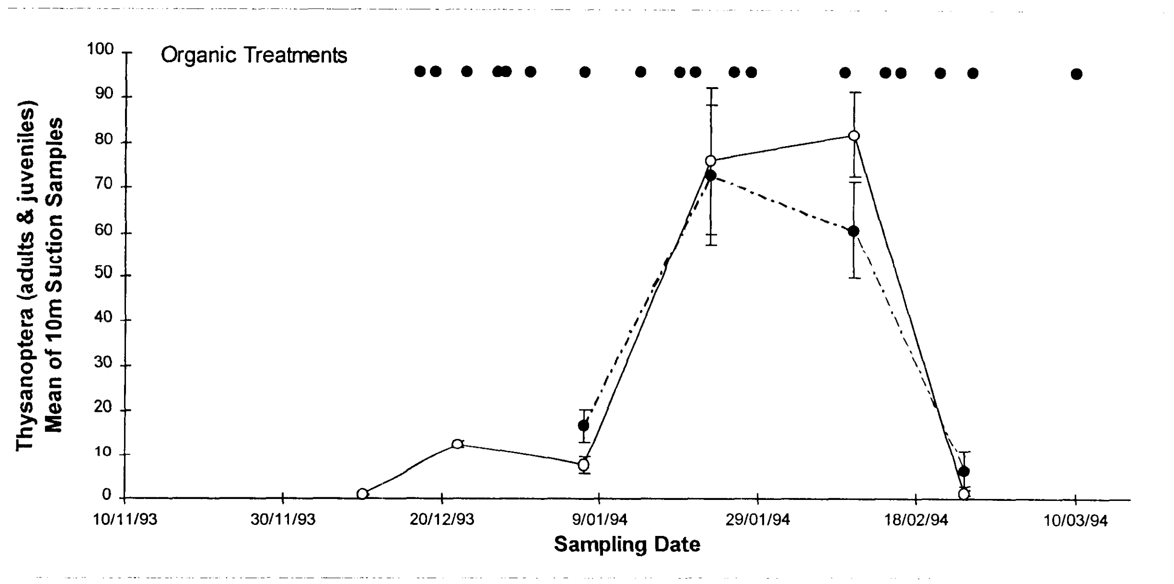

Figure 5.59 Thysanoptera (adults & nymphs), 'Alcheringa' 1993/4: The abundance of Thysanoptera recorded by **Bigvac** 10 meter suction samples from cotton (Field 5, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Alcheringa' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the treatments are in Table 5.3. The error bars represent the standard error of the means (n=4).

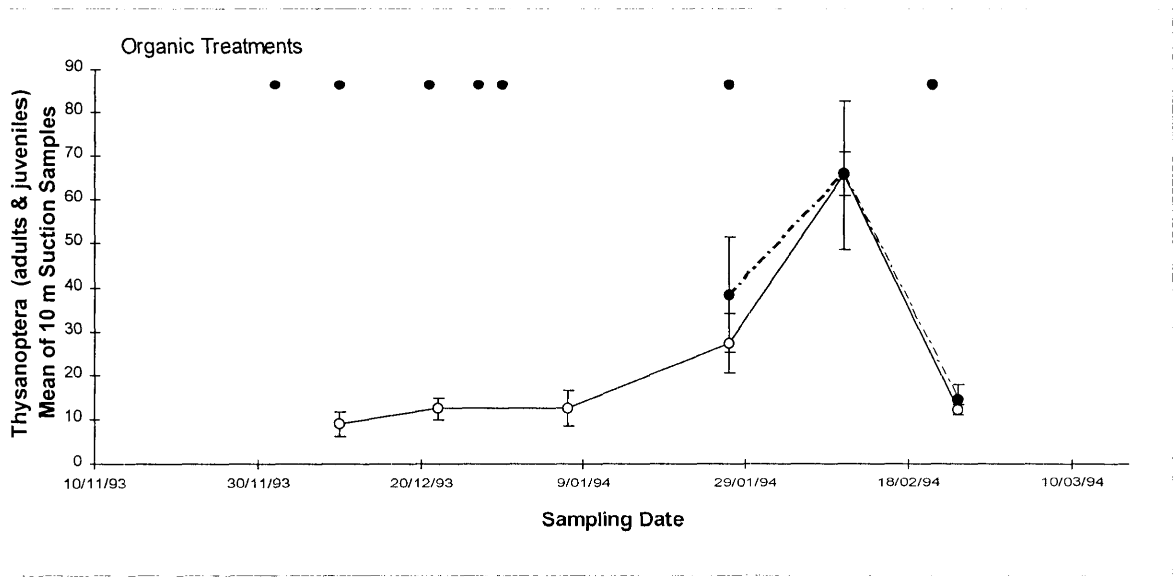

Figure 5.60 Thysanoptera (adults & nymphs), 'Wilby' 1993/4: The abundance of Thysanoptera recorded by **Bigvac** 10 meter suction samples from cotton (Field 6, refer to figure 5.1) treated with no insecticides (-O-) or organic treatments (--●--) at 'Wilby' over the 1993/4 cotton growing season. The timing of organic treatments are shown above the chart (•). The details of the insecticide treatments are in Table 5.4. The error bars are the standard error of the mean (n=4).

was not so pronounced in the following year at 'Midkin' (1993/4) probably because fewer insecticide treatments were used.

The effect of the other insecticide treatments was variable. Endosulfan did not appear to greatly affect the abundance of predators compared with the 'softer-options' used at 'Midkin' in 1992/93. The "soft-option" alternative in this case was a thiodicarb/ Bt mixture, but thiodicarb appeared to have a similar overall affect on predator abundance to endosulfan, and was clearly harder on some predators, for example *D. bellulus* and *N. kinbergii*.

A reduction of predator abundance occurred in the soft-option field over the same period synthetic pyrethroids were being used in the conventional field. This might be interpreted as spray drift, but evidence against this is that many vulnerable (for example cicadellids, *Geocoris* spp.) insects remained at high levels in the soft-option field throughout this period. This suggests an indirect effect which might operate in two ways; i) in which the widespread use of broad spectrum insecticides leads to a regional depletion in predator source areas and/or ii) some predators travel far enough during their general patterns of movement to visit surrounding insecticide treated fields. An alternative hypothesis is that spray drift occurred, but at low levels, and predators and other non-target insects varied in their susceptibility to these low levels.

Hogg and Nordheim (1983) recorded visual counts of a similar guild of predatory arthropods in unsprayed cotton over two years in Oktibbeha County (Mississippi U.S.A). Their predator profiles increase rapidly over the first month from planting and continued to increase or were at least maintained for about two months. Survival of 4-6 instars *Helicoverpa* and *Heliothis* was negligible until the later half of both seasons. However predators were well represented (3-10 per meter) throughout this period. A similar picture is evident in Australia.

Three major observations are relevant to predator activities in this study:

a) Predator numbers decline markedly from the onset of regional insecticide use.
b) In unsprayed cotton the decline in predators does not occur until defoliation of the cotton.
c) There is a large proportion of prey which is not *Helicoverpa spp.*

High rates and regular use of highly effective insecticides, such as pyrethroids, clearly reduce insect abundance to very low levels. The use of so-called 'soft' insecticides also considerably reduces the levels of some predatory arthropods with subsequent possible outbreaks of phytophagous insects such as leafhoppers. Broadly speaking the untreated areas harboured between 5 to 10 times the number of predators in any of the treated areas, and retained them over a much longer period of the season.

Although the annual number of insecticide applications to cotton have decreased from about 20 to 12 over recent years, the impact of insecticides on a regional scale remains sufficient to considerably reduce predator populations. What the populations of these arthropods would reach in the absence of these chemicals is paramount to the potential of predators to assist with the control of *Helicoverpa* spp. Therefore the maximum impact of predators was unrealised in the present study. With the advent of transgenic cotton, expressing Bt toxin, becoming available in the near future, large areas of lightly sprayed crops are imminent. This will present an opportunity, which has been absent for nearly two decades, to a) observe the potential abundance of predators and, b) observe the impact of predators on *Heliocoverpa* spp. in trial plots of non-Bt plants, without the confounding influence of regional insecticide use.
