CHAPTER 1

INTRODUCTION TO

MANGOES, SPIDERS AND PESTICIDES

Spiders are potentially important biocontrollers of pests in tropical mango orchards. The role of spider communities and the effects of pesticides on them have not been documented for mango orchards. This study examines some of the ecological relationships between mango orchards, spiders and pesticides.

All commercial mango cultivars are from a single species *Mangifera indica*. The genus *Magnifera* contains 41 species that are distributed naturally from India and Sri Lanka to the Philippines and many produce edible fruits. The mango is a deep rooted, dome shaped, evergreen tree which grows to 40m in height (Whiley, 1984). It is a tropical crop that grows under a wide range of climatic conditions. However, its profitable cultivation is limited by temperature and precipitation patterns with optimum growth and productivity around 24^o to 27^{o}C. The mangoes can tolerate a wide range of moisture regimes, being quite drought tolerant as well as capable of withstanding heavy rainfall. However, productivity of the tree is related to rainfall distribution, with flowering and fruit set requiring a dry season. Mango trees will grow on a wide range of soils but prefer deep well-drained sands to loams (Whiley, 1984).

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The central Queensland coastal area offers a good growing environment for this crop. The main variety grown is 'Kensington Pride' with fruit maturing in mid summer (January). It has a low resistance to the fungal disease Anthracnose and moderate resistance to bacterial spot (Whiley, 1984). Both diseases are common in mangoes. Generally, several chemicals are used to control these diseases. Mancozeb and prochloraz are used to control Anthracnose, and copper oxychloride prevents bacterial spot. Mangoes are also susceptible to several pests. Cunningham (1989) named seven major pests of mangoes. These included Mango scale, Mango tipborer, Mango plant-hoppper, Fruit flies, Pink wax scale, Fruitspotting bug and Mango seed weevil. He also named eight minor pests including flower feeding caterpillar, Redbanded thrips, Leafminer, Fruitpiercing moth, coccid (various species), termite, Tea red spider mite and Mango bud mite. Of these pests only the mango seed weevil larvae, the females of the mango and pink wax scales, the leaf miner and Mango bud mite are not potential prey for spiders. The mango seed weevil larvae are isolated in the seeds of the plant while the leaf miner, and the bud mite attack the inner part of the leaf and therefore would not come in contract with spiders or their webs. The female scales are restricted to the leaf surface and where they wait for males to mate them while still attached to the leaf.

Several registered pesticides are recommended to control these pests. These pesticides come from several different chemical groups which include organophosphates - methidathion; dimethoate and chlorpyrifos; a carbamate - carbaryl; a chlorinated hydrocarbon - endosulfan; a diphenol - dicofol and petroleum oil. Table 1.1 summarises the main pesticides used in central Queensland mango orchards and their toxicity levels to humans and longevities in nature. Appendix 1 lists the location of each orchard used in this study and the intensity of pesticides used at each. Appendix 2A and 2B, gives the spray history of the various orchards sampled in this study.

Table 1.1: The most commonly used pesticides used in mango orchards in central Queensland mango orchards with the toxicity to humans and the longevity in nature.

Pesticide	Human Toxicity	Longevity in Nature*
Endosulphan	high	M
Dicofol	moderate	L
Dimethoate	moderate	L
Methidathion	high	M
Carbaryl	moderate	S
Petroleum oil	low	S

* L - long resiual > 3 months
M - moderate residual, 1-3 months
S - short residual, 1-4 weeks
Taken from: Table 3.2, Brown,J.F., Kerr,A, Morgan,F.D, Panbery,I.H. (1980) A course manual in plant protection, Australian Vice-Chancellor's committee, Melbourne.

One of the issues arising from growing mangoes is the high use of pesticides rather than alternate methods such as Integrated Pest Management (Cunningham, 1989). The following discussion highlights the broader context of the study. Pesticides have several side-effects, not only in the crop in which they are used; but also in the surrounding ecosystem where they have the potential to accumulate. Often pesticides do not stay in the immediate area in which they have been used. This may have implications for human health and insect resistance. Zabik and Seiber (1993) suggested that organophosphate pesticides from California's Central valley can be atmospherically transported to the Sierra Nevada Mountains. They found that pesticides were detected in air and wet deposit samples at 114m elevation at the base of the foot-hills and at 533m and 1920m elevations. Therefore, pesticides may have far reaching effects outside the environment in which they were originally used. Of further concern is that pesticides may have an adverse effect on beneficial insects and spiders.

Once in the environment, pesticides are able to accumulate in the bodies of organisms and concentrate up the food chain. This biomagnification of pesticides creates many side-effects. It appears that the use of endosulfan, a mango pesticide, has far reaching effects to higher order animals such as fish. It also has the potential to remain in aquatic ecosystems, accumulating in the sediments. In Australia, Sunderam, Cheng and Thompson (1992) found that native and introduced fish were sensitive to endosulfan at low concentrations. The European Carp, *Cyprinus carpia* was the most sensitive, with measured 96-h LC_{50} of 0.1 μg/L, whereas the native Eastern Rainbow fish, *Melanotaenia duboulayi* and Silver Perch, *Bidyunus bidyunus* were the least sensitive, with measured 96-h LC_{50} values of 2.4 μg/L. Peterson and Batley (1993) found endosulfan present in high concentrations in sediments in lagoons in cotton growing areas in New South Wales and Queensland. This study is concerned only with spiders but they are directly and indirectly exposed to the pesticides in orchards.

Another pesticide used in mango orchards, has been found to affect terrestrial ecosystems. The impact of dimethoate on the rhythms of three granivorous bird species was assessed by Brunet and Cyr (1992) in Canada. They found that birds treated with dimethoate had reduced mean daily activity levels. These effects have the potential to become critical. The food finding ability of these birds may decrease which would increase their vulnerability to predators reducing their chances of surviving and reproducing successfully (Brunet and Cyr 1992). The effects of accumulation of pesticides in higher order animals including humans is now of concern to many researchers. Clearly the use of some pesticides, particularly those which accumulate in the environment can create "off site" problems in surrounding ecosystems.

Pesticide use can also create unwanted side-effects within the agroecosystem in which it is being used. Pesticides can produce resistance in target pest species. This occurs when individuals are regularly exposed to sublethal doses. As a result of selection for resistance, the proportion of individuals in a population which are able to survive exposure to the chemical is increased (Banks *et al.,* 1983). Red scale *Aonidiella aurantii*, a pest of citrus in south-east Queensland has shown resistance to methidathion (Collins *et al.*. 1994). This has implications for the mango industry that is dependent upon methidathion for the control of mango scale, mango tip-borer, pink wax scale, mango seed weevil and leafminer (Cunningham 1989). Once resistance to a pesticide has established in insects, it seems that loss or dilution of resistance traits is very slow, even if that pesticide is withdrawn from use (Banks *et al.*, 1983).

Emergence of new pest species can also occur due to resistance (Banks *et al.*, 1983). Non-target species that do not normally cause economic damage may develop resistance to the pesticides and quickly reach pest status (Banks *et al.*, 1983). Many researchers are addressing the problems of resistance in target and non-target pest species. Alternating the use of different chemicals in crops can reduce the evolution of resistance to pesticides (Banks *et al.*, 1983). The timing of pesticide application such that it will have the least effect upon beneficial arthropods and the maximum effect upon the pest is also considered practice (Banks *et al.*, 1983).

Emphasis is being placed on the use of beneficial animals. This includes the naturally occurring enemies such as spiders (Riechert and Lockley, 1984) as well as biological control agents that are introduced specifically to control a particular pest (Barbosa and Peters, 1972). The use of pesticides must be integrated with the requirements of these predators and parasites. Unfortunately there is a paucity of data for many systems, particularly tropical orchard crops.

Many pesticides have a broad spectrum effect and have the potential to decrease the numbers of beneficial animals in crops (Banks *et al.*, 1983). These beneficial animals may include earthworms, pollinators (eg bees), predators (eg spiders) and parasites (eg wasps) (Banks *et al.*, 1983). Many predators and parasites show density-dependent relationships with their prey (Ricklef, 1990). The number of predators or parasites increases with the number of prey or host. Initially, the build-up of beneficial populations is slow. Once established however, these animals can exert significant control of the pest. Pesticide use may disrupt this relationship by removing the predator or parasite or delaying the increase in their populations. Uygun *et al.*. (1994) found that methidathion was harmful to *Dretmoceerus debachi* pupae, a parasitoid of *Parabemisia myricae* the Japanese bayberry whitefly. This is a pest in citrus orchards in countries in the Mediterranean and USA. Emphasis has been placed on this parasitoid to control *P. myricae* as chemical techniques were not entirely successful. These authors concluded that the use of methidathion should be discouraged. They suggested that it should only be used during the pupal stage of the parasitoid when it has some resistance to the pesticide and even then only if it is the only chemical that can be used. This type of approach favours the survival of the parasitoid allowing it to maintain its status as an effective pest control agent. This strategy also increases the effectiveness of the pesticide (for emergency use) and reduces the likelihood of methidathion resistance in pests.

An alternative to the use of pesticides is the use of biological control strategies. Often monophagous or specialist predators or parasitoids are introduced to control a particular pest species at a level when it produces only sub-economical injury to the crop (Van Driesche and Bellow, 1996). The following discussion highlights the fact that despite considerable research, there are many gaps in our knowledge, particularly with respect to complex tropical agroecosystems and the role of spiders.

Some authors such as Simberloff and Stiling (1996) and Howarth (1991), suggest that the introduction of non-indigenous species may have unwanted side effects. Little is known of these effects as post-release monitoring of these species is not performed in the majority of cases. Researchers are more concerned as to whether the controller has been effective rather than their side-effects in the environment (Simberloff and Stiling 1996). Howarth (1991) cited the introduction of three predatory land snails (*Gonaxis kibweziensis, G. quadrilateralis* and *Euglandina rosea*) into the Hawaiian Islands to control giant African snail *Achatina fulica. E. rosea* moved away from *Achatina*-infested areas and invaded native forests, where it has been strongly implicated in the extinction of several species of endemic tree snails. After the arrival of *E. rosea* the endemic Oahu tree snail *Achatinella nustelina* suffered a complete extinction. Howarth (1991) suggested that "Achatinellines" are poorly adapted to predation pressure and are unable to cope with *E. rosea.* Disease or unknown mortality factors may also have been important, but the final blow was *E. rosea.* Howarth (1991) pointed out that the effects of alien species can be complex and difficult to predict. This is an important reason for examining the use of naturally occurring predators. If they are already present in the environment they are less likely to have an adverse effect on other species in the system. Their use as controllers may be easily incorporated into an Integrated Pest Management (IPM) program.

A heavy emphasis has been placed on naturally occurring predators and parasitoids in some IPM programs. The aim of IPM programs is to 'manage' pest populations rather than to eradicate them, thereby ensuring as little disruption to the local agroecosystem and the regional ecosystem as possible. In IPM, pesticides are used only when absolutely necessary to maintain crop damage at an economically tolerable level (Banks *et al.,* 1983). IPM aims to maximise natural control of pest populations, studies of natural enemies and alternative hosts and their relationships with the pest are a prerequisite (Banks *et al.,* 1983). However, Zalom and Merriman (1998) suggested that many IPM tactics, while reducing chemical use, are still chemically intensive. Therefore, further studies into the effectiveness of naturally occurring predators as pest control agents and the effects of pesticides on natural predators, are warranted in Australia.

To date, monitoring of pests in mango orchards has mainly occurred in northern Queensland (Kernot *et al.*. 1994). However, little monitoring has been done in the central Queensland area. The naturally occurring predators that occur in Australian mango orchards have not been studied. The only tropical orchard crop that has had a significant integrated approach has been citrus in south-east and central Queensland (Green 1996A; Papacek and Smith 1998). One naturally occurring predator group in mangoes is spiders. The only significant work on spiders in mangoes was by Sadana and Kumari (1991) who investigated the predatory potential of adult and the six instar stages of the Lyssomanid spider *Lyssomanes sikkimensis* on the mango hopper, *Idioscous clypealis.* They found that the predatory activity increased with the advancement of the age of spiderlings. This suggests that spiders may be important naturally occurring biocontrollers and may play a role in control of mango pests.

Spiders are predators in many terrestrial ecosystems. They are considered polyphagous, but feed almost exclusively on insects (Riechert and Lockley, 1984). Little attention has been paid to their natural predatory behaviour in agroecosystems, especially in Australia. There have been three papers on the predatory behaviour of spider in Australian agroecosystems. MacLellan (1973) found that spiders were natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. Bishop A.L. (1979) investigated the role of spiders as predators in a cotton ecosystem and Bishop and Blood (1981) investigated the interactions between natural populations of spiders and pests in cotton and their importance to cotton production in south-eastern Queensland. Table 1.2 summarises the research performed on predatory spider behaviour in crops in other countries.

Studies have shown that spiders do occur in agroecosystems. Young and Lockley (1985) summarised the agroecosystems the Striped Lynx spider *Oxopes salticus* were found in. They included cotton, soybean, grain sorghum, alfalfa, rice fields guar and apple trees. Mason (1992) found that spiders frequently outnumbered all other arthropods on the foliage of Douglas-fir and True Firs in the Cascade Range and Blue Mountains in Oregon and Washington. He suggested that low-density

Table 1.2: A summary of the research performed on predatory spider behaviour in crops in each country.

Crop	Title	Author	Country research performed
Soybean	Spider Predation on Velvetbean Caterpillar moths (Lepidoptera, Noctuidae) in a soybean field	Gregory B.M.Jr and Barfield C.S. (1989)	Florida, USA
Forest Floor	Significance of spider predation in the energy dynamics of forest-floor arthropod communities	Moulder B.C. and Reichle D. E. (1972)	Tennessee, USA
Cotton and Woolly Croton	Predation by Green Lynx Spider, *Peucetia viridans* (Araneae: Oxyopidae), Inhabiting Cotton and Woolly Croton Plants in East Texas,	Nyffeler M., Dean D.A. and Sterling W.L (1987)	Texas, USA
Citrus	The spiders of a citrus grove in Israel and their role as biocontrol agents of *Ceroplastes floridensis* (Homoptera: Coccidae)	Mansour F. and Witecomb W.H. (1986)	Israel
White Fir	Predation on Douglas-fir Tussock moth (Lepidoptera: Lymantriidae) and White Fir Sawfly (Hymenoptera: Diprionidae) larvae by captive spiders from White Fir in California	Swezey S.L., Dahlsten D.L., Schlinger E.I. and Tait S.M. (1991)	California, USA
Cotton	Interactions between natural populations of spiders and pests in Cotton and their importance to cotton production in Southeastern Queensland	Bishop A.L. and Blood P.R.B. (1981)	Queensland, Australia
Citrus	Mode of hunting and functional response of the spider *Marpissa tigrina* Tikader (Salticidae: Arachnida) to the density of its prey, *Diaphorinacitri*	Sadana G.L. (1991)	India
Alfalfa	Spider populations in Alfalfa, with Notes on spider prey and effect of harvest	Howell J.O. and Pienkowske R.I. (1971)	Virginia, USA
Cotton	Spiders in Queensland Cotton	Bishop A.L. (1980)	Queensland, Australia
Coconut	Observations on spiders (Order: Araneae) predacious on the coconut leaf eating caterpillar *Opisina arenosella* wlk. (*Nephantis serinopa* Meyrick) in Kerala: feeding potential	Sathiamma B., Jayapal S.P. and Pillai G. B. (1987)	India
Cranberry	Effectiveness of larval defenses against spider predation in Cranberry ecosystems	Bardwell C.J. and Averill A.L. (1996)	Massachusetts, USA

populations of important pests such as the Western Budworm and Douglas-fir Tussock moth were under considerable pressure from spider predation, especially when small larvae were feeding in early summer.

Mansour (1987B) determined the mean number of spiders per week per meter of cotton row to be 9.1 in unsprayed cotton fields in Israel. He found that spiders were important in suppressing pest populations and in delaying pest outbreaks early in the cotton growing season. Therefore, early pesticide applications to cotton fields were unnecessary. He also found that spiders suppressed larvae of the Egyptian Cotton Leaf Worm, *Spodotera littoralis,* thereby reducing damage to cotton leaves. These studies suggest that spiders are present in at least some agroecosystems in sufficiently large numbers to exert some control on pest insects.

The generally accepted theory for an ideal biological controller is one that controls the species by maintaining a density-dependant relationship with prey. There are two ways in which a predator or parasite can produce a density-dependent relationship, these can be categorised as either functional or numerical. A functional response occurs when the feeding and hunting behaviour of the predator changes in response to prey density. Thus when the prey species increases the predator changes its behaviour in order to devour a greater number of the prey species. A numerical response occurs when the number of predators increases either by aggregation or reproduction in response to an increase in prey density (Riechert and Lockley, 1984).

As spiders are generalist predators, they do not fit the 'classical' biological control model where monophagous species are preferred (Riechert and Lockley, 1984). Riechert and Luczak (1982) suggest that spiders rarely show specificity towards prey; however, Mansour, (1987B) who investigated spiders in cotton fields in Israel described a density-dependent tracking phenomenon. He suggested that the spiders were attracted to the pest population outbreak early in the season, and immediately afterwards the pests became suppressed, mainly due to spider predation. The spider density appeared to continue to track the prey population. Although the use of insecticide sprays may have biased the results, it does suggest that a community of spiders may show a numerical response to the increase of a particular pest species.

Mansour *et al.*. (1980) performed laboratory experiments that indicated a functional response in the spider *Chiracanthium mildei* to a lepidopteran larval prey *Spodoptera littoralis*. These spiders were fed 10, 50, 100, 150, 200, 250 and 300 larvae. As the density of prey increased, the number of prey consumed increased markedly. Only one replicate of this experiment was performed; however, the results suggest that *C. mildei* response was functional. One of the problems with laboratory studies is that they may not represent the activity of the spider in the field. Therefore, further investigations under field conditions are required to assess the true effectiveness of one particular spider species to control a pest.

Several studies have investigated spider communities in agriculture (Costello and Daane, 1995; Agnew and Smith, 1989; Topping and Lovei, 1997; Rypstra and Carter, 1995; Mansour and Whitecomb 1986; Howell and Pienkowski, 1971, Dippenaar-Schoesman, 1979) and in forests (Abraham, 1983; Mason, 1992; Jenning *et al.*, 1990; Renault and Miller, 1972; Docherty and Leather, 1987; Niemela *et al.*, 1994).

It would appear that agricultural ecosystems offer niches for spider asemblages. In these types of agroecosystems 1-4 species of spider were most common ie 4 species in alfalfa (Howell and Pienkowski, 1971), 3 species in peanut (Agnew and Smith, 1989), 3 species in grapes agriculture (Costello and Daane, 1995), 2 species in citrus (Mansour and Whitecomb 1986) and 1 species in strawberry (Dippenaar-Schoesman, 1979). The species found in these crops and orchards came from different families however each study found 14 families (Costello and Daane, 1995; Howell and Pienkowski, 1971; Dippenaar-Schoesman, 1979). Fourteen families were found in Douglas-fir (Mason, 1992) and only 11 families in *Aries blasamea* and *Picea rubens* (Jenning, *et al.* 1992). Both agricultural ecosystems and soft-wood forests appear to offer habitat for a large number of spider families.

If a large number of families exist in these agroecosystems then a large range of capturing techniques should be offered. The use of guilds has helped to examine the types of capturing techniques available. In crops such as grapes and peanuts, hunting spiders were the most common spiders found. Costello and Daane (1995) in four of the vineyards investigated found that hunting spiders dominated the fauna representing an average of 79.7% of the specimens collected. In the other three vineyards, hunting and web-weaving spiders were more equal represented with average 43.5 and 50.0% respectively, of all spiders collected. In Agnew and Smith's (1989) study in three peanut fields they found that hunting species made up 85.8% and 91.7% of the spider fauna during 1981 and 1982 respectively, the remainder were web-builders. Mason (1992) found that over half of all individuals were hunting spiders of the families Salticidae and Philodromidae. The rest were web-spinners, mostly of the families Dictyidae, Araneidae, Linyphiidae and Theridiidae. The relative abundance of families had a consistent statistical pattern in which their frequencies were apportioned according to a Northwest fir stands have a similar familial structure, probably determined by the branch and foliage characteristics of their habitat. Jenning *et al.* (1990) found species of web spinners were more prevalent (68.2% of total species) among branch samples (N=613 branches) than species of hunters (31.8%). Rypstra & Carter (1995) documented the web-spider community in a soybean agroecosystem over the entire growing season in 1990 and 1991 and over the period of peak spider abundance in August of 1993. Web-spider abundance was higher in 1991 than in 1990 or 1993 and lower in 1993 than the other two years. The composition of the community in terms of web-types also differed among years with sheet web (Linyphiidae, Agelenidae) being much more abundant in 1991 and orb webs (Araneidae) more abundant in 1990. Rypstra and Carter (1995) investigated web spiders and their web-types placing Linyphiidae and Agelenidae in sheet weavers and Araneidae in web weavers. They found that spider abundance correlated with specific vegetation characteristics.

The spiders in a Queensland cotton ecosystem have been shown to form a complex which was continuously present and which exhibited a wide range of ecological characteristics (Bishop, 1979). This facilitated an immediate response to possible pest insect problems during each phenological stage of cotton crop development. Bishop (1979) suggested that spiders may act to reduce or delay pest effects prior to the activity by more effective insect predators, many of which do not have the same immediate synchrony as prey but have a lag phase that does not allow them to immediately predate on the prey. Therefore, spiders as an assemblage of predators may be very beneficial in agroecosystems.

It could be argued that there are advantages in maximising (or at least conserving) the diversity of spiders in agroecosystems. While, spiders are generalists predators, they use a variety of prey-capture techniques and can be quite specialised (Marc and Canard, 1997). A diversity of species with many foraging tactics maximises the numbers of encounters that spiders have with potential prey. This may increase the effectiveness of spider communities as controllers of insect pests, (Riechert and Lockley 1984).

Niche segregation and prey specialisation has been documented in a few cases. Olive (1980) found that foraging specialisation occurred in orb-weaving spiders. *Araneus* and *Argiope*, two genera found in the family Araneididae, predate on different types of prey due to their physical characteristics and the type of web that they use. He found that *Araneus* which had short, stout, legs, large fangs and high, simple, open-meshed webs specialise on 'innocuous', rapidly escaping prey types such as Diptera and Lepidoptera. *Argiope* with long legs, small fangs, and low, densely meshed, ornamented webs specialise on 'dangerous', slowly escaping insects such as Orthoptera, Homoptera and Hymenoptera. This study suggests that the physical differences in spiders and the types of webs they use may be useful when examining spider communities as biocontrollers.

Studies on the Green Lynx spider, *Peucetia viridans* and the Striped Lynx, *Oxyopes salticus* found that their combined predatory activities were complementary. The striped lynx fed on small prey (2.41 +/- 0.17 mm average prey length), while the green lynx killed medium and large sized prey (7.04 +/- 0.73 mm average prey length) (Nyffeler *et al.*. 1992). While this may be the result of niche segregation, utilisation of different sized prey is of practical importance in agriculture, as insect pest size can vary enormously. Examples are very small aphids, relative to some moths that are up to 3 cm in length.

The positioning of spiders in trees may also be important when considering this group as biocontrollers. Ender (1974) noted that vertical stratification occurred in immature *Argiope aurantia* and *Argiope trifasciata*. He suggested the coexistence of the two spider species may depend in part upon the usual occurrence of high mortality during the immature stages. Vertical stratification offers a variety of heights in which spiders can potentially prey upon pest insects.

In addition there are also nocturnal and diurnal specialists within spider communities. Herberstein and Elgar (1994) studied the differences between nocturnal and diurnal orb-weaving spiders in Australia. These spiders were similar in size, but had different temporal foraging patterns. *Nephila plumipes* was a diurnal feeder and spun a relatively permanent web. It captured mainly Hymenoptera that were abundant during the day. *Eriophora transmarina* foraged nocturnally. It spun a new web every night and dismantled it in the morning. This species captured mainly Lepidoptera that were abundant at night. The segregation of spiders into nocturnal or diurnal hunters allows them (as a group) to exert predatory influence at all times during the day.

The above studies suggest that many hunting techniques can be exhibited by an assemblage of spiders. The way in which foraging guilds are arranged in the assemblage will have much to do with the effect that spiders have on prey populations.

The habitat plays a role in determining the type of spiders present. Moring and Stewart (1994) found that members of a guild of cursorial spiders (*Pardosa* spp. and *Alopecosa* spp.) were spatially segregated among five discrete habitats. They ranged from a streamside cobble habitat extending laterally along a successional gradient to the leaf litter zone of a transition or climax high elevation riparian coniferous forest in Colorado. They found that males and females of all guild species differed in their distribution among habitats and over months of collection.

Sundberg and Gunnarsson (1994) examined the effect on spiders of different micro-habitats caused by needle loss in Spruce forests in Sweden. These authors removed on average 24.3% of the needles and found that the mean density of spiders was significantly lower on the needle-thinned branches (78%) than on the control branches. This was shown to be an effect of reduced density of large (length > = 2.5 mm) spiders, but not of small (1< = 2.5 mm) spiders. In this research the authors considered that 1) the needle-loss in itself, and 2) the interaction between needle density and bird predation may have caused this effect. However, they did not consider the possibility that there were less prey present due to the reduction of needles. However, Bishop and Riechert (1990) found that by adding mulch, and mulch and flowers to mixed vegetable plots, the spiders' density increased significantly and significantly lower insect damage occurred. Therefore, changes in micro-habitats can change the relative abundance of types of spiders. If spider assemblages are to be used as a source of natural predators then their habitat requirements have to be considered.

The use of pesticides in agroecosystems can reduce the number of spiders in these systems making them less effective as predators. There are a few well documented effects of pesticides on spiders. Mansour (1987B) determined the mean number of spiders per week per meter of cotton row was 9.1 in an unsprayed cotton field and 5.1-5.6 in a sprayed field in Israel.

Mansour (1987A) tested the susceptibility of *Chiracanthium mildei* to 17 pesticides. He found that when grapefruit leaves were dipped for five seconds in aqueous emulsions of chlorpyrifos, fenpropathrin, fenvalerate, phosphamidon and biphenate there was 100% mortality of spiders within one hour, and cypermethrin and that similar treatment with fluvalinate 60% mortality. Acaricides, fungicides and herbicides caused about 10-40% mortality. In another study by Mansour *et al.* (1981) found that *C. mildei* was suppressed by endosulfan after contact with the pesticide for 48 hours. While, these results were not replicated, they do suggest that chlorpyrifos and endosulfan, which are recommended for use in mango orchards, did have a high mortality rate on *C. mildei*.

Mansour (1987A) also treated a grapefruit orchard with formothion and carbaryl. After 55 days on 10 randomly selected branches, the sprayed trees had a total of 11 spiders, while the unsprayed trees had a total of 232 spiders. In another study, a general population of apple spiders was sprayed with methidathion and was found to be suppressed by this pesticide (Mansour *et al.*, 1981). Carbaryl and methidathion are both recommended for use in mangoes and are both probably lethal for most spiders.

Samu *et al.*. (1992) found that orb webs actually collect pesticides. Orb webs exposed to agricultural sprays collected small droplets of the pesticide. These webs were found to collect one order of magnitude more of the spray than paper strips. Samu and Vollrath (1992) found that pyrethroid insecticide suppressed the web-building frequency and severely affected the web size and building accuracy of *Araneus diadematus*. They suggested that spiders could be used as bioassays for pesticide side-effects, as other spiders would show similar effects as *Araneus diadematus*.

From the foregoing discussion it is evident that while spiders represent potential biocontrollers of pests in agroecosystem little has been done to research their actual role. There are relatively few studies of the diversity of spiders in orchards and even fewer studies on the ecological factors affecting the spiders. If spiders are to be used as biocontroller then the effects of the pesticides must be taken into account. An effective IPM program should utilise all the possible natural predators and encourage their establishment in the orchards. The use of certain pesticides will almost certainly be detrimental to spiders but the extent of this impact needs to be explored further.

This study aimed to establish the ecology of spiders present within mango orchards in central Queensland. The diversity and richness of species in unsprayed orchards was investigated to assess the types of capturing techniques used by this assemblage of predators. Further, the activity of the spiders over a 24 hour period was monitored to gain an understanding of the types and amount of insects utilised by the spider community. This study gives an indication of their potential as pest controllers. Comparisons were made between sprayed and unsprayed orchards to gain an understanding of the long and short-term effects pesticides have on the spider communities of mango orchards.

CHAPTER 2

SPIDER COMMUNITIES

IN CENTRAL QUEENSLAND MANGO ORCHARDS

2.1 INTRODUCTION

Very little is known of the spider communities or their possible pest control attributes in agroecosystems. Spider populations were investigated in apples (Specht and Dondale, 1960), alfalfa (Howell and Penhowski, 1971), Douglas-fir and True Fir (Mason, 1992) and peanuts (Agnew and Smith, 1989). Spider communites were studied in strawberries (Dipenaar-Schoeman, 1979), fir-spruce (Renault and Miller, 1972), grape vineyards (Costello and Daane, 1995) and carrots (Sivasubramaniam and Wratten, 1997). In Australia only Green (1996A) in citrus, Bishop (1980) in cotton and Dondale (1966) in apples have investigated spider communities in crops. Much of the overseas research has focused on individual species such as the Striped Lynx spider *Oxyopes salticus* (Young and Lockley 1985) which are numerically dominant in agroecosystems in the USA. Randall (1982) recorded the prey of the Green Lynx spider *Peucetia viridans*. These studies investigate the predatory role of these spiders and disregard the overall potential of assemblages or communities of spiders as predators. Riechert and Lawrence (1997) found that regardless of such potential interference effects, they found that the spider assemblage did approximately two times as well in limiting prey than did any given predatory species by itself.

Little is known of spider communities in mango orchards. As tree crops should provide stable habitats for spiders as the only major disturbances experienced in these orchards occur while the fruit is being picked or if the orchard is sprayed with pesticide. Gibson *et al.* (1992) found that as architectural diversity of the plants increased with relaxation of grazing pressure from sheep, a variety of spider species colonised the area. Larger web-spinning species were found to be the most sensitive to grazing pressure. This suggests that physical disturbance such as cattle moving through pasture and fruit picking machines moving through mango orchards, may change the structure of the community.

To understand the effects disturbances such as pesticides have on spiders in orchards, base line measurements are required in non-effected orchards. A comparison of sprayed and unsprayed orchards will give an understanding of the extent of variation between these two types of orchards. Basic characteristics such as species composition, number of spiders present, species richness, diversity and guild structure describe the structure of the spider community. Many spiders have been found to be seasonal such as those of boreal forest floor (Niemela *et al.*. 1994). They found that the overall abundance and species richness was highest in the early season, May and June. Seasonal spider catch was not correlated with temperature, but was negatively correlated with rainfall. In other studies such as in a big sage community in Utah (Hatley and MacMahon 1980) and in strawberry beds near Pretoria (Dippenaar-Schoeman 1979) spider communities have been shown to change in the number of species and species dominance with the seasons.

The guild structure of spider community expresses the types of capturing techniques used by spiders. By expressing the relative abundance of spiders within each guild an understanding of the dominant types of capturing techniques can lead to a broader understanding of the spider community. These capturing techniques assist in assessing the potential of spiders as predators of pest insects in agroecosystems. Turnbull (1973) reviewed prey selection and prey-attack strategies of web-building spider and strategies of hunting. He concluded that spiders have an enormous impact on insect populations. However, this does not necessarily imply that they are either regulative in the community or that they would be effective agents of biological control. Their ability as biocontrollers depends upon prey selection by spiders and their reaction to changes in density and structure of prey populations (Turnbull 1973).

This chapter describes a study to assess the abundance, species richness, species diversity and guild structure of the spider communities present in mango orchards. Seasonal variations of the community and the numerical dominant species were assessed. The following chapter (Chapter 3) will describe the actual impact of the spiders on insect prey.

2.2 MATERIALS AND METHODS

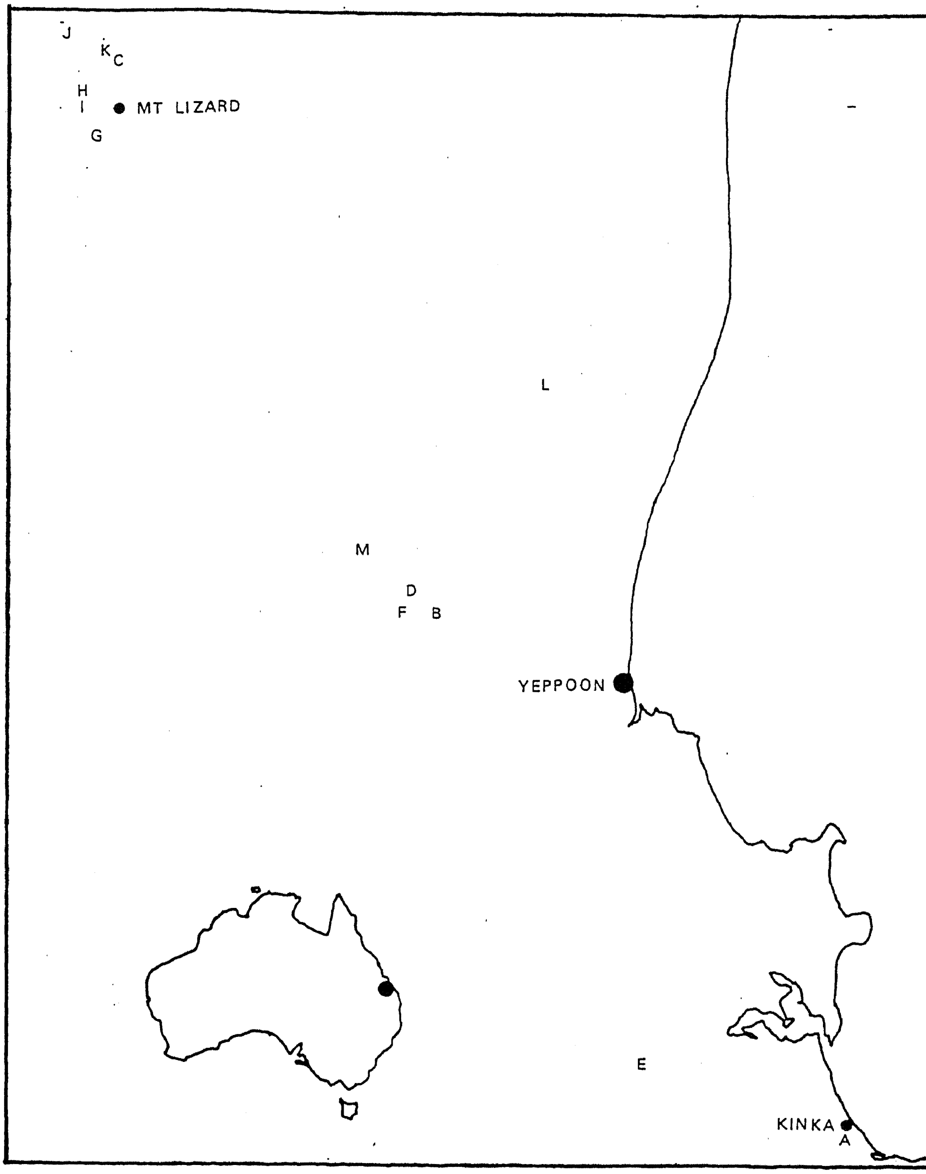
2.2.1 The mango orchards

The mango orchards used in these studies were relatively small, ranging in size from 50 to 200 trees. They were established orchards, with fruit bearing trees of at least three years of age, and were all located in coastal areas in central Queensland between Mt Lizard and Kinka. The map given in Figure 2.1 shows the location of the orchards studied and whether they were unsprayed or sprayed with pesticides. The sprayed orchards will be discussed in Chapter 4. The 'Kensington Pride' variety of mango was grown in all of the orchards studied. The three unsprayed orchards had no pesticide use for at least 2 years prior to the study (see Appendix 1 for site locations and the intensity of pesticides used at each orchard).

The climatic conditions during the sampling period were not typical due to drought-like conditions (see Table 2.1A). Both the maximum and minimum temperatures were above the average from 1993 to 1996. The actual rainfall was below normal for all three years (see Table 2.1A). Due to the low rainfall throughout the study, growers were forced to irrigate their crops. Irrigation reduces the water-stress experienced by the trees during fruit set but increased the costs of production (Whiley, 1984). Table 2.1B shows the temperature and rainfall from January to December, 1994.

2.2.2 Spider sampling

Initially, seven samples were taken over a twelve month period (October, November, December, March, May, August and October, 1993/1994). At each sampling time all the spiders were collected for 30 minutes from two randomly selected trees in each



A	Unsprayed	B	Unsprayed
C	Unsprayed	D	Frequently sprayed
E	Frequently sprayed	F	Frequently sprayed
G	Infrequently sprayed	H	Infrequently sprayed
I	Infrequently sprayed	J	Infrequently sprayed
K	Infrequently sprayed	L	Infrequently sprayed
M	Frequently sprayed		

Figure 2.1: Map of the central Queensland coastal area showing the locations of the unsprayed, frequently and infrequently sprayed orchard.

orchard. For the months of October, November and December, 1993 no distinction was made between immature and adult spiders. The total number of each was pooled to give a total number of spiders present in each orchard. After this initial three month period it appeared that there were changes in the ratio of adults to immature

Table 2.1A: Summary of the temperature and rainfall for the nearest weather station at Rockhampton, from 1992 to 1996.

Year	Temperature (°C)						Rainfall (mm)	
	High Max.	Max. Mean	Depart from norm	Low Min.	Min. Mean	Depart from norm	Actual (mm)	Normal (mm)
1992	39	28.6	0.4	3	16.8	0.4	489	833
1993	38	28.9	0.4	7	18.0	1.1	589.4	833
1994	39	28.8	0.7	2	16.2	0.2	518	833
1995	39	28.7	0.6	2	17.4	1.0	787	833
1996	40	28.8	0.6	3	17.0	0.6	733	833

Table 2.1B: Summary of the temperature and rainfall for the nearest weather station at Rockhampton, from January to December, 1994.

Months of 1996	Temperature (°C)						Rainfall (mm)	
	High Max.	Max. Mean	Depart from norm	Low Min.	Min. Mean	Depart from norm	Actual (mm)	Normal (mm)
January	42	34.2	2.5	20	22.8	0.8	42	148
February	34	30.7	-0.3	20	21.9	0	151	153
March	35	29.5	-0.7	14	19.5	-1.2	137	107
April	32	28.1	-0.5	8	16.7	-1.0	15	42
May	28	26.5	0.7	6	13.1	-0.9	18.	47
June	28	24.6	1.3	3	9.5	-1.1	2	36
July	27	23.7	0.8	4	9.5	0.3	12	32
August	29	24.7	0.1	2	10.3	-0.2	3	26
September	37	29.0	1.9	5	12.7	-0.6	2	23
October	38	30.5	1.0	10	17.4	0.6	27	48
November	39	32.7	1.6	15	20.1	0.7	38	67
December	38	31.7	-0.3	17	20.9	-0.1	71	108

spiders. So, the total number of adult and immature spiders was combined to give a total number of spiders per orchard. The total number of adults and immatures were monitored separately to assess any changes between the two. The collections of spiders were made around the lower, outer limbs and then under the canopy of the trees, while moving in an anti-clockwise direction. A ladder was used to gain access to the higher limbs to a height of 3m after the lower limbs were searched and the upper branches searched in the same way as the lower. This technique was used to standardise sampling methods as the trees in each orchard were not the same size, age or shape. The spiders collected were killed and stored in 70% ethanol, for later identification in the laboratory. The data from the two trees were pooled. After October, 1994, the spiders were collected each month from December, 1994 to January, 1996 (inclusive) using the same techniques as previously mentioned. By sampling monthly, a greater understanding of the seasonal variations in spider populations within these orchards could be obtained.

Wherever possible the spiders were identified to species or genus level. Individuals that were not identified (mainly immature spiders) were allocated a specimen number. Over the full sampling period many of these immature spiders were later identified to species, as it was possible to link instar stages, as time passed and the spiderlings developed into adults. Where possible, identifications were verified by comparison with specimens at the Queensland Museum, Brisbane.

2.2.3 Data analysis

The species composition of the orchards was established to obtain an overview of the types of spiders present in unsprayed mango orchards. The numerically dominant spider species were noted particularly as they were most likely to be the species with the greatest potential to control insect pests. The greater abundance of a species suggests greater efficiency of prey capture and adaption to the habitat at the sampling time.

The abundance of spiders and their species richness were determined for each orchard at each sampling time. Further, species diversity within each orchard was assessed by the Shannon-Wiener Diversity Index (Ricklef 1990) which was calculated by the 'Primer' v4.0 software (Carr). In all samples after December, 1993 the differences in number of adult and immature spiders were noted as there appeared to be significant differences in the numbers of adult and immature spiders. Each species was assigned to one of four guilds defined largely in terms of their prey capture strategies. Those individuals that required the use of an orb web for capturing prey were placed in the 'orb-weaving' guild. These spiders build orb webs that have frame threads that are attached to the substrate and which support the web. The radiating threads diverge from the centre of the web and the 'catching spiral' which is a thread that begins near the centre or 'hub' and spirals outwards to the outer edge of the web (Foelix, 1996). A glue substance is produced with the silk that ensnares insects that fly into the web. This guild included members of the Araneidae and Tetragnathidae. Within these two families there is considerable variation upon this general web structure. *Cytrophora* sp. built elaborate tent-like structures that are attached to the orb. This assists in the capture of insects that easily escape single orb webs (Foelix, 1996). *Cyclosa* sp. built orb webs with leaf litter and debris attached to the central hub (Brunet, 1996). The spider sits at the centre and is able to lunge at prey from its camouflage. The broad variation in the prey capturing techniques of this group of spiders should assist in the capture of many different types of prey.

The spiders from Families Linyphiidae, Theridiidae and the Pisauridae were placed into the 'Tangle-weaving' guild. These spiders build untidy looking webs which are either sheet-like in appearance (Linyphiidae) or irregular meshes (Theridiidae) (Foelix 1996). The Pisauridae are normally associated with aquatic environments. In this case the immature *Dolomedes* sp. built webs at the end of the racems on the ends of the mango tree branches, and captured prey. Adult Pisauridae were not observed throughout the 21 month of sampling. It was assumed that these spiders move away from the orchards after maturity (Child, 1977). Both the tangle-weavers and the orb-weavers belong to the ecribellate group of spiders. These spiders do not have a cribellum and secrete glue with the web.

The 'Cribellate' guild consisted of members of the Uloboridae and the Amaurobiidae families. This group of spiders built both orb-webs and tangled-webs. The spiders build very sticky webs and spin them using a cribellum on their opisthosma. This assists them to position the silken threads. They also have calamistrum which are hook-like structures attached to their fourth legs. The calamistrum allow the spider to draw the silk from the spinnerets. The silken threads do not possess any gluey substance. The spiders add glue to the web regularly. This enables these webs to effectively capture prey for a longer duration than the ecribellate spiders' web (Foelix, 1996).

The 'Hunting' guild includes those spiders that either 'ambush predators' or actively seek out their prey. This group consisted of the Families Clubiondae, Heteropodiidae, Lycosidae, Oxyopidae, Salticidae, Thomisidae and Zodariidae. These do not build webs for capturing prey. The silk thread is used to secure the spider to the substrate, while physically grasping prey. It acts as a secure anchor if the spider looses its grip with the substrate. The silk is also used to build nests to protect the eggs and the developing. Some species live in shelters made from silk (Foelix, 1996).

2.3 RESULTS

2.3.1 Species composition of spiders

Table 2.2 summarises the total number and species of spiders in each family from October, 1993 to January, 1996. During the sampling period October, 1993 to January, 1996, 1721 individuals were collected from the foliage of unsprayed mango trees. There were twelve families collected from the foliage of unsprayed mango trees. These were Araneidae, Clubionidae, Desidae, Heteropididae, Oxyopidae, Pisauridae, Salticidae, Tetragnathidae, Theridiidae, Thomisidae, Uloboridae and Zodariidae. These results suggest a high diversity of the spiders present in these orchards. The most abundant species were found in the families Araneidae, Theridiidae and Desidae. The Araneidae had the highest number of individuals with 794 individual spiders compared to the Theridiidae with 484 individuals while there were 137 individuals of one species, *Badumna* sp. 56 belonging to the family Desidae. There were 16 spider species that had high number of individuals collected (defined as more than 20 individuals in total) from 5 families, Araneidae, Clubionidae, Desidae, Tetragnathidae, Theridiidae and Thomisidae. Of the total number of spiders collected the Araneidae constituted 44.5%, Clubionidae 2.5%, Desidae 8.0%, Heteropodidea, Oxyopidae and Pisuaridae 1.6%, Salticidae 4.5%, Tetragnathidae 5.8%, Theridiidae 28.1%, Thomisidae 4.0%, and Uloboridae and Zodariidae 1.1%.

Table 2.2: Summary of the number and species of spider (or specimen number) collected from three unsprayed mango orchards for 21 sampling periods from October, 1993 to January, 1996.

Spiders collected	No. of spiders	Spiders collected	No. of spiders
F. Araneidae		**F. Clubionidae**	
Araneus praesignis	66	*Cheiracanthium* sp.	8
Araneus sp. 9	11	*Clubiona sp.* 21	22
Araneus sp. 15	253	*Clubiona sp.* 27	3
Araneus sp. 104	4	*Clubiona sp.* 181	2
Araneus sp. 113	16	unidentified immature 83	1
Araneus sp. 129	16	unidentified immature 137	5
Araneus sp. 132	5	unidentified immature 162	2
Argiope aetherea	136	**Number of individuals**	**43**
Cyclosa camelodes	5	**Number of species**	**7**
Cyclosa sp. 59	3	**F. Desidae**	
Cyclosa sp. 131	23	*Badumna* sp. 56	137
Cyclosa sp. 173	12	**Number of individuals**	**137**
Cyclosa trilobata	4	**Number of species**	**1**
Cyrtophora exanthematica	58	**F. Heteropodidae**	
Cyrtophora hirta	67	*Olios* sp.	1
Eriophora sp	1	Unidentified immature 47	1
Gasteracanthus mimax	5	**Number of individuals**	**2**
Gasteracanthus sp. 26	5	**Number of species**	**2**
Gasteracanthus sp. 81	12	**F. Oxyopidae**	
Gasteracanthus sp. 176	2	*Oxyopes maculensis*	9
Nephila sp. 49	8	*Psuedohostus squamous*	1
Nephila sp. 75	6	Unidentified immature 98	2
Ordgarius sp.	1	**Number of individuals**	**12**
Poltys sp.	7	**Number of species**	**3**
Unidentified immature 93	4	**F. Pisauridae**	
Unidentified immature 114	19	*Dolomedes* sp.	13
Unidentified immature 131	23	**Number of individuals**	**13**
Unidentified immature 132	5	**Number of species**	**1**
Unidentified immature 152	5	**F. Salticidae**	
Unidentified immature 157	2	*Cosmophasis bitaeniata*	9
Unidentified immature 164	5	*Cytaea* sp. S18	20
Unidentified immature 175	1	*Cytaea* sp. S26	2
Unidentified immature 185	2	*Cytaea* sp. S37	1
Unidentified immature 192	1	*Helpis* sp.	1
Unidentified immature 193	1	*Mospsis* sp.	14
Number of individuals	**794**	*Opisthoncus* sp.	7
Number of species	**35**	*Tara* sp .	6

Table 2.2 (continued)

Spiders collected	No. of spiders	Spiders collected	No. of spiders
F. Salticidae (Contin.)		**F. Theridiidae (Contin.)**	
Unidentified immature S4	2	Unidentified immature 55	1
Unidentified immature S7	1	unidentified immature 112	3
Unidentified immature S20	2	unidentified immature 112b	11
Unidentified immature S22	1	unidentified immature 116	2
unidentified immature S27	1	unidentified immature 120	23
unidentified immature S28	4	unidentified immature 127	4
unidentified immature S30	1	unidentified immature 133	1
unidentified immature S33	2	unidentified immature 144	4
unidentified immature S39	1	unidentified immature 151	8
unidentified immature S41	1	unidentified immature 153	1
unidentified immature S42	1	unidentified immature 170	1
Number of individuals	**77**	**Number of individuals**	**484**
Number of species	**19**	**Number of species**	**19**
F. Tetragnathidae		**F. Thomisidae**	
Deliochus humulus	10	*Dianea sp.*	23
Leucage sp.	44	*Thomisus spectabilis*	11
Phonognatha sp	2	*Xysticus sp.*	10
unidentified immature 25	15	unidentified immature T12	2
unidentified immature 32	10	unidentified immature T14	4
unidentified immature 79	3	unidentified immature T16	9
unidentified immature 86	2	unidentified immature T18	8
unidentified immature 103	12	unidentified immature T21	1
unidentified immature 165	2	**Number of individuals**	**68**
Number of individuals	**100**	**Number of species**	**8**
Number of species	**9**	**F. Uloboridae**	
F. Theridiidae		*Philoponella* sp.	1
Archaearanea mundula	26	*Miagrammopes bradleyi*	14
Archaearanea sp. 50	87	**Number of individuals**	**15**
Argyrodes antipodiana	124	**Number of species**	**2**
Argyrodes rhobopheid	17	**F. Zodariidae**	
Euryopis sp.	1	unidentified immature 24	4
Unidentified immature 20a	150	**Number of individuals**	**4**
Unidentified immature 29b	17	**Number of species**	**1**
Unidentified immature 29c	3		

2.3.2 Fluctuations in spider abundance

The means of the total number of spiders (all species and ages) collected from the unsprayed orchards from October, 1993 to January, 1996 are plotted in Figure 2.2. For reasons that are not clear, unusually large numbers of spiders were collected in October 1994. However generally, spiders were present through-out the year and there are no obvious seasonal patterns. Correlation between rainfall and number of spiders for the sampling period was not significant at P = 0.263. Figure 2.3 shows the mean number of immature and Figure 2.4 shows the mean number of adults spiders collected at each sampling time from March, 1994 to January, 1996. Both adults and immatures appear to show some variation in numbers with no distinct seasonal trends.

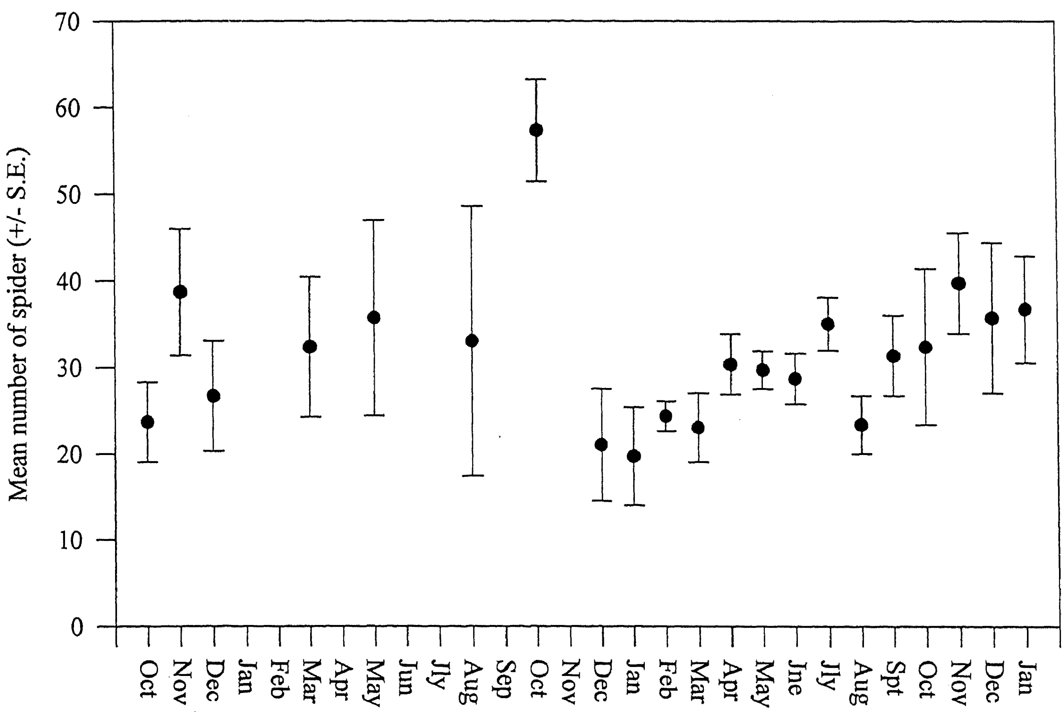


Figure 2.2: Mean number of spiders (+/- S.E.) collected in unsprayed orchards from October, 1993 to January, 1996 (n=3).

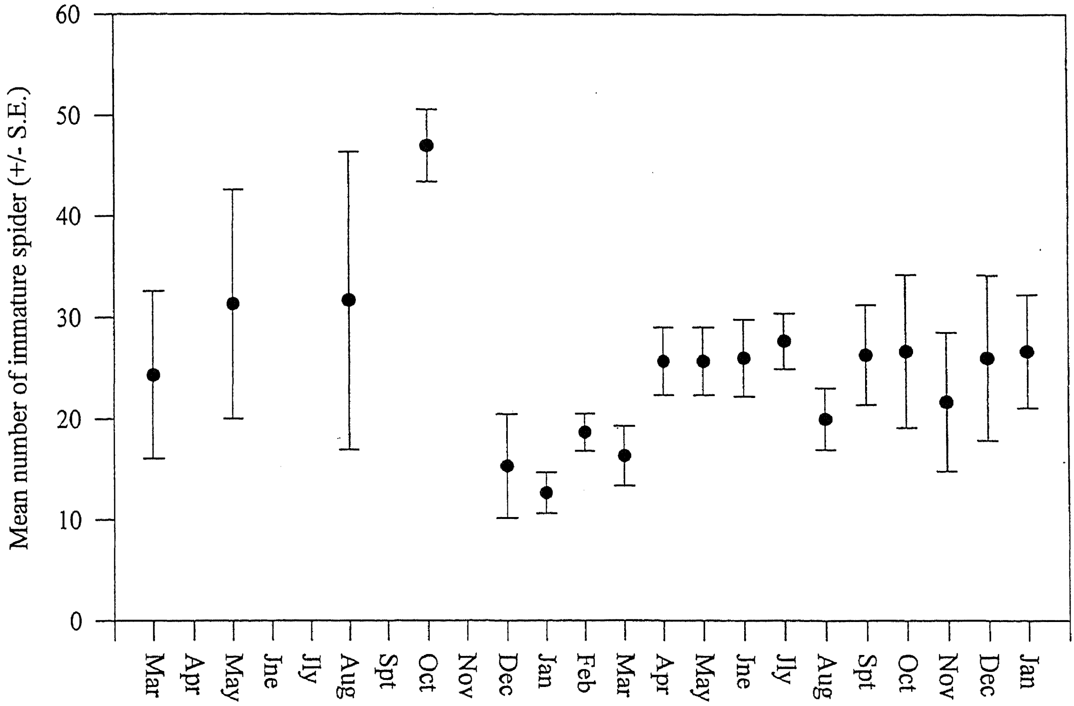


Figure 2.3: Mean number of immature spiders (+/- S.E.) collected in unsprayed mango orchards from March, 1994 to January, 1996 (n=3).

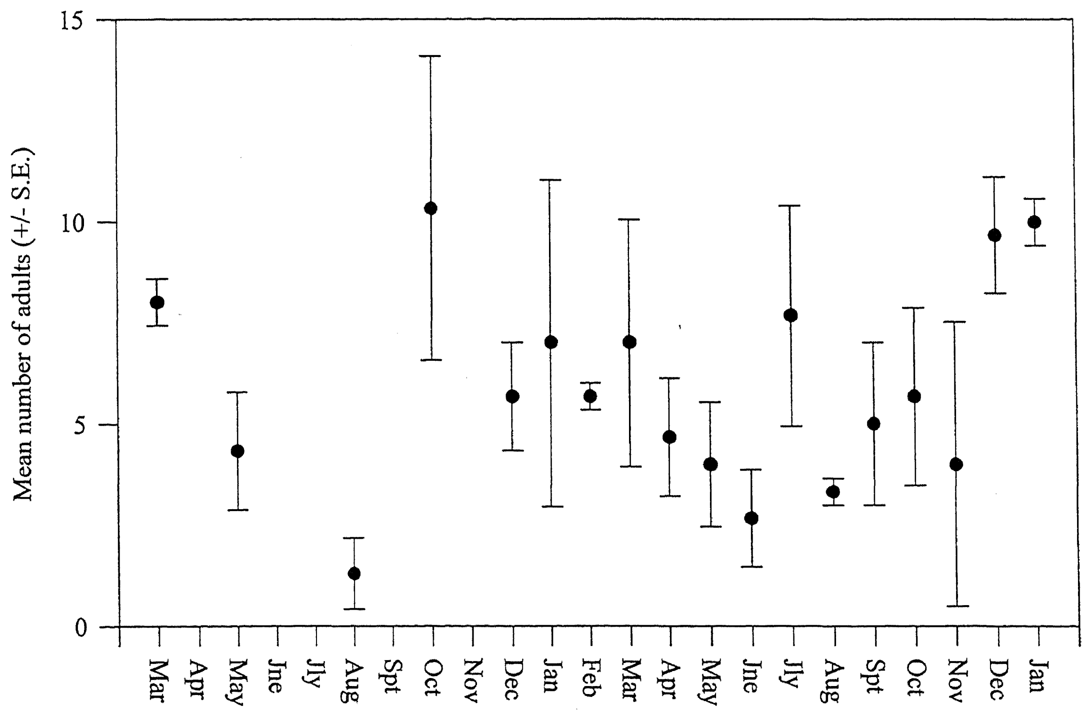


Figure 2.4: Mean number of adult spiders (+/- S.E.) collected in unsprayed orhards from March, 1994 to January, 1996 (n=3).

The numbers of both adult and immature spiders in the orchards peaked during October, 1994 with 69 adults and 429 immatures collected. The ratio of immature to adult spiders 6.2:1, is higher than the average of 4.2:1. This suggests that the conditions for October, 1994 were favourable for the emergence of immature spiders, and the survival of adults was high. Perhaps the below average rainfall for the previous 6 months followed by 27 mm in October (Table 2.1B), triggered emergence of large numbers of immature spiders. Additionally, the orchards may have offered a more suitable habitat than the surrounding habitats, causing adult spiders to move into the orchard. Although largely unexplained, the increased spider abundance in October, 1994 does suggest that spiders survive dry periods, which can only be a benefit to mango growers.

The abundance of the four most common species; *Araneus* sp. 15, *Argiope aethera, Badumna* sp. 56 and immature specimen. 20a, were compared in Figure 2.5. These four numerically dominant species did not show any seasonal changes in abundance which suggests that they are present within the orchards through-out the year.

In summary, spiders are present in orchards throughout the year and there are no obvious seasonal patterns with either adults or immatures or mean number of spiders. This suggests a dynamic equilibrium with more-or-less continuous recruitment to the orchard populations.

2.3.3 Species richness and diversity

The mean number of spider species collected at each sampling time was plotted in Figure 2.6. There does not appear to be any seasonal variations in the number of

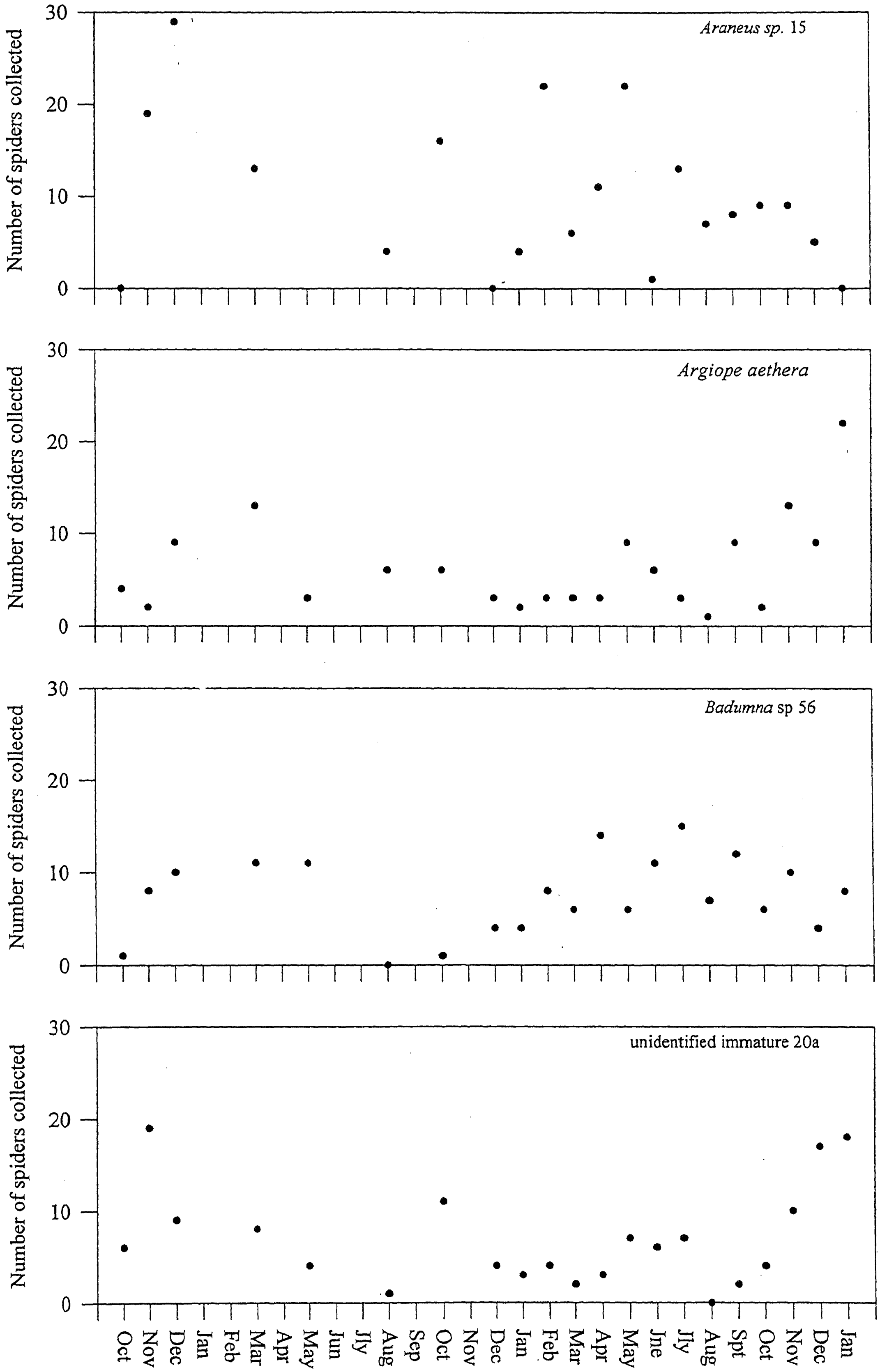


Figure 2.5: Number of *Araneus sp.* 15, *Argiope aetheria, Badumna sp.* 56 and *sp* 20a collected in the unsprayed mango orchards from October, 1993 to January, 1996 (n=3).

species present. However, the mean number of spiders is the greatest in October, 1994. Therefore, not only were the number of spiders high but the number of species of spider were high at this sampling period.

The mean values of the Shannon-Wiener diversity indices for each sampling periods are shown in Figure 2.7. The first three sampling periods (October, November, December, 1993), appeared to have a higher diversity than the remaining months sampled. Generally, there does not appear to be any seasonal patterns in these results. Shannon-Wiener Diversity Indices were calculated from Russell-Smith and Stork's (1995) data supplied in Appendix 1 (see Table 2.3). The diversity indices range from 2.917 to 3.708 which are higher results to my results (see Figure 2.7).

Table 2.3: Calculated Shannon-Wiener Diversity Indices from data taken from Appendix 1 in Russell-Smith And Stork (1995)

No. of Trees	Shannon-Wiener Diversity Indices	No. of Trees	Shannon-Wiener Diversity Indices
1	3.535	6	3.184
2	3.488	7	2.916
3	3.020	8	3.139
4	3.180	9	3.488
5	3.117	10	3.708

2.3.4 Guilds

The total number of spiders in each guild is plotted in Figures 2.8. The total number of individuals from each guild and each of the three unsprayed orchards were pooled and plotted for the 23 sampling periods (October, 1993 to January, 1996). The orb-weaving spiders were the most abundant guild found in the foliage of unsprayed mango trees. They appear to have been present through-out the year in high numbers.

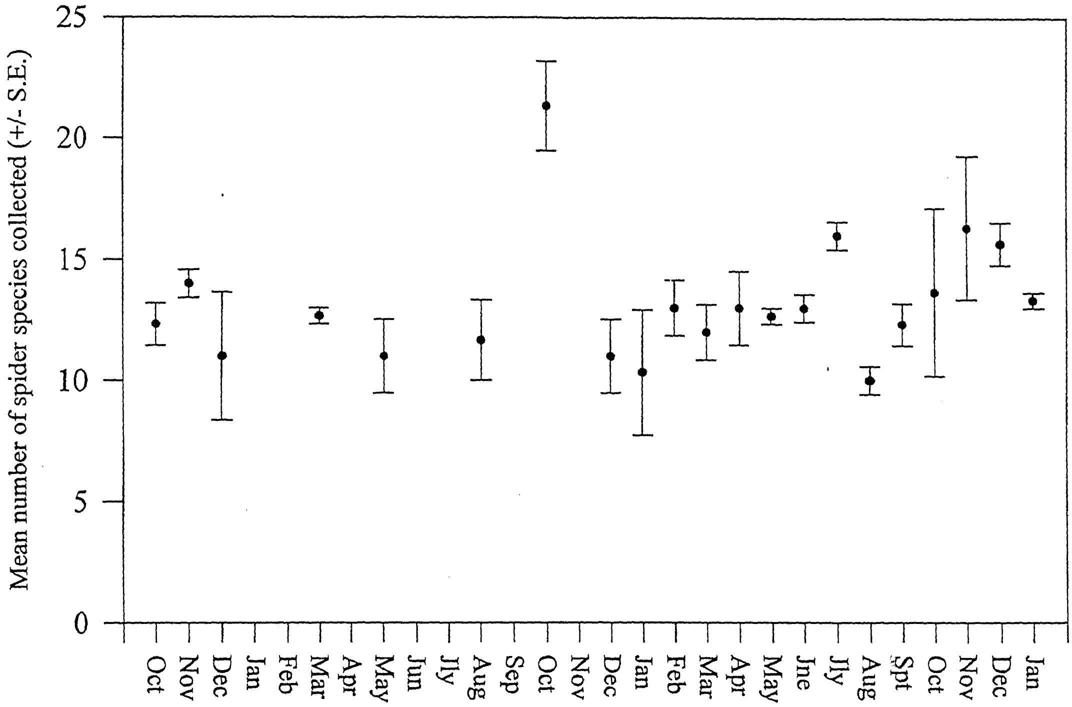


Figure 2.6: Mean number of spider species (+/- S.E.) collected in unsprayed mango orchards from October, 1993 to January, 1996 (n=3).

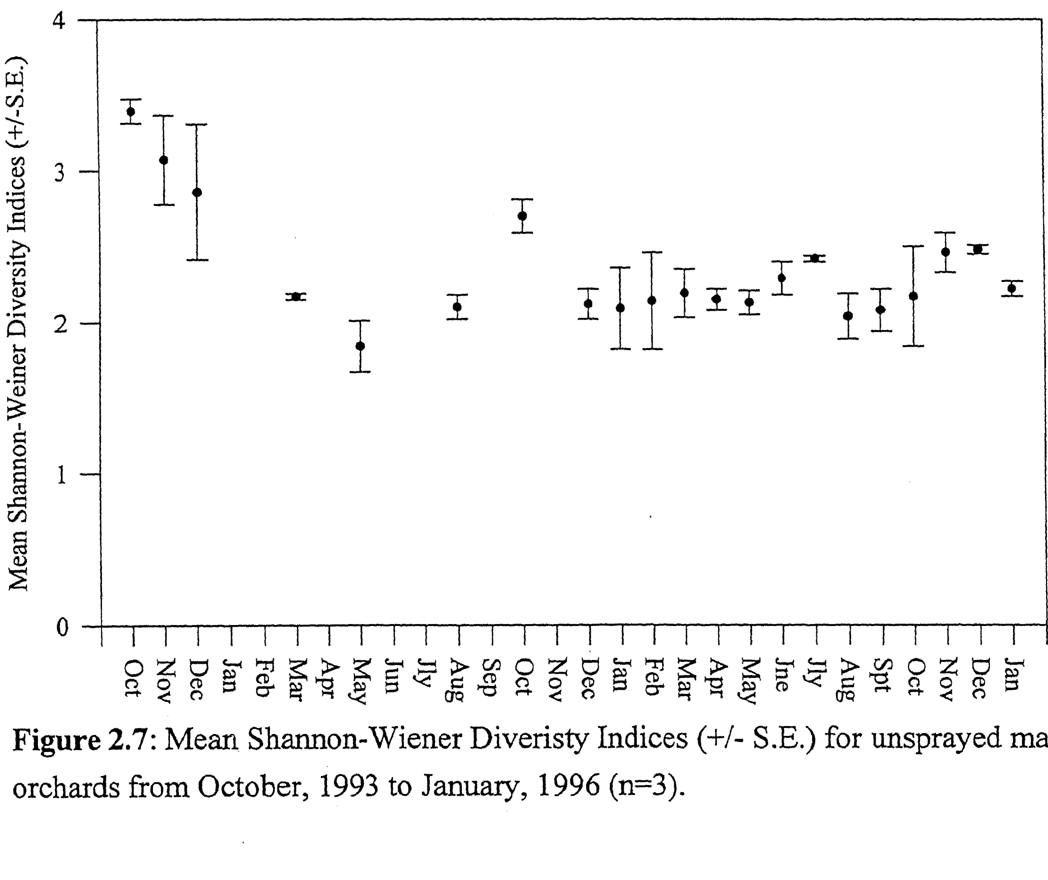


Figure 2.7: Mean Shannon-Wiener Diveristy Indices (+/- S.E.) for unsprayed mango orchards from October, 1993 to January, 1996 (n=3).

There was no obvious seasonal pattern in the relative abundance of different guilds over the course of the study. Figure 2.9 shows the total mean number of spiders in each guild (mean of three orchards) over the October, 1993 to January, 1995 sampling periods.

The number of tangle weaving spiders was less than orb-weaving spiders, but still represented a significant proportion of all the spiders collected. The cribellate guild had the least representation, accounting for only 10% of all the spiders collected (Figure 2.9). However, this guild was present at all sampling times except August, 1994 (Figure 2.8). The hunting spiders were relatively constant in total number over the sampling period except for peaks in October, 1994 and October, 1995 (total numbers were 63 and 23, respectively). This event corresponds to flowering in the mango orchards. The Thomisidae may have moved into the orchards to prey on the increase in the pollinators. *Xysticus* sp. was found camouflaged on both living and dead flowers. This suggests that the hunting spiders either tend to be more transient than the other guilds of spiders, or that the family group is well camouflaged in the foliage and normally difficult to find using visual collection methods. This also suggests that the visual technique used to detect spiders may not have been highly effective for finding those spiders that are well camouflaged. To ensure that spiders were detected all limbs and leaves were turned to maximise observation of these spiders. However, the presence of the four types of spider guilds indicates that there is a diversity of capturing techniques within these orchards.

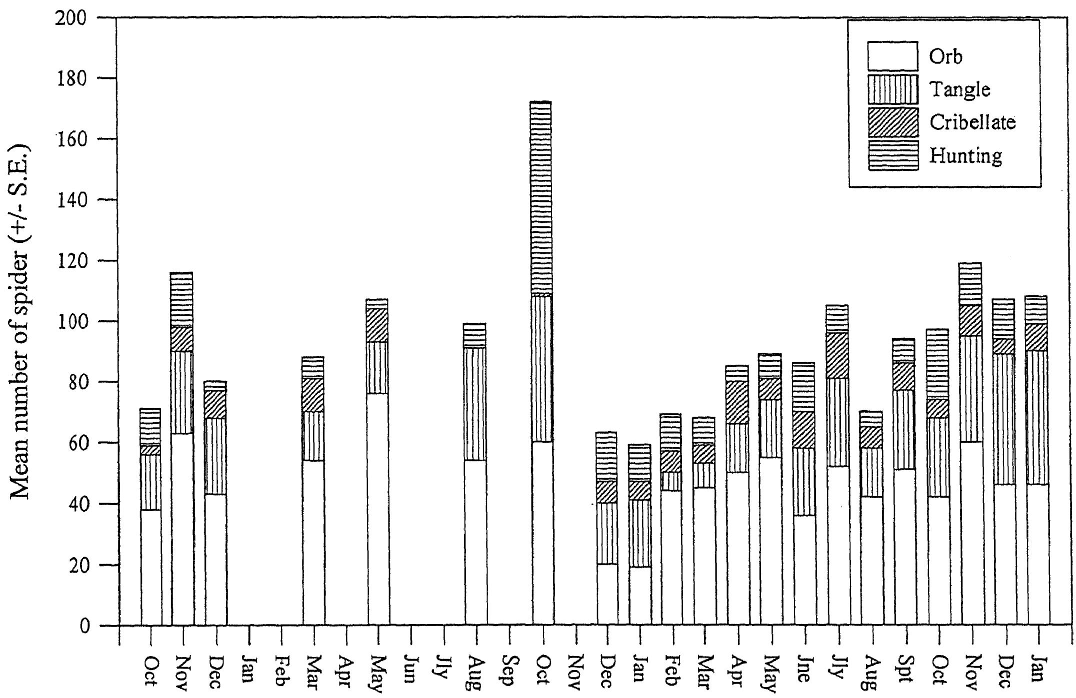


Figure 2.8: Total number of spiders collected in four guilds in unsprayed orchards from October, 1993 to January, 1996 (n=3).

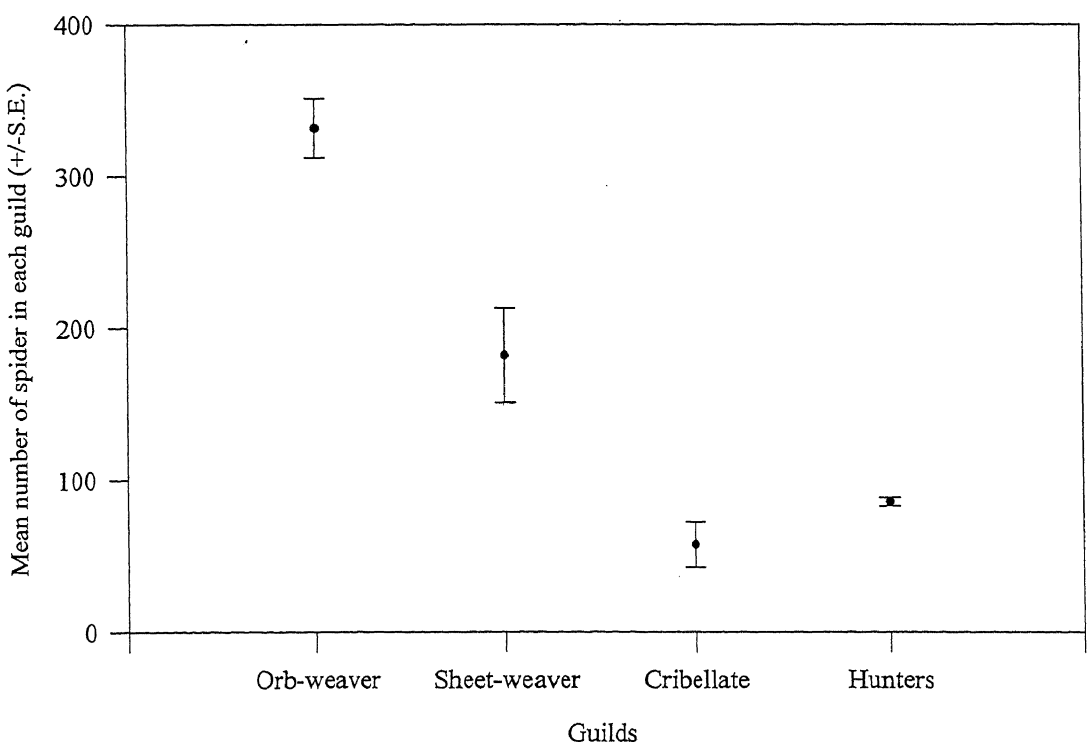


Figure 2.9: Mean number of spiders (+/- S.E.) in each guild collected from unsprayed mango orchards from October, 1993 to January, 1996 (n=3)

2.4 DISCUSSION

It is of interest to compare the diversity found in the present study with those of the other agroecosystems that have been studied in Australia. In the unsprayed mango orchards a total of 109 species of spiders from 12 families were collected from October, 1993 to January, 1996 (see Table 2.2). Dondale (1966) identified 38 spider species from an apple orchard in the Australian Capital Territory (ACT). These included species from five families Theridiidae, Araneidae, Clubionidae, Thomisidae and Amaurobiidae. The Amaurobiidae family has since been reclassified by taxonomist and the two species *Badumna inornata* and *Ixeuticus candidus* have both been placed in family Desidae. All five of these families were also collected in the mango orchards in the present study. The other seven families that were collected in the mango orchards were Heteropodidae, Oxyopidae, Pisauridae, Salticidae, Tetragnathidae, Uloboridae and Zodariidae. The larger number of species, from a greater variety of families compared to those from the apple orchard, may suggest that mango orchards offer a more diverse array of micro-habitats for spiders. Another explanation is that more species are found in the tropics than at higher latitudes (Ricklefs, 1990).

Green (1996A) found 36 genera in 14 families in her initial studies in Queensland citrus. The unsprayed mango orchards yield at least 33 distinctly different genera from 12 families (see Table 2.2). It is difficult to compare her results with the unsprayed mango orchards as the sampling techniques and types of orchards varied greatly from the mango orchards. Green (1996A) collected spiders using suction and pit trap methods, both diurnally and nocturnally. The orchards were under varying management regimes (chemically sprayed, unsprayed and Integrated Pest Management), different localities (coastal and inland) and different fruit varieties.

Bishop (1980) identified 10 families, 19 genera and 25 species of spider in unsprayed cotton in south-eastern Queensland from 1973-77. The results from the mango orchards had again suggested that mango orchards offer more micro-habitats than cotton (109 species, with at least 33 genera from 12 families). Bishop (1980) used several techniques to collect boreal and arboreal spiders. These included sweep netting, destructive sampling of plants, and pitfall trapping in two seasons, 1973-75. Then, in the following season the spiders were collected by trapping and collecting all individuals in 1m of row using a frame sampling apparatus.

Examination of spider diversity and natural ecosystems in the tropics has been performed by Russell-Smith and Stork (1995) who investigated a Borneo rainforest canopy. They collected 945 individuals from 190 species and 22 families. This result contrasts strongly with the families found in the foliage of the mango orchards. Of the 11 families these studies had in common, the mango orchards appeared to have more species of Araneidae (34 compared to 31), Heteropodidae (4 compared to 2), Tetragnthidae (10 compared to 3). There were less species of Clubionidae (8 compared to 19), Oxyopidae (3 compared to 4), Thomisidae (8 compared to17), Theridiidae (20 compared to 55) and Zodariidae (1 compared to 2) but the same number of species for Pisaudidae (1 to 1), Salticidae (19 to 19) and Uloboridae (2 to 2). The rainforest results are difficult to compare with the mango orchard as Russel-Smith and Stork (1995) used fogging techniques to collect their spiders and presumably this was more thorough than manual searches. The comparison does suggest that monocultures such as orchards, may encourage species from similar families rather than from a large selection of families. Presumably, this is due to the reduction in structural diversity providing less variety of microhabitats, particularly with respect to web spiders which require a variety of suitable substrates (Rypstra, 1983). An alternative interpretation of the results from all these studies (Dondale, (1966); Green (1996A), Bishop (1980), Russell-Smith and Stork, 1995 and this study) is that they may reflect a general trend for diversity to decrease with increasing latitude (Ricklef, 1990). As the apples and mangoes are similarly structured the differences between the tropics and higher latitudes would explain the differences in diversity between apples in Canberra (Dondale, 1966) and this study. It would also explain the similar results between this study and Green's (1996A). Green (1996A) did her studies in Gayndah at latitude 25.6° (approximately) compared to my sites at latitude 23.3 ° (approximately). However Green (1996A) collected ground spider as well as those found on foliage which makes conclusions from this comparison difficult.

One limitation of comparing these studies was that Russell-Smith and Stork (1995) were the only authors to calculate diversity indices. However, the results can not be compared with my results as Russell-Smith and Stork (1995) calculated William's α indices. Therefore, Shannon Wiener Diversity Indices were calculated for their data in Appendix 1 (see Table 2.3).

For the spider community to hold a prey population in check it must maintain its community diversity to maximise the number of predators that will encounter the pest prey (Riechert and Lockley 1984). The diversity of the mango community remained relatively constant between 2-2.5 in the unsprayed orchards from March, 1994 to January, 1996 (see Figure 2.7). Russell-Smith and Stork's (1995) results ranged from 2.916 to 3.706. Lubin's (1978) also calculated Shannon-Wiener diversity indices which ranged from 2.518 - 3.568 in different samples from tropical forest understorey on Barro Colorado Island. These differences may be due to the structure of the habitats. Trees in forest habitats have more diversity than orchards in vegetative structure. This lower structural diversity may account for the lower Shannon-Wiener diversity indices in unsprayed mango orchards where the habitat offers less web attachment sites. The latitudinal distances between these three sites also explain the differences in species diversity. Barro Island is at a lower latitude than the mango orchards of central Queensland in Australia. Never-the-less these mango orchards appear to have a relatively diverse spider communities with a large variety of capturing techniques.

The numerically dominant spider in these unsprayed mango orchards was *Araneus* sp.15, an Araneidae (see Table 2.2). There were 253 individuals of this species collected. Another 35 species of Araneidae in Table 2.2 were found with four species of Araneidae found in large numbers. The most numerically dominant of these were *Araneus sp.* 15 (253), *Argiope aethera* (136), *Cytrophora exanthematica* (58), and *C. hirta* (67) (see Table 2.2).

Four numerically dominant species that were investigated further to assess their seasonal variation in mangoes orchards. These were *Araneus* sp 15, *A. aethera*, *Badumna sp* 56 and unidentified immature 20a (see Figure 2.3). There appeared to be changes in the number of individuals collected within all four species. These variations however, do not show seasonal differences within the populations. This differs from Costello and Daane's (1995) study that investigated eight of the most common spiders found in vineyards in California. These populations changed in seasonal abundance, with several species showing overlapping of age structures over the seasons. These patterns do not emerge in the mango orchards. The spider community in mango orchards appears to be dynamic with abundances of spider and the species composition changing regularly. However, there are no regular seasonal patterns shown in these results (see Figure 2.3, 2.4 and 2.5).

Eleven species of Araneidae and one species of Tetragnathidae were described by Dondale (1966) in the apple orchards. Six species of Araneid were recognised as potential predators and five other Araneidae species that were considered as non-predators of *Epiphyas postvittana* larvae (MacLellan, 1973). The orb-weaving spiders appear to be more common in tropical mango orchards than in temperate apple orchards. These results are difficult to compare with the mango orchard. Many of the spiderlings and large spiders were not included in MacLellan's (1973) list of spiders as he only recorded predator of *E. postvittana* larvae. The Araneidae and the Tetragnathidae commonly occur in mango orchards and are potentially important predators. However, in order to judge their effectiveness as predators their impact on prey must be assessed. Chapter 3 of this study examines this aspect.

The most common spider in the ACT apple orchards was a Theridiidae, *Archaearanea veruculata* (Urquhart) (Dondale 1966). Bishop (1980) also targeted this species as a dominant species in south-east Queensland cotton. In the mango orchards five species from the family Theridiidae were common. These were unidentified immature 20a, *Argyrodes antipodiana*, *Achaearania* sp. 50, *Achaearania mundula* and unidentified immature 120, none of which occurred in the ACT apple studies.

One of the numerically dominant species was *Badumna* sp. 56, which belongs in the family Desidae (see Table 2.2). This was the only representative from this family with a total of 158 individuals collected. Due to the common occurrence of this species in the mango orchards, it may be an important controller of insect pests and requires further investigation.

The number of spiders collected at each sampling time over the three year period does not show any regular seasonal variation. The number of individuals remained similar through out the survey period except for a peak in October, 1994 (see Figure 2.2). These results differ from Lubin's (1978) who found that there was an overall trend of low numbers of spiders in the late dry season and early wet season in tropical forest understorey at Barro Colorado Island, Panama. The fact that spiders show little seasonal variation in mango orchards suggests that the climatic conditions affecting this community are relatively stable. The constant presence of spiders may be beneficial to the mango growers by offering a constant source of predation through out the year.

The unsprayed orchards showed a ratio of 5.5:1 immature to adult spiders. This varied from Harrison's (1968) ratio of 3.5:1, which was found on banana leaves. He found that the two stages (adult and immature) were equal in abundance on older, hanging leaves and the immature spiders were much less abundant on psuedostems.

Both of these crops are grown in tropical environments, the difference between the ratio of immature to adult spiders in mangoes and bananas may be the availability of microhabitats or differences in reproductive rates. Bananas do not offer a great variation in physical structure. They have large leaves with no branches and the actual stem of the plant is underground. Mango trees by contrast tend to be multi-branched, with compact foliage that offers more sites for immature spiders to attach webs. Rypstra (1983) recognised that an essential part of a web-builders requirements was the physical complexity of the structure of the habitat. This affects the size of the spider, as smaller spiders require plants with dense stems to attach their webs (Gunnarsson 1992). Therefore, mangoes with their more complex structures should offer more spaces for web attachment and consequently greater scope for spiders of various sizes.

These results also suggest that the reproductive rate is higher in mangoes than bananas. To establish these differences would require comparative studies between mangoes and bananas under the same growing conditions. Reproduction is influenced by climatic conditions, number of predators present, availability of food, interspecific and intraspecifiic competition, availability and condition of habitat and availability of mates. Investigation of these factors was outside the scope of this study.

The evaluation of guilds in spider communities was undertaken to increase the understanding of the types of capturing techniques used in the orchards. The graph in Figures 2.8 suggests that in unsprayed orchards the most numerically dominant guild was the orb-weavers, followed by tangle-weavers, hunters and then the cribellates.

Jenning *et al.*. (1990) found web-spinning spiders more prevalent (68.2%) than hunting spiders (31.8%) in Red Spruce and Balsom Fir. Again, there is relatively high structural diversity in fir and spruce trees as well as in mangoes. This offers web building spiders attachment points to stems, branches, the ends of branches and onto leaves.

Although mangoes are grown in monoculture situations, it does appear that they offer sufficient micro-habitats to attract a wide range of spiders to take up residency. The spiders are present in mango orchards at relatively high abundance, high species richness and high diversity throughout all seasons. This pattern throughout all seasons strengthens the suggestion that spiders are important predators in mango agroecosystems.

The following chapter documents the examination of the types of insects present in orchards and the types of insects actually caught by spiders over 24 hour periods. The chapter will further develop our understanding of the actual role these potentially beneficial predators in mango orchards.

CHAPTER 3

SPIDERS AS PREDATORS OF PESTS IN MANGO ORCHARDS

3.1 INTRODUCTION

Spiders are polyphagous predators utilising a wide range of capturing techniques (see example Child, 1977). The range of size in spiders and their prey is considerable. In addition, different species of spiders are active at different times of the day (Cloudsley-Thompson 1987). In any particular ecosystem a diverse range of insects are thus utilised as prey by this group. Spiders are potentially able to restrict outbreaks of insect pests, but on the other hand, it is possible that these predators catch beneficial insects including parasitoids, as well as the pest species. The significance of spiders in agroecosystems is therefore ambiguous, and worthy of investigation.

In mango orchards, several orb-weaving species are found for which the behaviour has been studied. *Nephila* (Herberstein and Elgar 1994) and *Argiope* (Bradley, 1993) construct their webs and renew them as needed. These species are generally diurnal feeders. Other genera such as *Eriophora* construct their webs in the evening and pull them down at dawn (Herberstein and Elgar 1994). While some *Araneus* spp. have the opposite behaviour (pers. obs). These different patterns of activity between species over a twenty-four hour period suggest that the spider community represents a constant source of predators with potentially complex temporal patterns of resource partitioning.

The activity of some orb-weaving spiders appears to be directly related to the activity of insects. Ward and Lubin (1992) found that activity patterns of six species of nocturnal orb-weaving spiders corresponded to the change in sizes of flying insects throughout the night. Small spiders of all species built their webs early in the evening and progressively larger spiders put their webs up through the night. However, Bradley (1993) found that the activity of the Australian species *Argiope keyserlingi* did not track temporal prey distribution. He suggested that prey distribution was unpredictable in both time and space and that neither the activity patterns nor local density of *A. keyserlingi* tracked these fluctuations. Most studies of temporal activity have examined particular spider species. There are few attempts to consider the entire spider community. The present study examines the diel activity of the whole spider community in a mango orchard.

The only work on spiders and pest insects in mangoes was done in India. Sadana and Kumari (1991) examined *Lyssomanes sikkimensis* as a potential predator of the mango hopper, *Idioscopu clypealis*. This species of mango hopper has not been recorded in Australia and there have been no studies in this country on spider interactions with mango pests. In Queensland, Cunningham (1989) identified seven major (Mango scale, Mango tipborers, Mango planthopper, Fruit flies, Pink wax scale, Fruitspotting bugs and Mango seed weevil) and eight minor (Flower feeding caterpillars, Redbanded thrips, Leafminer, Fruitpiercing moths, Coccid, Termites, Tea red spider mite and Mango bud mite) pests in mangoes.

The research described in this Chapter investigates the potential impact of spider communities on insect populations in mango orchards. The diel activity of both spiders and their insect prey was assessed. Further, the prey caught by web spinning spiders was estimated by sampling of webs. The results from this study allows us to comment for the first time on the significance of spiders as predators in mango orchards.

3.2 METHODS AND MATERIALS

3.2.1 Preliminary Observations

Observations of the prey caught by spiders were performed in an unsprayed mango orchard (Site B, see Figure 2.1). Ten mango trees were selected randomly using a random number generator. These were searched systematically for one hour before dawn and then again at mid morning. The search commenced on the eastern side of the tree and rotated in an anti-clockwise direction around the outer edge of the foliage. All spiders were counted, irrespective of whether or not they could be identified. The prey was taken from the webs of web-building spiders and the jaws of hunting spiders and preserved in 70% ethanol for later identification. Most of the prey items from the web-building spiders were wrapped in webs. These were placed in a weak bleach solution in the laboratory for up to 10 minutes to dissolve the web and free the prey. These prey were returned to the 70% ethanol solution for preservation. Much of the prey had already been fragmented by the spiders' feeding activities. This made identification of many of the insects very difficult. Only those prey which could be positively identified to the level of order were included in the prey species list, others were counted as unidentified prey.

3.2.2 Twenty-four hour Surveys

The preliminary observations gave an indication of the types of insects that were caught by spiders before dawn and during the day. To gain a greater understanding of spider activity and the prey taken, two, 24 hour surveys were performed, beginning at 10 am. These two surveys were performed two weeks apart (Survey 1 - 27/28-Oct-96 and Survey 2 - 10/11-Nov-96). Spiders were observed at two hour intervals during each survey. Initially four trees from the same unsprayed orchard as used in the preliminary observations were randomly selected and were monitored over the twenty-four hour period. All spiders observed were identified visually to family level or wherever possible to species level by systematically circling anticlockwise on the outside of the tree then circling under the branches. Any prey found in the webs of these spiders were collected and handled using the same method as described in section 3.2.1.

3.2.3 Insects Trapped

In conjunction with the collection of spider prey, the insects present in the orchard were also monitored. In a pilot study, two types of sticky traps were trialed, clear plastic, cylindrical traps and traps made from a flat board covered with plastic. They were both sprayed with 'Tangle trap' which allows insects to become ensnared on contact with the surface. Traps were placed underneath the foliage at a height between 1-2 m. A total of 666 insects were collected from four board traps over a week. Each of these traps had a surface area of 4836 cm^2. The four cylindrical traps with a surface area of 2418 cm^2 (length = 260 mm, width = 310 mm) ensnared a total of 623 invertebrates during the same period. The cylindrical traps were used in the twenty-four hour surveys as they were more efficient at capturing potential prey and they could be place in the foliage of the trees making the comparison between insects trapped and insects caught be spiders more relevant. The board traps would only give an indication of the insects moving between the trees or around the trees. Two cylindrical traps were placed in each of four trees, underneath the foliage 1-2 m above the ground. The traps were replaced every two hours except between 2 am and 6 am, when the same sticky traps were left in place for a four hour period, as very few flying insects were caught during this time. When collected, the two sticky traps were removed from each tree and placed together with their sticky surfaces facing each other. This sealed the insects between the two layers of plastic sheeting and preserved them in the 'Tangle trap' adhesive. This technique allowed easy identification to ordinal level under a dissection microscope. Important predatory groups such as F. Braconidae and F. Formicidae (Hymenoptera) and F. Reduviidae (Hemiiptera) and pest insects such as F. Aphidiidae (Homoptera) were identified to family level.

3.2.4 Analysis

The spider families were grouped into guilds in association with the type of hunting technique used. The families Araneidae and Tetragnathidae were placed in the 'Orb-weavers', while Family Theridiidae was placed in the 'Sheet-weavers'. Family Desidae were placed in cribellates and the remaining families were grouped together as 'Hunters' (see section 2.2.2 for descriptions of these guilds).

To assess if there was a relationship between the abundance of spiders and the insects present at each sampling time, correlation coefficients were calculated. Correlation coefficients were selected over regression equations as there could be no a priori certainty that there was a casual relationship between the number of prey and the number of spiders present in these trees, or the number of insects collected in sticky traps and the number of spiders. Correlation coefficients may establish the degree of association between these groups without implying a causal relationship (Sokal and Rohlf, 1981). An index of capture success (number of prey caught/number of spiders present) was calculated for each observation time. This gave the average number of prey caught by spiders. The index was correlated with the number of insects trapped, to compare the prey caught with the available prey present. The average was also correlated with the number of spiders present, to compare the prey caught with the number of spiders present.

3.3 RESULTS

3.3.1 Spiders

The spiders observed in the orchard were separated into guilds according to their predatory behaviour (see section 2.2.3). Predatory insects were rated separately. The five functional groups were predatory insects, orb-weaving, sheet-weaving, cribelate and hunting spiders. Those spiders that were not identified to family level under field conditions were not included in the data. They represented a small subset of the data. In all, 957 observations of spiders were made over the two, 24 hour Surveys. The spiders and the other predators observed in the orchard are listed in Tables 3.1 and 3.2.

The results of this set of observations conformed to the patterns described in Section 2.3.4. The most common spider family present in the orchard was Araneidae belonging to the orb-weaver guild. The dominant spider species level within this family in both surveys were *Cyrtophora exanthematica*, *Araneus* sp.15, *Araneus praesignis*, *Argiope aethera* and *Eriophora* sp.; *Archaearanea mundula* was the dominant identified species from the family Theridiidae in Survey 1 while *Argyrodes antipodiana* was the dominant identified Theridiidae species in Survey 2. There appeared to be a change in the numbers and species of spiders present within these orchards during the course of the study. In Survey 1, *Cyrtophora* sp., *Cyrtophora hirta*, *Nephila* sp., *Araneus praesignis*, *Araneus* sp., *Eriophora* sp. and *Poecilophachys australasia* were present in considerable numbers (Table 3.1). *Gasteracanthus mimax* and *Poltys* sp. were present in the second survey but not in the first. In Survey 2, which was performed two weeks later, both of these species were observed along with the other above mentioned species except *Cytophora* sp.

Table 3.1: The number of spiders observed in a 24 hour period (Survey 1 - 27/28-Oct-96) in an unsprayed mango orchard.

	Time surveyed												
Spiders Observed	10am	12pm	2pm	4pm	6pm	8pm	10pm	12am	2am	4am	6am	8am	10am
ORB-WEAVERS													
F. Araneidae													
Unidentified species	13	8	3	4	8	22	16	23	14		10	4	4
Cyrtophora exanthematica	2	3	4	4	3	3	2	2	2		3	3	3
Aranea sp.	13	18	20	10	13	4	7	2	2		3	4	15
Araneus praesignis	9	4	2	6	3	4			1		1	9	2
Argiope aethera	1	2	1			1							
Cyclosa sp.	1							1					
Eriophora sp.						3	4	5	2	3			
Cytrophora sp.	3		1	2	1	1	1	1	1	1			
Cytrophora hirta	2	1	1	1	2				2	2	1	1	
Poecilopachys australasia		1				1	1	1	1				
Nephila sp.		5	8	4	6							4	5
Acyrs sp.						1							
Araneus sp.										2			
Total Orb Weaving Spider	44	42	40	31	36	40	31	35	25	8	18	25	29
TANGLE WEAVERS													
F. Theridiidae													
Unidentified species	4	2	3	2		14	11	2	12	8	1	1	3
Argyrodes antipodiana								1					
Archearanea mundula	3	3	2	1	1	2	4	5	1	1	3	4	4
Total Tangle Weaving Spiders	7	5	5	3	1	16	15	8	13	9	4	5	7

Table 3.1(Continued): The number of spiders observed in a 24 hour period (Survey 1 - 27/28-Oct-96) in an unsprayed mango orchard.

	Time surveyed												
Spiders Observed	10am	12pm	2pm	4pm	6pm	8pm	10pm	12am	2am	4am	6am	8am	10am
CRIBELLATES													
F. Desidae													
Badumna sp.	1	2		1									
Total Cribellate Spiders	1	2	0	1	0	0	0	0	0	0	0	0	0
HUNTERS													
F. Clubionidae													
Unidentified species							1	2					
F. Hersiliidae													
Tama sp.								1					
F. Heteropodidae													
Olios sp.						1							
F. Oxyopidae													
Oxyopes maculensis	1	2		2	1	2	3	3	3		1		
F. Pisauridae													
Dolomedes sp.		1	1	1	1								
F. Salticidae													
Unidentified species		2					2	2					
F. Thomisidae													
Unidentified species	1			1		2	4	1	1	1			1
Total Hunting Spiders	2	5	1	4	2	6	9	9	4	1	1	0	1
PREDATORY INSECTS													
Mantodea		1	2	1									
F. Reduviidae											1		
F. Asilidae					1								
Total Predatory Insects	0	1	2	1	1	0	0	0	0	0	1	0	0

Table 3.2: The number of spiders observed in a 24 hour period (Survey 2 -10/11-Nov-96) in an unsprayed mango orchard.

Spiders Observed	Time surveyed												
	10am	12pm	2pm	4pm	6pm	8pm	10pm	12am	2am	4am	6am	8am	10am
ORB WEAVERS													
F. Araneidae													
Unidentified species	9	4	5	5	2	14	15	18	15	8	4	2	3
Cyrtophora exanthematica	1	3	3	2	2		1	2	1	3	2	2	2
Aranea sp.	9	12	10	6	4	2	2	1		2	3	3	7
Araneus praesignis	2	3	2	3	1		2		1	1	2	3	2
Argiope aethera	1	1	1	1	1	1	1	1					1
Gasteracanthus mimax	1	1	1	1	1	1	1					1	1
Cyclosa sp.				1									
Poltys sp.					1	1							
Eriophora sp.					2	4	3	3	1	3			
Cytrophora sp.												1	
Cytrophora hirta	2	1	1	1	2				2	2	1	1	
Poecilopachys australasia		1				1	1	1	1				
Nephila sp.		5	8	4	6							4	5
Acyrs sp.						1							
Araneus sp.										2			
F. Tetragnathidae													
Unidentified species						1							
Total Orb Weaving Spiders	25	31	31	24	22	25	26	26	21	21	12	17	21
TANGLE WEAVERS													
F. Theridiidae													
Unidentified species	3	4	8	4	2	2	5	6	3	4	3	10	5
Argyrodes antipodiana		6	6	2	4	8	6	6	7	9	5	3	3
Archearanea mundula				1				1					
Ariannes sp.								1					
Total Tangle Weaving Spiders	3	10	14	7	6	10	11	14	10	13	8	13	8

Table 3.2 (continued): The number of spiders observed in a 24 hour period (Survey 2 -10/11-Nov-96) in an unsprayed mango orchard.

	Time surveyed												
Spiders Observed	**10am**	**12pm**	**2pm**	**4pm**	**6pm**	**8pm**	**10pm**	**12am**	**2am**	**4am**	**6am**	**8am**	**10am**
CRIBELLATES													
F. Desidae													
Badumna sp.	1												
Total Cribellate Spiders	1	0	0	0	0	0	0	0	0	0	0	0	0
HUNTERS													
F. Salticidae													
unknown species								1				1	
Mopsus sp.	1											2	1
F. Thomisidae													
unknown species				1		7	7	3	1				
Miscellaneous													
Total Hunting Spiders	1	0	0	1	0	7	7	4	1	0	0	3	1
PREDATORY INSECTS													
Mantodea	1	2											
Neuroptera								1	1	1			
F. Reduviidae			1	1									
F. Asilidae													
Total Predatory Insects	1	2	1	1	0	0	0	1	1	1	0	0	0

that was only observed once (Table 3.2). The hunting spiders were represented in Survey 1, with *Oxyopes maculensis* dominating this guild.

At each sampling, web-building spiders were the dominant predators present in the orchard. Hunting spiders were found in lower numbers but were also present in both surveys. Predatory insects were low in numbers with less than 2% of the total being observed in both surveys. They were only observed a few times during the survey. While the technique used may have underestimated both the hunting spiders and the predatory insects a diligent visual search was performed and the foliage was explored thoroughly. Generally, the predators were less abundant in Survey 2 than in Survey 1 (Tables 3.1 and 3.2, Figures 3.1 and 3.2). There was no obvious ecological reason for the observed differences between the two samples. The differences may reflect the high mobility of spider populations and the rapid turnover in species within the community (Bishop and Riechert, 1990).

Figures 3.1 and 3.2 give a visual representation of these data and explore the diel patterns. There does not appear to be any distinct patterns of spider activity when comparing the two graphs. There appears to be a slight decrease in the number of individuals observed at dawn followed by a slight increase at 8 pm in the first survey. In general, the spiders are present in relatively high numbers at all times of the day and night.

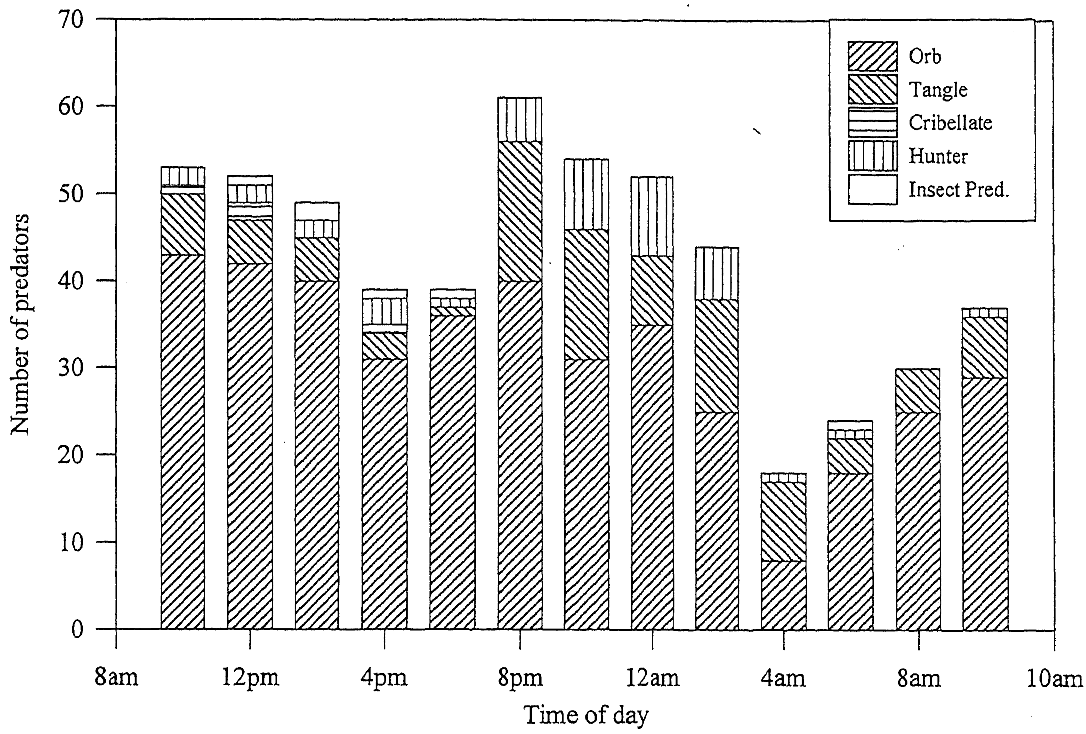


Figure 3.1: A comparison of the spider and predatory insect guilds observed in four trees in an unsprayed mango orchard (Survey 1 - 27/28-Oct-96).

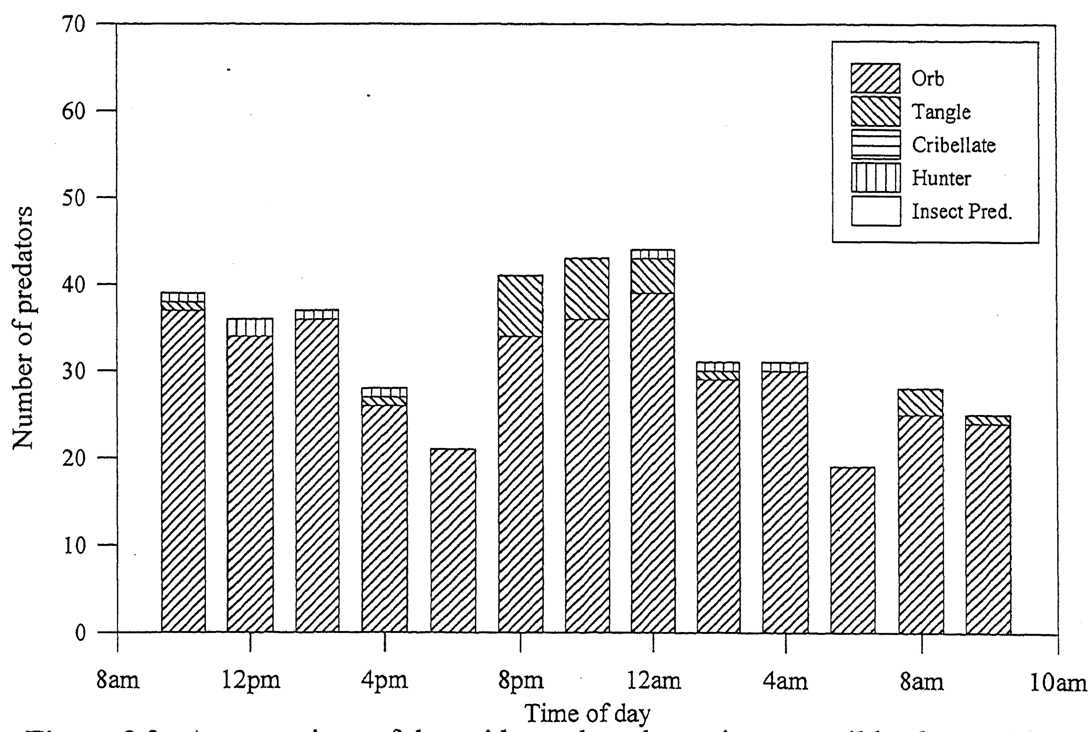


Figure 3.2: A comparison of the spider and predatory insects guilds observed in four trees in an unsprayed mango orchard (Survey 2 - 10/11-Nov-96).

3.3.2 Insect activity

A large number of insect taxa were collected in the sticky traps over a 24 hour period. The most abundant insects collected at night in the sticky traps were the Reduviidae and Diptera. During the day, Braconidae and the Aphidiidae were the most abundant arthropods collected (Tables 3.3 and 3.4). The Reduviidae are predatory Heteroptera. However, no Reduviidae species were identified from the spider prey samples. This presumably reflects the fact that the Reduviidae do not fly when foraging and do not come into contact with the webs. Figure 3.3 and 3.4 show the total numbers of insects caught in sticky traps and the total numbers of spiders observed at the same time during each 24 hour survey. In Figure 3.5, the number of trapped insects at overall sampling times in both surveys was compared to the number of spiders observed. The correlation coefficient of 0.296 was not significant ($0.20<P<0.10$). The number of spiders at overall sampling times in both surveys and the number of prey caught by spiders is shown in Figure 3.6. The correlation coefficient was not significant with a value of 0.287 ($0.20<P<0.10$). These results suggest that there is no relationship between the number of trapped insects and the number of spiders observed, nor the number of spiders and the total number of prey caught.

The number of insects caught in sticky traps and the number of prey caught in webs at each sampling time over a 24 hour period in the two surveys are shown in Figure 3.7 and 3.8. Spiders and prey counted in the initial sampling at 10 am are not included in these Figures as the initial samples would include prey trapped previous to the start of both surveys. These graphs suggest that the prey caught by spiders tracks the number of insects collected in sticky traps. A scattergram showing the

Table 3.3: The total number of insects collected in sticky traps from four mango trees over a 24 hour period (Survey 1 - 27/28-Oct-96) in an unsprayed mango orchard.

	Time surveyed										
Insects collected	**12am**	**2pm**	**4pm**	**6pm**	**8pm**	**10pm**	**12am**	**4am**	**6am**	**8am**	**10am**
Collembola						1		2		1	1
Coleoptera		1	1	1	2	2				1	1
Diptera	3	2	3	3	5		1	1	4	2	1
Other Hemiptera					1			1			1
F. Reduviidae				1	4			4			
F. Aphidiidae				1							
Other Hymenoptera	3	2	1	1	1		2	1		2	2
F. Braconidae	16	29	20	14							
F. Formicidae						1					1
Isoptera											
Lepidoptera					1				1		
Aranea	1				1	1	1				1
Unidentified Orders				1	2		1			2	2
Total	23	34	25	21	17	5	5	9	5	8	10

Table 3.4: The total number of insects collected in sticky traps from four mango trees over a 24 hour period (Survey 2 - 10/11-Nov-96) in an unsprayed mango orchard.

	Time surveyed										
Insects collected	12pm	2pm	4pm	6pm	8pm	10pm	12am	4am	6am	8am	10am
Coleoptera	1										1
Diptera	1	3			4	2			6	5	1
Other Hemiptera	1		1	3		1					
F. Reduvidiidae					3	3	1				
F. Aphidiidae			1								
Other Hymenoptera		5	3	7	1	1				1	1
F. Braconidae	2	5	7	5	3						
Psocoptera					1				1		
Trichoptera	1										
Aranea		3				1	2			2	
Unidentified Orders			1								1
Total	5	16	13	15	12	8	3	0	7	8	4

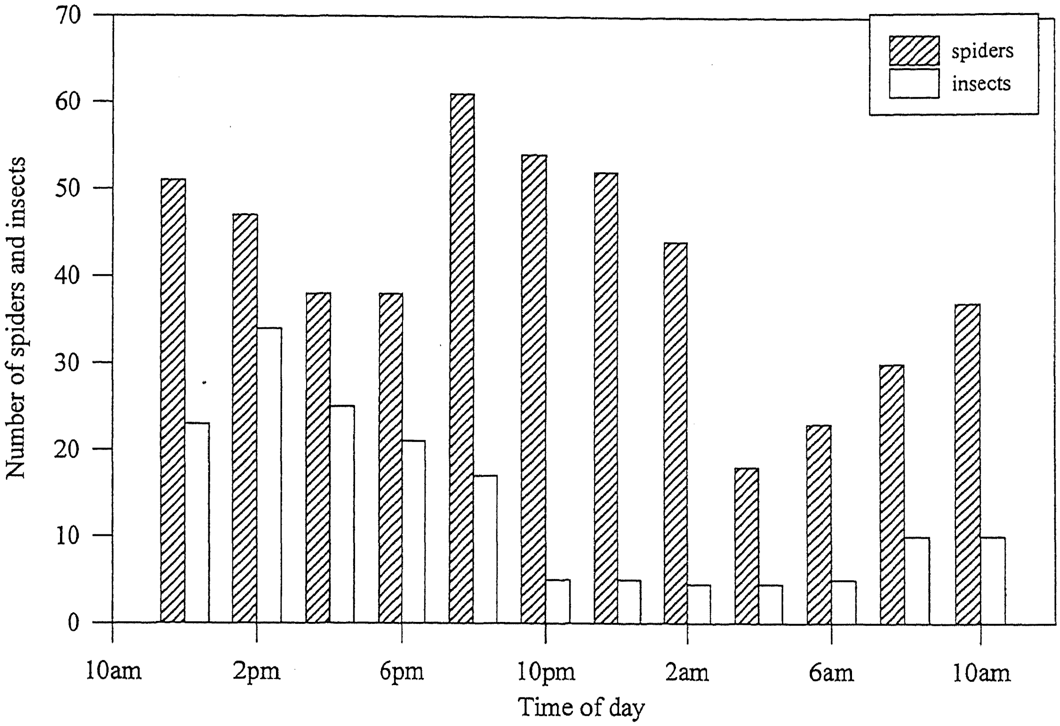


Figure 3.3: Survey 1 comparison of numbers of spiders and insects over the twenty-four hour period (27/28-Oct-96).

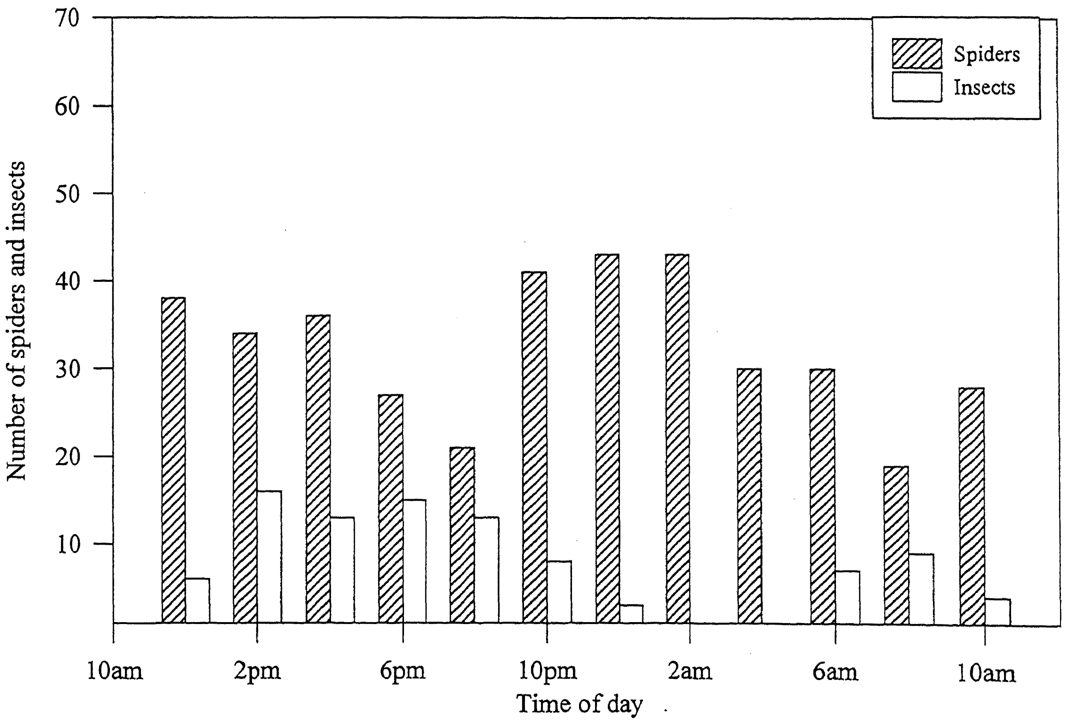


Figure 3.4: Survey 2 comparison of numbers of spiders and insects over the twenty-four hour period (10/11-Nov-96).

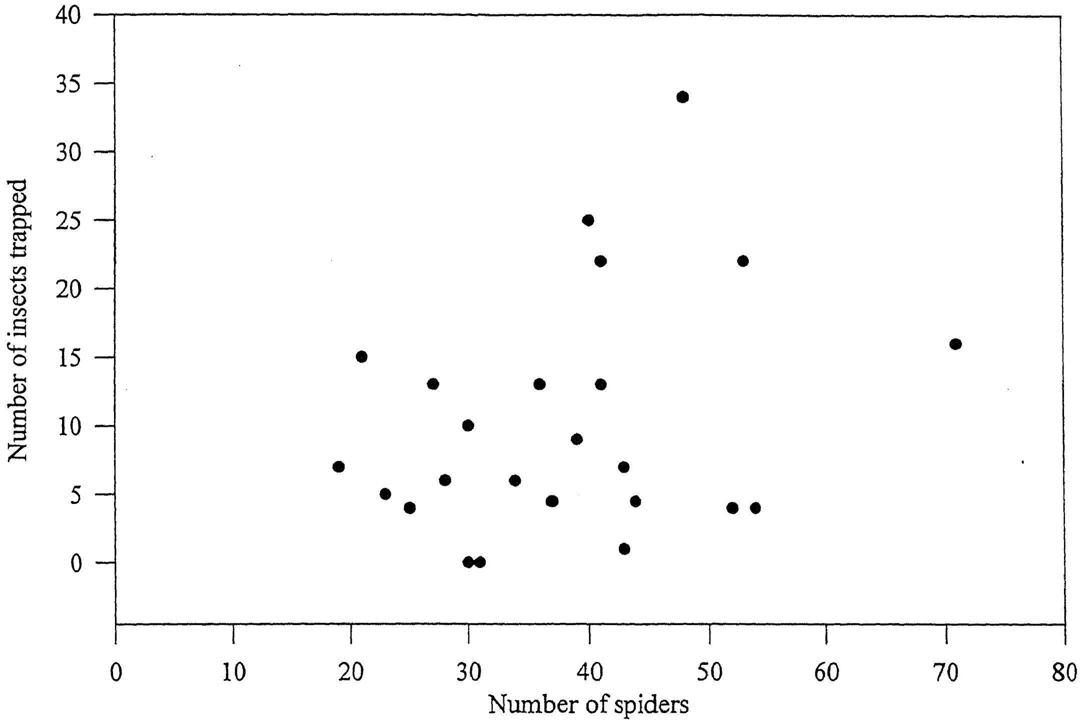


Figure 3.5: The number of spiders compared to the number of trapped insects over all times of the two surveys in an unsprayed mango orchard.

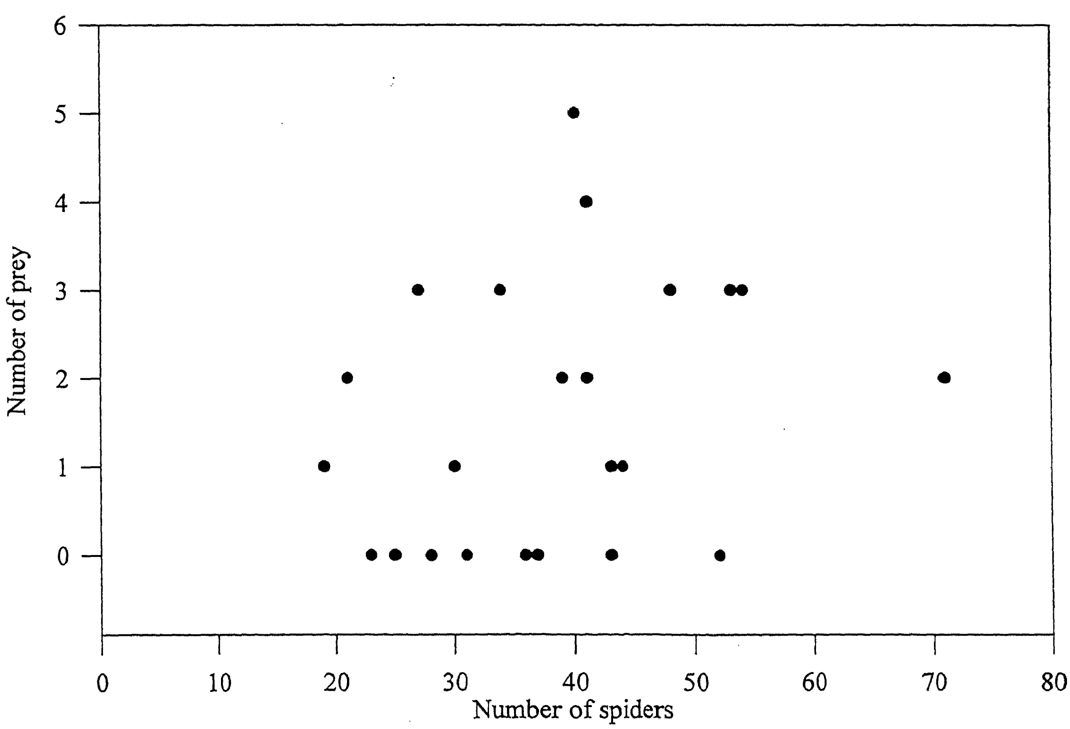


Figure 3.6: The number of spiders and the number of prey caught by these spiders over all times of the two surveys in an unsprayed orchard.

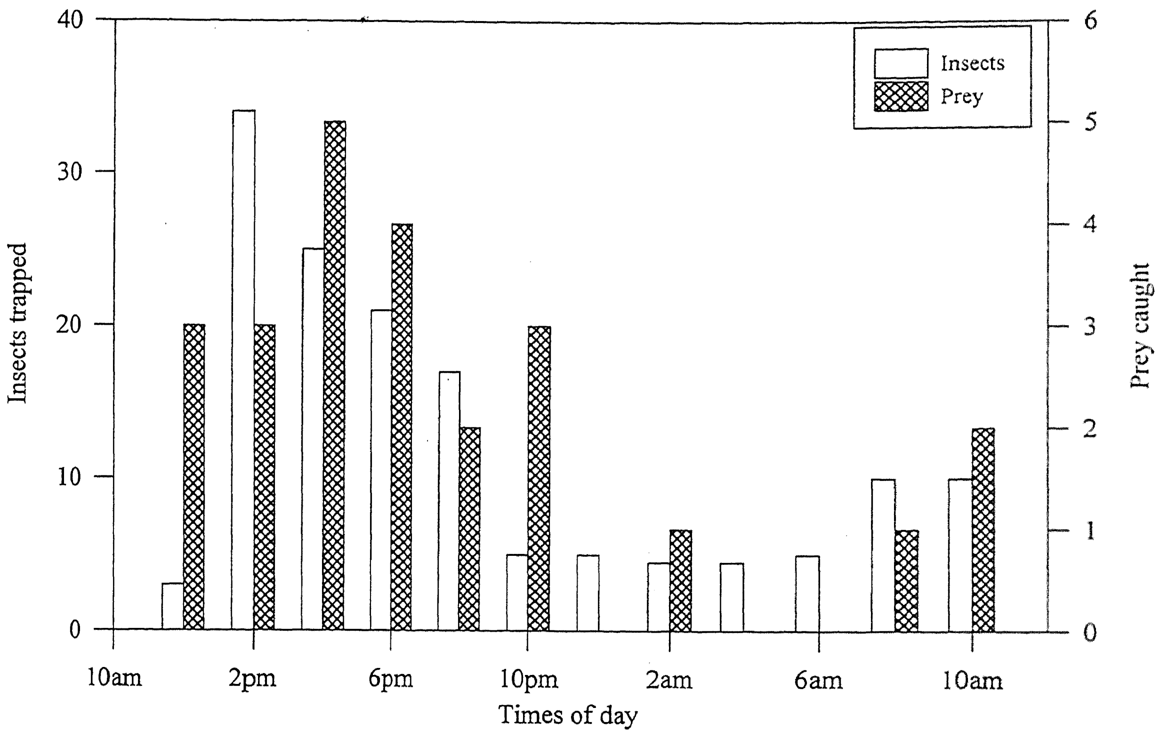


Figure 3.7: Comparison of prey caught by spiders and insects collected in sticky traps from four trees in an unsprayed mango orchard (Survey 1 - 27/28-Oct-96).

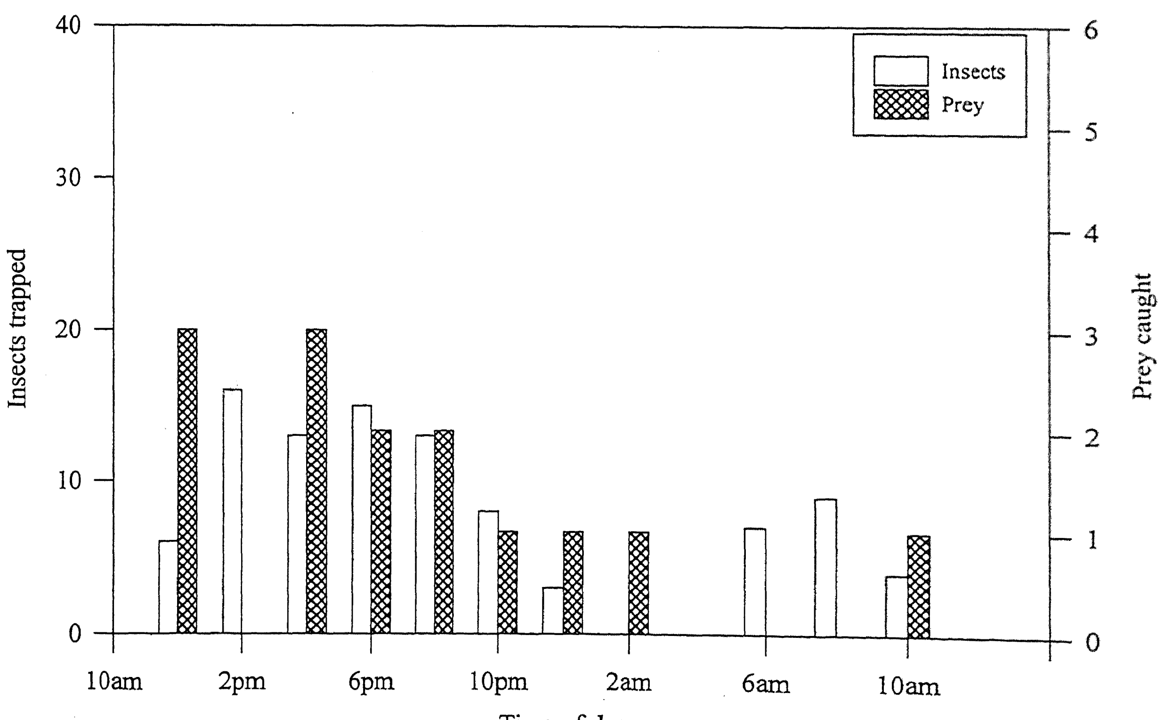


Figure 3.8: Comparison of prey caught by spiders and insects collected in sticky traps from four tree in an unsprayed mango orchard (Survey 2 - 10/11-Nov-96).

relationship between the number of insects collected in sticky traps and the number of prey caught by spiders at different sampling times is shown in Figure 3.9. A significant correlation of 0.508 was found (0.02<P<0.05). This suggests more strongly than other data that there is an overall relationship between the insects present in the orchard and the prey caught by spiders.

An index of capture success (number of prey caught/number of spiders present) was calculated to examine if the average number of prey caught by spiders correlated with the number of available prey or with the number of spiders present. This was plotted against the number of spiders present (Figure 3.10) and the number of insects trapped (Figure 3.11) at the different sampling times during the two surveys. The data in Figure 3.10 gave a correlation of -0.032, which was not significant at P<0.5

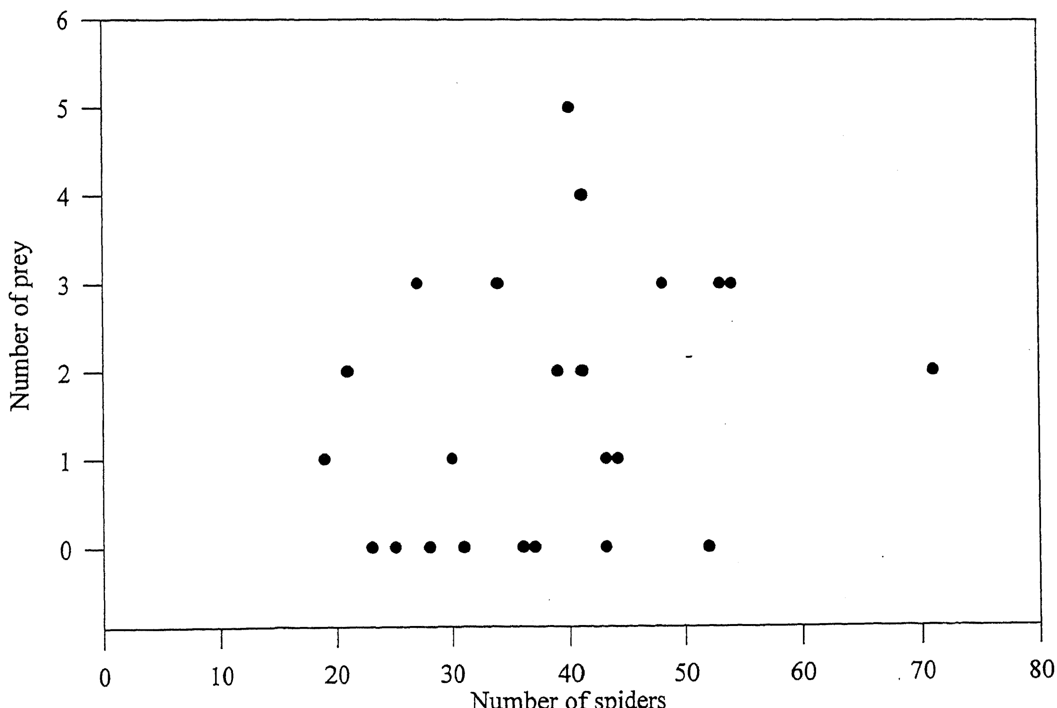


Figure 3.9: The number of spiders and the number of prey caught by these spiders over all times of the two surveys in an unsprayed orchard.

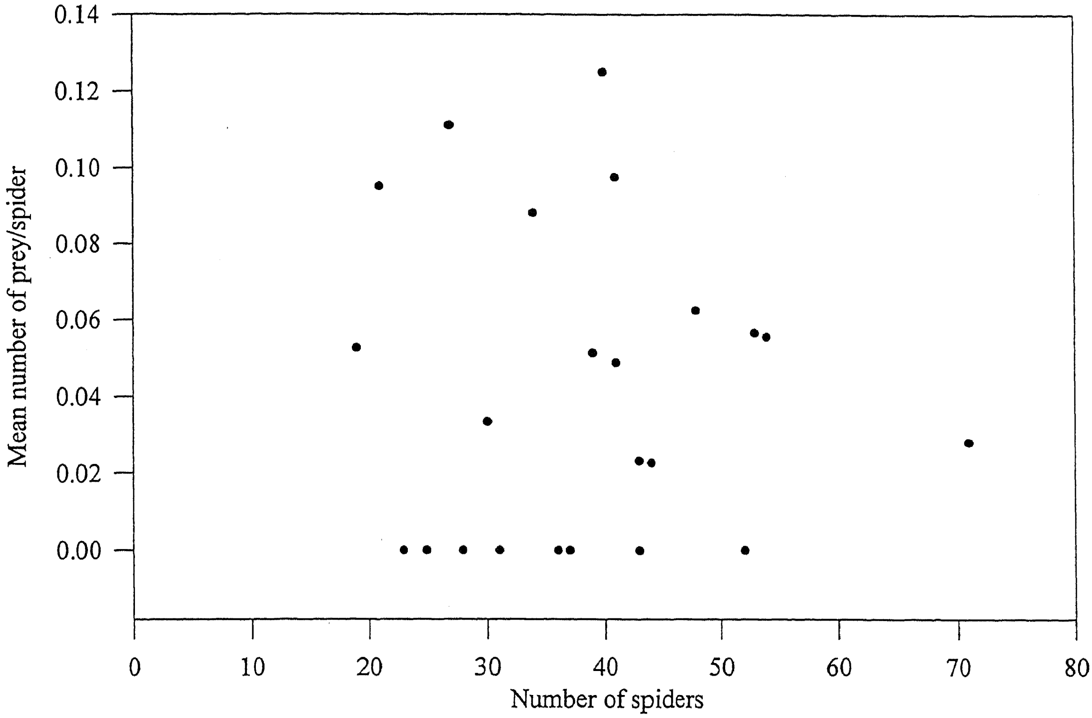


Figure 3.10: The number of spiders compared to the ratio of prey to spiders in an unsprayed mango orchard from two surveys.

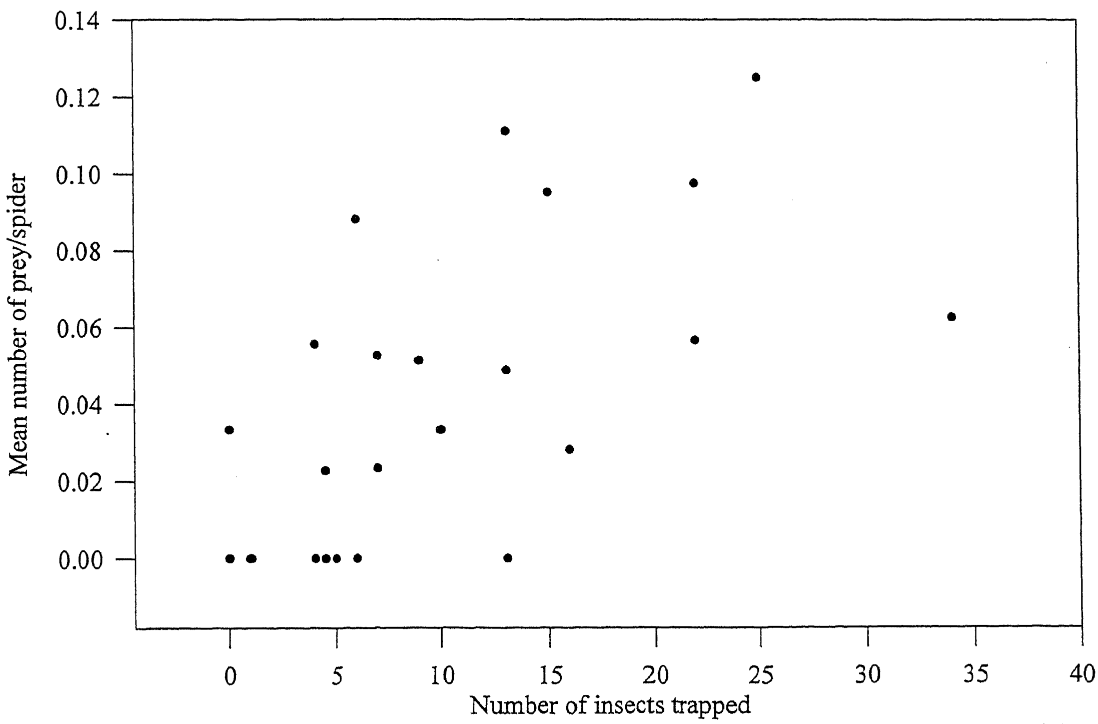


Figure 3.11: The number of insects trapped compared to the ratio of prey to spiders in an unsprayed mango orchard from two surveys.

spiders present. But, there was a relationship between the number of insects caught per spider and the number of insects collected in sticky traps.

3.3.3 Prey Captured

The preliminary observations in Table 3.5 suggest that a high proportion of both the before dawn and the mid-morning samples contained Hymenoptera. The Homoptera were also quiet common. Also significantly more prey were found in spider webs at mid morning than at dawn ($\chi^2 = 11.84$, $P<0.001$) (Table 3.5).

Although, the numbers of prey caught by spiders over a 24 hour period were quite small in both surveys, some trends are indicated (Table 3.6 and 3.7). The initial samples at 10 am on the first mornings are high because some webs would have contained prey which had been stored for extended periods before the survey. It appears that most prey were caught in the afternoon and early evening, between the hours of 12 pm to 10 pm (Survey 1) and 12 pm to 8 pm (Survey 2). The most common insects caught by spiders in both these surveys were Hymenoptera (Table 3.8). In Table 3.9 the total number of spiders observed are compared with the number of those spiders with prey (Surveys 1and2). In survey 1, 3.76% and in survey 2, 2.65% of the spiders observed had captured prey.

Table 3.5: The number and type of insects collected from spider webs in an unsprayed mango orchard before dawn and mid-morning over a 1 hour period at five different sampling times.

Insects Identified	Before Dawn					Mid-morning			
	Summer			Spring		Summer		Spring	
	3/12/95	9/12/95	1/1/96	26/9/96	28/9/96	2/12/95	23/12/96	26/9/95	28/9/96
Hymenoptera	2	4		1	1	17	10	3	1
Diptera		2	1				1		1
Lepidoptera		1					1		
Hemiptera	2	3				1	8	4	
Coleoptera		1	1				2		2
Trichoptera	1								
Isoptera					1	1			1
Mantodea		1							
Araneae				1					
TOTAL	5	12	2	2	2	19	22	7	5

Table 3.6: The total number of prey collected by spiders in a 24 hour period (Survey 1 - 27/28-Oct-96) in an unsprayed mango orchard.

	Time surveyed												
Insects collected	**10am**	**12pm**	**2pm**	**4pm**	**6pm**	**8pm**	**10pm**	**12am**	**2am**	**4am**	**6am**	**8am**	**10am**
Blattodea	1												
Coleoptera		1											
Diptera	3	2	2	1			1						
Other Hemiptera													
F. Aphidiidae				1									
Other Hymenoptera	8	2	1	3									
F. Braconidae					3								2
F. Formicidae						1							
Lepidoptera	1				1	1						1	
Psocoptera									1				
Trichoptera							1						
Miscellaneous							1						
Total	13	5	3	5	4	2	3	0	1	0	0	1	2

Table 3.7: The total number of prey collected by spiders in a 24 hour period (Survey 2 - 10/11-Nov-96) in an unsprayed mango orchard.

	Time surveyed												
Insects collected	**10am**	**12pm**	**2pm**	**4pm**	**6pm**	**8pm**	**10pm**	**12am**	**2am**	**4am**	**6am**	**8am**	**10am**
Diptera	1				1								
Embioptera							1						
Other Hemiptera	1												
F. Aphidiidae				1									
Other Hymenoptera				2		1					1		
F. Formicidae	1	3			2				1				
Miscellaneous						1							
Total	3	3	0	3	3	2	1	0	1	0	1	0	0

3.4 DISCUSSION

Spiders are recognised predators in most terrestrial and even some aquatic environments (Foelix, 1996). They are present in agroecosystems, particularly where pesticide use is limited. Their potential benefit as control agents against pest species in agroecosystems still requires research especially in the tropics (Green, 1996A, Russell-Smith and Stork, 1995).

This study provides some basis for evaluating the significance of spiders as potential biocontrol agents. I have proposed that the effectiveness of spider communities in controlling insect pests depends on several criteria. Spiders must:

1. be present in significant numbers,
2. have a range of capturing techniques so that they capture a variety of insects,
3. be active as predators when insects are active, and
4. capture a significant proportion of the population of pests present.

If spiders can meet all four criteria, then they can be considered as potential biocontrollers in agroecosystems. Their overall contribution will also depend on the extent to which they have a negative impact on other pest predators.

Although the two surveys in this study were of short duration they do indicate a number of important findings which have not previously been documented for spiders in tropical mango orchards. In both surveys there were significant numbers of spiders at all times of the day in the unsprayed mango orchards surveyed. The number of insects present and the number of insects caught as prey showed some diurnal variation but only one relationship was statistically significant. A relationship was shown between the number of insects present and the number caught by spiders.

There is a need to extend surveys of this type both spatially and temporally to give a greater understanding of the relationship involved. The following discussion expands on the significance of such relations.

A diverse community of spiders allows for a greater range of capturing techniques and consequently, a greater range of insects can be caught. Marc and Canard (1997) suggested that species considered separately are quite specialised predators. Hence spider species are not equally efficient in controlling a precise pest and a greater biodiversity increases the potentialities of finding a particular species able to do so in a given agroecosystem. There was a considerable taxonomic diversity of spiders in the foliage of the mango trees. A total number of 29 species were observed in the two surveys. The dominant family was Araneidae belonging to the orb-weaving guild. Spiders from the genus, *Eriophora* specialise in nocturnal capturing of prey. The golden orb-weaving spider, *Nephila* built large golden webs in open areas usually between high trees (Foelix, 1996). The *Cyrtophora* build lattices or tents attached to their orbs (Foelix, 1996). This allows them to ensnare insects that may escape from the orb. These insects often fall into the lattice and become further entangled. Another genus in this family is *Acyrs* that has abandoned its web in favour of an ambushing strategy (Green, 1996B). This family has a diverse range of capturing techniques that should result in the capture of a wide variety of insects in the mango orchard.

The orb-weaving spiders were the dominant guild observed in the mango orchard. This guild also included the family Tetragnathidae (long-jawed spiders), which capture prey by horizontal with very radii orb web (Foelix, 1996). The Theridiidae that belong to the tangle weaving guild, were also abundant (Foelix, 1996). These spiders produce a lattice of fine web that ensnares passing insects. The cribellate spiders that are represented by *Badumna* sp. 56 also produce a sticky mass of lattice web, which is much stickier than that of the Theridiidae (pers. obs.). These two groups capture prey that move under the protection of the foliage in the trees.

Although the hunting spiders were not present in large numbers, those that were present offered a variety of hunting techniques. The lynx spiders *Oxyopes maculata* (F. Oxyopidae) represented in mango orchards are considered to be active day-time hunters. This family has been identified in the U.S.A. as the most frequently occurring species in field crops in agroecosystems (Young and Edward 1990). *Peucettia viridans* was observed feeding on cotton fleahoppers that are a key pest in cotton (Nyffeler *et al.* 1987). No work has been done on this family in tropical orchards. Their populations are not as high in number in mango orchards, as they are in temperate cotton and crops, so they may not be as important here as they are in other crops. Other hunting spiders were observed in the mango orchard. Salticidae are active hunters jumping on their prey as they approach (Green, 1996B). Heteropodidae, Thomisidae and Clubionidae tend to 'sit and wait' for their prey Green, 1996B and pers. obs.).

Of the predators observed in the orchards, over 98% were spiders. At times, throughout the day and night, no insect predators were observed in the orchard. Twenty-nine species of spider were observed, in comparison to the four species of predatory insect. These findings are similar to De Barro (1992) who found that spiders dominated the predatory fauna of perennial grasses. He reports only 11 species of spiders dominated the predatory fauna a perennial grass pasture in South Australia but grassland communities are structurally less complex than tree communities. The only predatory insect found was *Platycoelus* sp. (Carabidae).

These two factors - abundance and diversity, suggest that spiders in mango orchards meet Criteria 1 and 2 for biocontrollers. Criterion 3 for biocontrollers is that they must be active as predators when prey are active. Three of the four spider guilds were present throughout the 24 hour sampling periods (Figure 3.1 and 3.2). More insects were active during the day than at night, with 80% and 77% of the total insects (Surveys 1 and 2, respectively) collected between 6 am and 6 pm. There was a distinct period of insect inactivity between 10 pm and 6 am with an average of 1.81 insects trapped/hour compared to an average of 5.27 insects trapped/hour over the 24 hour period (Table 3.3 and 3.4). This is a similar result to Springate and Basset (1996) who found that 72% of the arthropods were collected during the day in submontane rain forest in Papua New Guinea. There was a difference in the sampling technique between their work and mine, although both studies used interception traps. Springate and Basset (1996) used malaise traps and collections were made at 12 hour intervals. By contrast, I used sticky traps and collected them every 2 hours. Despite these differences, the results appear to be broadly comparable.

The temporal patterns of spider abundance and insect activity in the two surveys (Figure 3.3 and 3.4) in this orchard differed slightly. In both surveys relatively large numbers of spiders were observed at night when insect activity was at its lowest. However, spiders were also present in substantial numbers during the day-light hours when insects were most active. The reason for the observation of relatively large numbers of spiders during the night is unclear, but may relate to an attempt to reduce energy expenditure. If the timing of insect activity is variable from day to day it may be more energetically efficient to set a web for an extended period. This would increase the average chance of successful capture of any available prey.

The degree to which insects are subject to various forms of environmental stress will shape the diurnal patterns of activity (Young, 1990). In general, insect activity varies due to temperature, humidity and photoperiod. Both surveys were performed in spring and similar patterns of activity can not be expected throughout the year. It is reasonable to conclude however, that for spiders to be effective predators in these orchards, they would have to be active during the day and night throughout the year. This would allow them to utilise the insects during their maximum activity periods. The results from Chapter 2 suggest that this is the case. Further studies are required to determine the patterns of insect activity throughout the year. However, it is tentatively concluded that spiders in mango orchards meet Criterion 3 for successful biocontrollers.

The fourth Criterion for biocontrollers is that they capture a significant portion of the population of pests present. The spiders in this orchard had a very low catch rate with 0.38 and 0.26 prey/day in Survey 1 and 2 (respectively). Nyffeler *et al.* (1987) suggested that *Peutica viridans* in cotton and woolly croton plants in East Texas captured an average of less than one prey daily. Mansour *et al.* (1995) found that *Chiracnthium mildei* consumed 18.9 mites/day, an Oxyopidae species 16.8 mites/day, a salticid 10.1 mites/day and a theridiid 9.5 mites/day. The low capture rate for spiders in mango orchards may be due to the spring sampling time. The total number of prey counted during the surveys was also not great (Table 3.9). Further investigation is needed to determine how capture rates and total prey vary throughout the year. On the basis of the results of this study it appears that spiders do not capture a significant portion of insects.

There was no correlation between the number of spiders found in the orchard and the number of insects caught in sticky traps in this orchard (Figure 3.5). Further, neither the total number of prey caught at different times, or the number of prey caught per spider were found to be correlated with the number of spiders observed (Figure 3.6 and 3.10). This is similar to Kajak's (1965) findings. She found that there was no correlation between the abundance of Diptera in sweep-net samples and the densities of two species of *Araneus* in a meadow, nor did she find a correlation between spider density and the rate of prey capture per spider. However in the present study, both the total prey caught at each sampling time and the number of prey caught per spider were correlated with the number of insects caught in sticky traps. These results taken together with the data relating abundance of spiders, to numbers of trapped insects during the 24 hour cycle (Figure 3.3 and 3.4), indicate that spider activity is not closely associated with the activity of the insects in this orchard. These spiders appear to employ a "sit and wait" strategy which enables them to exploit insect prey whose temporal activity patterns may not be predictable.

One of the problems with using a polyphagous predator in biocontrol is that they may not only capture the pest species, but may capture other beneficial predators present. The main prey taken by spiders in the mango orchards were Hymenoptera. This appears consistent with other studies where Hymenoptera were common prey for spiders in agroecosystems. Herbenstien and Elgar (1994) found that *Nephila plumipes* caught mostly hymenoptera. Nentwig (1985) found winged Formicoidea and other Hymenoptera were (6-15%) of the prey found in the webs of four tropical orb-weaving spiders. The braconids were the most numerous insects present in the sticky traps in both surveys (Tables 3.3 and 3.4). These hymenopterans were observed swarming under the foliage of the mango trees during the day and many of these individuals became ensnared in the sticky traps that were placed low in the branches. They did not appear to go higher into the foliage where the majority of the spiders were observed. This was confirmed in the web surveys where only five braconids were collected from spider webs in the first survey (Table 3.6) and none were collected in the second survey (Table 3.7). This group of Hymenoptera are considered as beneficial insects in many agroecosystems as they parasitise Lepidoptera. The only lepidopteran species that are significant pests to mangoes are the tip borers *Pencillari jacosatrix* and *Chlumetia euthysticha*. These pests appear in late summer. Some flower feeding caterpillars are noted but do not cause significant damage (Cunningham 1989). It is therefore unlikely that these particular wasps are as beneficial as other species in this family.

Other beneficial insects collected in the sticky traps were the reduviid species. These are predatory Hemiptera were found in relatively high numbers. However, none were recorded as spider's prey. Although the data were limited it can be argued that spiders do not appear to impact on the potentially useful reduviids.

Aphids were one of the pest insects trapped. They are a pest in many crops. De Barro (1992) found that aphid numbers increased when spiders were removed from irrigated perennial grass pasture. The results in my study show that aphids were present and that spiders did prey upon them. However, Cunningham (1989) did not register them as a significant pest of mangoes. Several pest species were observed in the mango orchards I surveyed in years previous to this survey. However, the only species that appeared to increase to pest status was the mango scale (*Phenocaspis dilatata* and *Aulacaspis tubercularis*) and the pink wax scale (*Ceroplastis rubens*). Scale insects were not collected in the sample as the females adhere to the surface of leaves and spend their lives in one position. The males are the only ones that are mobile. Therefore, the females are unlikely to be collected in my samples and would not be intercepted in spider webs. Only the males can be considered as potential prey, although no males were collected from spiders' webs or sticky traps. This suggests that if scale insects are the only major pests then the use of pesticides specific to them and less detrimental to spiders could be used. This would control the scale insects and maintain the spider community allowing an integrated approach to the control of pests in mango orchards.

Other pests observed were the mango tipborer (*Penciciblaria jocosatrix*) which was a problem in 1994 in an immature orchard with trees less than two years old and Queensland fruit fly (*Dacus* sp.) in an adjacent orchard in January of that year (personal observations). The other species listed by Cunningham (1989) did not appear to increase to large numbers. When a comparison was made between the prey caught by spiders and the sticky traps, very few pest insects were collected in either.

Further investigations into the prey taken by these spiders are required, as there were no significant pest species found in the mango orchard during sampling. A true understanding of the interactions between the spiders and pest insects was not possible within the time constraints of this study. An in-depth examination of the type of insects, preyed upon by spiders is required. It is possible that some beneficial insects will become victims to spiders. This aspect of the spider's predatory role needs to be established as further identification of the Hymenoptera are required to establish if hymenopteran parasitoids are caught by spiders in significant numbers.

Riechert and Lockley (1984) discussed the role of spiders as biological controllers. They suggested that while they do not fit the role of the specialist predator or parasitioid that their pest control effects should be actively pursued. They suggested that conservation of the diverse spider fauna that is characteristic of most natural systems must be emphasised rather than the life histories and foraging behaviour of individual spider species. Individual spiders do not have controlling effects. However the spider community as a whole apparently does (Riechert and Lockley, 1984). It is essential that further investigation be undertaken into the actual role that spiders play in control of pest species in agroecosystem if they are to be considered in Integrated Pest Management. An investigation of the seasonality of pest species would enhance the understanding predator/pest dynamics in mangoes.

During the two surveys described here, the spider community appeared to fulfil the first three criteria to be considered as effective bio-controllers of pest insect criterion. Spiders were present in relatively high numbers compared to the insect predators and were constantly present within the orchard both day and night. This assured that they were active when the insects were active. They demonstrated a range of capturing techniques that allowed them to capture a variety of different insect types. The fourth criterion requires the total number of insects captured by spiders to be a high proportion of the insects present in the orchard. Unequivocally this research fails to answer this fourth criterion. Although no serious pests were collected in the sticky traps, the prey caught by spiders in the orchard reflected the number of insects and a correlation was found between the two. Never-the-less the proportion of insects taken by spiders was not high. For the spider community to be effective biocontrollers they must meet all four criteria. If further investigations prove that spiders do not take significant portions of insect pests then they can not be considered as beneficial predators in mango orchards.

CHAPTER 4

ACUTE AND CHRONIC EFFECTS OF PESTICIDES ON SPIDER COMMUNITIES.

4.1 INTRODUCTION

One of the problems with the use of pesticides in agroecosystems is that most of these chemicals have broad-spectrum effects and have the potential to remove beneficial predators as well as the pest insects. Spiders are likely victims of these chemical sprays as they are in direct contact with the pesticides during the spraying process. It is convenient to distinguish between acute and chronic effects of pesticides. An acute effect is a short-term event where the spiders are killed by the pesticides or the spiders may emigrate. This movement may be due to either the undesirable conditions produced by the pesticides or the absence of prey after the pesticide have been used. Alternately, there may be long term or chronic effects on the spider community. The structure of the spider community may be disrupted with the removal of particular species and the reduction in the number of individual spiders present in the orchard. Subsequently some species may not return to the orchard, either because they do not have the opportunity to re-establish, due to the chronic effects of the pesticide residues or that migration into the orchard is inhibited. Such disruptions to the assemblages of spiders are likely to show changes in the capturing abilities of the spider community as a whole.

We would expect *a priori* that the frequency of pesticide spraying would have a significant effect on the composition of the spider community. A frequently sprayed orchard should show chronic-type effects while an infrequently sprayed orchard should be dominated by acute effects (and the possibility of recovery). Unsprayed orchards are typical of organic farming practice while frequently sprayed orchards are typical of farming practices for the export market.

Many insects develop resistance to pesticides. It is not unreasonable to argue that some spiders may also develop resistant. Both spiders and insects are arthropods which have a similar cuticle layers made of a protein called chitin (Arms and Camp, 1982). Mansour *et al.* (1983) suggested that spiders have been found to be reduced or eliminated by non-selective insecticides although some resistance has been noted. In mango orchards they would be exposed to the same pesticides at similar concentration when crops are sprayed. These spiders will either remain in the orchards after spraying or be among the first species to return to the orchard after the spray event. They may be important in the initial stages of the re-colonisation of the orchards after pesticides are used. Further investigation of resistant predators may reveal possibilities for augmentation into orchards to enhance the capturing capabilities of the spider assemblages present.

The effects of pesticides on spider communities in mango orchards were investigated in two surveys October, 1993 to October, 1994, and December, 1994 to January, 1996. Comparisons are made between spider abundance, the abundance of adult and immature spiders, species richness, species diversity and the number of spiders in guilds in unsprayed, frequently and infrequently sprayed mango orchards using univariate and multivariate techniques. This study contributes to the knowledge of spiders in Australian agroecosystems where pesticides are commonly used. It also provides a preliminary assessment of the most common spider species that maintain a predatory status in mango orchards that are unsprayed and sprayed with pesticides.

4.2 METHODS AND MATERIALS

4.2.1 The analysis of the chronic effects of pesticides using univariate methods

Sampling began in October, 1993. There were three categories of mango orchards: unsprayed, frequently and infrequently sprayed. This classification was dependent upon the amount and frequency of pesticide used in the orchard during the first three months surveyed. The infrequently sprayed orchards received heavy applications of fungicides (copper oxychloride and mancozeb) but minimal amounts of insecticides (methidithion, endosulphan and dimethoate). The frequently sprayed orchards received heavy applications of both fungicides and insecticides. Unsprayed orchards received no pesticides. The unsprayed orchards were the same orchards used in Chapter 2 to assess the abundance, species richness, species diversity and guild structure of the undisturbed spider community. There were three unsprayed, three frequently sprayed and six infrequently sprayed orchards. The locations of each site are described in Appendix 1 and shown in Figure 2.1. Details of the spray regimes for each orchard are presented in Appendix 2A. This study was continued until October, 1994. During this thirteen month period the orchards were sampled seven times (October, November, December,1993; March, May, August and October 1994).

A later more intensive study examined the effects of pesticides on spider communities in frequently sprayed and unsprayed orchards. This later phase sampled the same unsprayed and frequently sprayed orchards from the first study but ignored the infrequently sprayed orchards. These samples were taken each month over a 14 month period from December, 1994 to January, 1996 (inclusive) (See Appendix 2B). The sampling techniques for both phases were the same as those described in section

2.2.2. By sampling monthly, a greater understanding of the seasonal variations within these orchards could be obtained. A modification to the original experimental design was necessary in January, 1995. Another frequently sprayed orchard was found and collections started at that site in January, 1995. This replaced an orchard (Site F) whose owners had decided not to continue spraying pesticides. Only three replicates for each of the frequently sprayed and unsprayed orchards could be used in statistical analysis. No other matched unsprayed and frequently sprayed orchards could be found in the area. While, three replicates is not high, it is more than other authors have used (Mansour 1987b, Madsen and Madsen 1982).

In the first three samples (October, November and December, 1993), the immature and adult spiders were aggregated in the total number of spiders collected. There appeared however to be changes in the ratio of adult to immature spiders over the three months period. Therefore, in all subsequent samples (March, May, August and October, 1994 and for each month from December, 1994 to January, 1996) immature and adult spiders were recorded separately.

A list of the spider species identified in all the orchards during both surveys is supplied in Appendix 3. The number of species and the families to which they belong were counted to give an indication of the effect of pesticides on the abundance and types of spiders. Shannon-Wiener diversity indices were calculated using 'Primer v4.0' (Carr) to give an indication of the diversity of the spider community in each orchard type. The structure of the spider communities was assessed by guild analysis. Spiders were placed into four guilds in accordance with the type of capturing techniques they used (see section 2.2.3). These were orb-weavers, tangle-weavers, cribellate and hunting spiders. The univariate comparisons were performed between the unsprayed, frequently and infrequently sprayed orchards in the first survey (October, November, December, 1993; March, May, August and October, 1994) and unsprayed and frequently sprayed orchards at each month from December, 1994 to January, 1996. The abundances of spiders, species richness and diversity were square root transformated, then two-factor ANOVA's of sampling time and orchards type as factors were performed using the commercial software analysis package 'Systat' (Evanston, 1994). The number of immature and adult spiders and spider guilds were also square-root transformed and 3-factor ANOVA's with spider age (adult versus immature), sampling time and orchard type as factors, were performed using 'Systat' (Evanston, 1994). The guilds, orchard type and sampling time as factors were performed in a 3-factor ANOVA.

4.2.2 The multivariate analysis of the chronic effects of pesticides

The effects of pesticides on the spider community were also assessed using multivariate techniques. The relative abundances of spiders of each species, collected from the twelve orchards for October, November, December, 1993; then March, May, August and October, 1994 and the six orchards for the later 14 month period (December, 1994 to January, 1996) were compared. Multidimensional Scaling (MDS) was performed using Primer v4.0 (Carr). Warwick (1993) recommended the use of MDS to investigate the impact of oil spillage's from tankers. In these cases it was unusual to have data of the marine community before the pollution event. This is a similar case to mango orchards, as pesticides were used for a number of years before sampling began. In this study the Bray-Curtis distance formula was used from a report by Bray and Curtis (1957) (cited by Clark 1993) and the calculation was performed treating each sample as an independent replicate.

An ANOSIM test, a non-parametric multivariate statistical test (Clarke 1993), was used to test the null hypothesis that there was no significant difference in the relative abundances of spider species between orchard types (frequently sprayed or unsprayed).

4.2.3 The acute effects of pesticides

To assess the acute effects of pesticides one orchard was selected to examine the spider community immediately before and after spraying. The spider community was again sampled at a later date to determine if the spiders were re-populating the orchard. Most growers in the area used specialised tractor equipment that releases an aerosol of pesticide, allowing penetration of the whole orchard. This technique was not suitable for this experiment. Some mango trees in the orchard needed to be sprayed with pesticides, while other trees remained unsprayed, thus acting as controls for the experiment. For maximum coverage of each separate tree a manual spray unit was required. Site F, which was a small orchard with 46 mango trees was chosen (see Appendix 1). The equipment that was regularly used in this orchard consisted of a back-pack with an extension arm to reach the tops of the trees. This allowed the whole tree to be completely covered with the pesticide. The spray unit produced a very fine spray that could easily be blown onto adjacent trees. To reduce the risk of over-spray to other trees, the orchard was sprayed at dawn, while the air was still.

Five rows of trees with two groups of three trees in each row were selected. Each of these groups were randomly assigned as either 'sprayed' or 'unsprayed' trees, giving five groups of sprayed trees and five groups of unsprayed trees. One randomly chosen tree from each of the 10 groups was sampled the day before spraying occurred. The techniques used to collect and preserve the spiders were the standardised technique described in section 2.2.2. The trees that had been allocated into the 'sprayed' group were sprayed with methidathion on the 29th October, 1994. A different tree from each of the 10 groups was randomly chosen and sampled 4 days after the spraying event. The remaining un-sampled trees were sampled 11 days after spraying. This produced five replicates per tree type (sprayed or unsprayed). Consequently, the sample size was quite small. This sampling technique was unavoidable, due to the requirement to remove the spiders for identification. The results from these collections gave a comparison of the spider communities before and after the pesticide was used. Further, sampling 4 and 11 days after the spray event, an indication of the amount of time required for the spiders to return to this orchard after disruption by pesticides could be established.

The Wilcoxon Non-Parametric Paired Sample Test (1-tailed) (Zar 1984) was used to test the null hypothesis of the difference in the change in spider abundance in sprayed and unsprayed trees at four and eleven days following spraying. The second aspect was the diversity (as assessed by the Shannon-Wiener diversity index) of the spider community found in sprayed and unsprayed trees following spraying. The Wilcoxon paired sample test (1-tailed) was used to test the null hypothesis of no difference in the change in spider diversity in sprayed and unsprayed trees at four and eleven days following spraying. It was intended to replicate this trial. However, the owner decided to stop using pesticides in this orchard and another orchard that used similar spraying techniques could not be found.

4.3 RESULTS

4.3.1 Differences in species composition between sprayed and frequently sprayed orchards.

A comparison of the total number of spiders of each species collected in unsprayed and frequently sprayed orchards was performed. The data from the two separate studies were pooled and summarised in Table 4.1. Of the 127 species recorded, there were 83 species that showed a decrease in the number of spiders from unsprayed compared to frequently sprayed orchards, while nine were more abundant in sprayed orchards. The numerically dominant spider in frequently sprayed orchards was *Badumna* sp. 56. There were more individual spiders of this species collected from frequently sprayed orchards (206) than unsprayed orchards (137). *Argiope aethera* was common in both unsprayed (136) and frequently sprayed (119) orchards. Several species showed small non-significant differences between unsprayed and frequently sprayed orchards. These included *Araneus* sp. 9, *Nephila* sp. 49, and *Dianea* sp. (see Table 4.1). Four species had many more individuals in the frequently sprayed than unsprayed orchards. These were *Deliochus humulus, Oxyopes maculensis,* immature specimen 25 and *Archaearanea mundula*. The presence of these species in high numbers suggests that either they are resistant to pesticides being used or that under disturbance condition resulting from the spraying of pesticides some species are more competitive than others.

A summary of the total number and percentage of spiders in each family and the total number of species and percentage of species collected in each spider family in unsprayed and frequently sprayed orchards is shown in Table 4.2. The Araneidae was the most numerically dominant and species-rich family in mango orchards. There

Table 4.1: Summary of the number and species of spiders collected from three unsprayed (**Un**) and three frequently (**Freq**) sprayed mango orchard 21 sampling periods from October, 1993 to January, 1995.
* decrease in the number of spiders from unsprayed to frequently sprayed orchards

Spiders collected	Un	Freq	Spiders collected	Un	Freq
F. Araneidae			**F. Clubionidae**		
Araneus sp. 9	11	11	**Cheiracanthium* sp. 54	8	1
**Araneus* sp. 15	253	9	**Clubiona* sp. 21	22	5
**Araneus praesignis.*	66	15	**Clubiona* sp. 27	3	2
**Araneus* sp. 104	4	3	**Clubiona* sp. 181	2	
**Araneus* sp. 113	16		unidentified immature 83	1	1
**Araneus* sp. 129	16	2	*unidentified immature 137	5	
**Araneus* sp. 132	5	3	*unidentified immature 162	2	1
**Argiope aetherea*	136	119	**F. Desidae**		
Arkys sp.		1	*Badumna sp.* 56	137	206
**Cyclosa camelodes*	5	1	*Badumna* sp. 169		1
**Cyclosa* sp. 59	3		*Badumna* sp. 186		3
**Cyclosa* sp. 131	23	10	**F. Heteropodidae**		
**Cyclosa* sp. 173	12	3	*Olios* sp. 135	1	3
**Cyclosa trilobata*	4	1	*unidentified immature 47	1	
**Cyrtophora exanthematica*	58	29	**F. Linyphiidae**		
**Cyrtophora hirta*	67	39	Unidentified immature 183		4
**Eriophora* sp	1		**F. Lycosidae**		
**Gasteracanthus* sp. 26	5		Unidentified immature 48		1
**Gasteracanthus* sp. 81	12		**F. Oxyopidae**		
**Gasteracanthus mimax*	5	2	*Oxyopes maculensis*	9	12
**Gasteracanthus* sp. 176	2		*Psuedohostus squamous*	1	1
Nephila sp. 49	8	8	Unidentified immature 98	2	
**Nephila* sp. 75	6	2	**F. Pisauridae**		
**Ordgarius* sp.	1		*Dolomedes* sp. 18	13	7
Poltys sp.	7	26	**F.Salticidae**		
Unidentified immature 58a		4	*Bavia* sp. S24		1
Unidentified immature 93	4	14	**Cosmophasis bitaeniata*	9	
Unidentified immature 100		2	**Cytaea* sp. S18	20	
*unidentified immature 114	19		**Cytaea* sp. S26	1	
*unidentified immature 131	23	10	*Cytaea* sp. S34		1
*unidentified immature 132	5	3	**Cytaea* sp. S37	2	
Unidentified immature 152	5	13	**Helpis* sp.	1	
*unidentified immature 157	2	1	**Mospsis* sp.	14	1
*unidentified immature 164	5	2	**Opisthoncus* sp.	7	
*unidentified immature 175	1		**Tara* sp.	6	1
Unidentified immature 184		1	*unidentified immature S4	2	
Unidentified immature 185	2	3	*unidentified immature S7	1	
*unidentified immature 192	1		*unidentified immature S20	3	1
*unidentified immature 193	1		Unidentified immature S22	1	1
Unidentified immature 196		1	*unidentified immature S27	1	
Unidentified immature 197		1	*unidentified immature S28	4	1

Table 4.1 (continued)

F.Salticidae (Contin)			**F. Theridiidae (contin)**		
*unidentified immature S30	1		*unidentified immature 55	1	
*unidentified immature S33	2		unidentified immature 112	3	4
*unidentified immature S39	1		*unidentified immature 112b	11	1
*unidentified immature S41	1		*unidentified immature 116	2	
*unidentified immature S42	1		*unidentified immature 120	23	14
F. Scytodes			*unidentified immature 127	4	
Scytodes fusca		11	*unidentified immature 133	1	
F. Tetragnathidae			*unidentified immature 144	4	1
Deliochus humulus	10	16	unidentified immature 151		1
**Leucage* sp.	44	40	*unidentified immature 153	8	2
Phonognatha sp.	2	2	*unidentified immature 170	1	
unidentified immature 25	15	26	*unidentified immature 180	1	
*unidentified immature 32	10	1	**F. Thomisidae**		
*unidentified immature 79	3		**Dianea* sp. T1	23	21
*unidentified immature 86	2		**Thomisus spectabilis* T4	11	5
*unidentified immature 103	12		**Xysticus* sp.	10	3
unidentified immature 165	2	2	unidentified immature T10		1
F. Theridiidae			unidentified immature T12	2	5
Achaearania mundula	26	34	*unidentified immature T14	4	
**Archaearania* sp. 50	87	8	*unidentified immature T16	9	7
**Argyrodes antipodiana*	124	36	unidentified immature T18	8	9
**Argyrodes rhobopheid*	124		unidentified immature T21	1	1
**Euryopis* sp. 177	1		**F. Uloboridae**		
*unidentified immature 20a	150	15	*Philoponella* sp.	1	1
unidentified immature 29a		2	**Miagrammopes bradleyi*	14	6
*unidentified immature 29b	17	12	**F. Zodariidae**		
*unidentified immature 29c	3	1	*unidentified immature 24	4	
unidentified immature 28		2			

Table 4.2: A summary of the total number and percentages of spiders and spiders in each family, collected from unsprayed and frequently sprayed mango orchards for 21 sampling periods from October, 1993 to January, 1995.

	Unsprayed		Frequently sprayed		Unsprayed		Frequently sprayed	
Families	Total no. of spiders	% of total spiders	Total no. of spiders	% of total spiders	Total no. of species	% of total species	Total no. of species	% of total species
Araneidae	794	29.1	339	12.4	35	18.5	30	15.9
Clubionidae	43	1.6	10	0.4	7	3.7	5	2.6
Desidae	137	5.0	210	7.7	1	0.5	3	1.6
Heteropodidae	2	0.1	3	0.1	2	1.1	1	0.5
Linyphiidae	0	0	4	0.1	0	0	1	0.5
Lycosidae	0	0	1	0	0	0	1	0.5
Oxyopidae	12	0.4	13	0.5	3	1.6	2	1.1
Pisauridae	13	0.5	7	0.3	1	0.5	1	0.5
Salticidae	78	2.8	7	0.3	19	10.1	6	3.7
Scytodidae	0	0	11	0.4	0	0	1	0.5
Tetragnathidae	100	3.6	87	3.2	9	4.8	6	3.2
Theridiidae	591	21.6	133	4.9	19	10.1	14	7.4
Thomisidae	68	2.5	52	1.9	8	4.2	8	4.2
Uloboridae	15	0.5	7	0.3	2	1.1	2	1.1
Zodariidae	4	0.1	0	0	1	0.5	0	0
Total	1857	65.8	884	32.5	107	56.7	81	43.3

were a total of 886 individual spiders from 33 species in unsprayed orchards and 467 individuals from 32 species in frequently sprayed orchards.

4.3.2 Univariate analysis of the chronic effects of pesticides

The mean numbers of all the spiders collected in unsprayed, frequently and infrequently sprayed orchards during the time period October, 1993 to October, 1994 are shown in Figure 4.1. A two-factor ANOVA indicated significant differences between orchard types (F=5.956, P=0.004) and months sampled (F=2.659, P=0.023) and no significant interaction. An *a posteriori* Bonferroni test indicated that frequently sprayed orchards had significantly fewer spiders than unsprayed (P=0.007) and infrequently sprayed (P=0.014) orchards; and that there were significantly more spiders in October, 1994 than in October, 1993 (P=0.028) (see Table 4.3).

The graph in Figure 4.2 shows the mean number of spiders collected in frequently sprayed and unsprayed orchards for each month from December, 1994 to January, 1996. A 2-factor ANOVA indicated that there were significantly less spiders in frequently sprayed than unsprayed orchards (F=91.277, P<0.001). There were no significant differences in the number of spiders in each month sampled (F=1.628, P=0.105) and there was no significant interaction (F=0.846, P=0.611) (see Table 4.4).

The mean number of immature and adult spiders at the different sampling times for the two surveys and in different orchard types are shown in Figure 4.3 and 4.4. The number of adult and immature spiders collected during the months March, May,

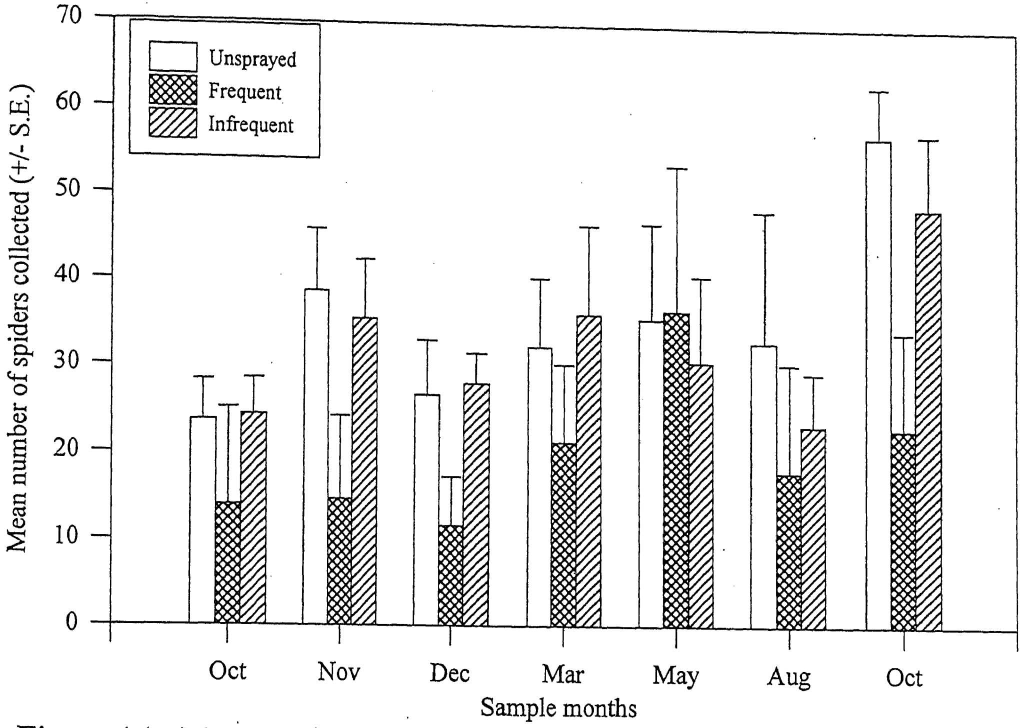


Figure 4.1: Mean number of spiders collected in unsprayed, frequently and infrequently sprayed mango orchards from October, 1993 to October, 1994 (n=3,3,6, respectively).

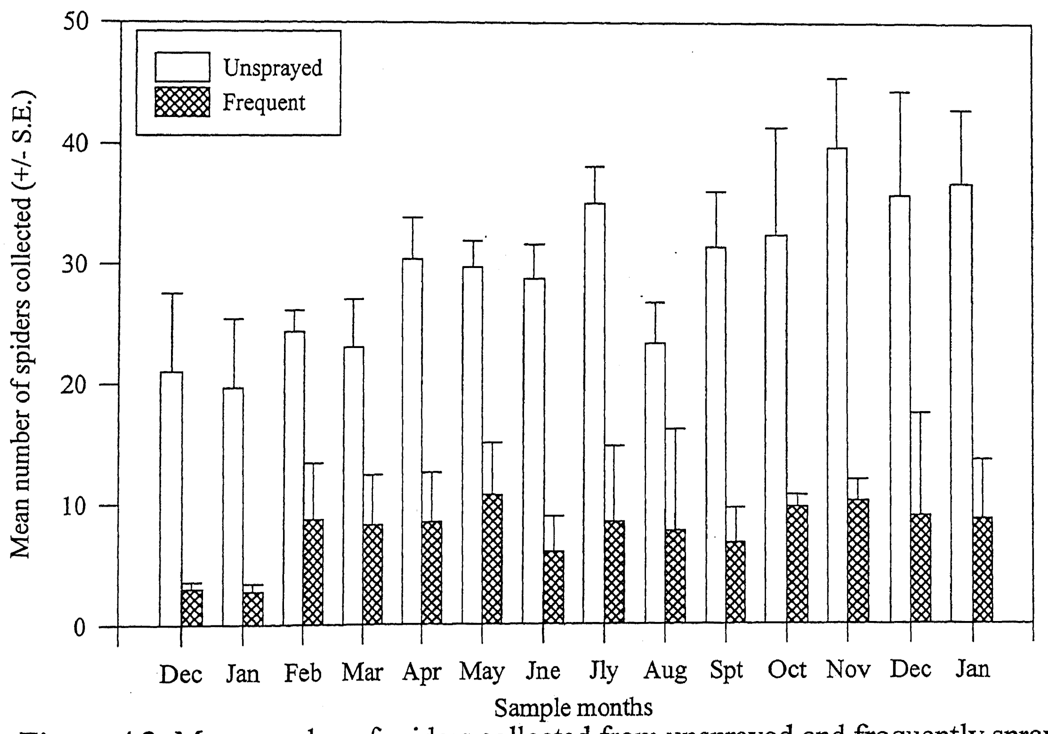


Figure 4.2: Mean number of spiders collected from unsprayed and frequently sprayed mango orchards from December, 1994 and January, 1996 (n=3,3, respectively).

Table 4.3: Summary of two-factor ANOVA's for mean numbers of spiders, number of species and Shannon-Wiener diversity indices unsprayed, frequently and infrequently sprayed orchards and sampling times for (October, 1993 to October, 1994).
*P< 0.05, ** P< 0.01, ***P< 0.001, NS not significant

Characteristics	*P* from two factor ANOVA			Results of Bonferroni test
	Orchard type	Sampling month	Interaction	
Mean no. of spiders	**	*	NS	frequently sprayed less than unsprayed ** P=0.007 frequently sprayed less than infrequently sprayed * P=0.014 October, 93 less than October, 94* P=0.028
Number of species	***	NS	NS	frequently sprayed less than unsprayed*** P=0.000 frequently sprayed less than infrequently sprayed*** P=0.001
Shannon-Wiener diversity indices	NS	NS	NS	

Table 4.4: Summary of two-factor ANOVA's for mean numbers of spiders, number of species and Shannon-Wiener diversity indices amongst unsprayed and frequently sprayed orchards and sampling times (December, 1994 to January, 1996).
***P< 0.001, NS not significant

Characteristics	*P* from two factor ANOVA		
	Orchard type	Sampling month	Interaction
Mean no. of spiders	***	NS	NS
Number of species	***	NS	NS
Shannon-Wiener diversity indices	***	NS	NS

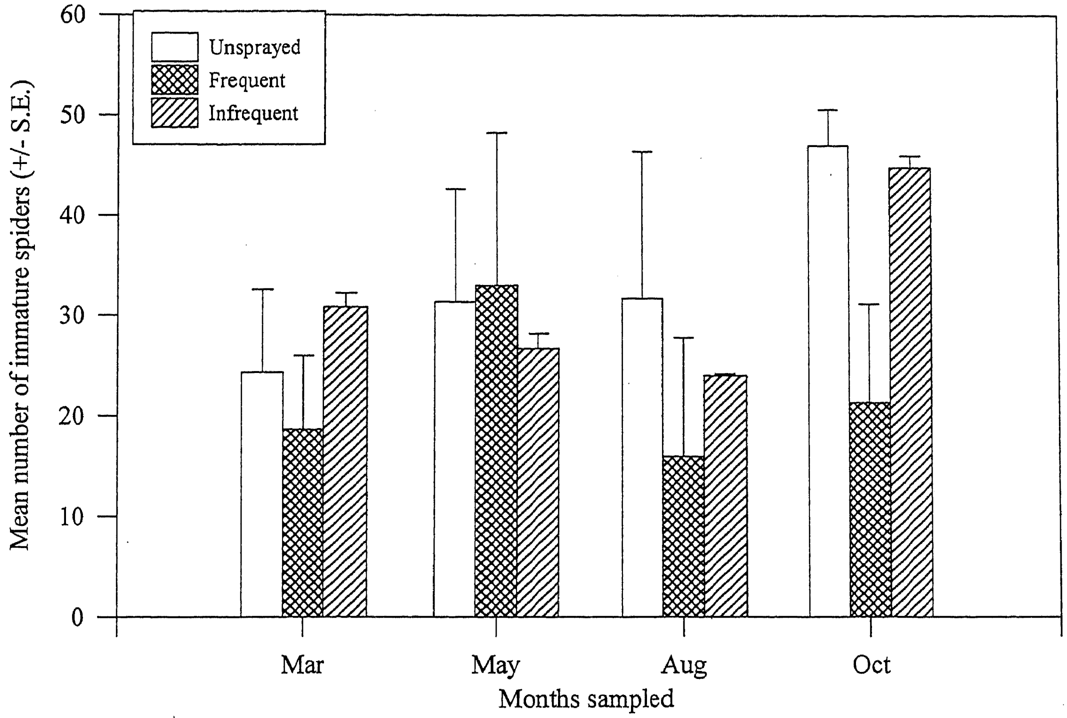


Figure 4.3: Mean number of immature spiders collected from unsprayed, frequently and infrequently sprayed mango orchards in March to October, 1994 (n=3,3,6 respectively)

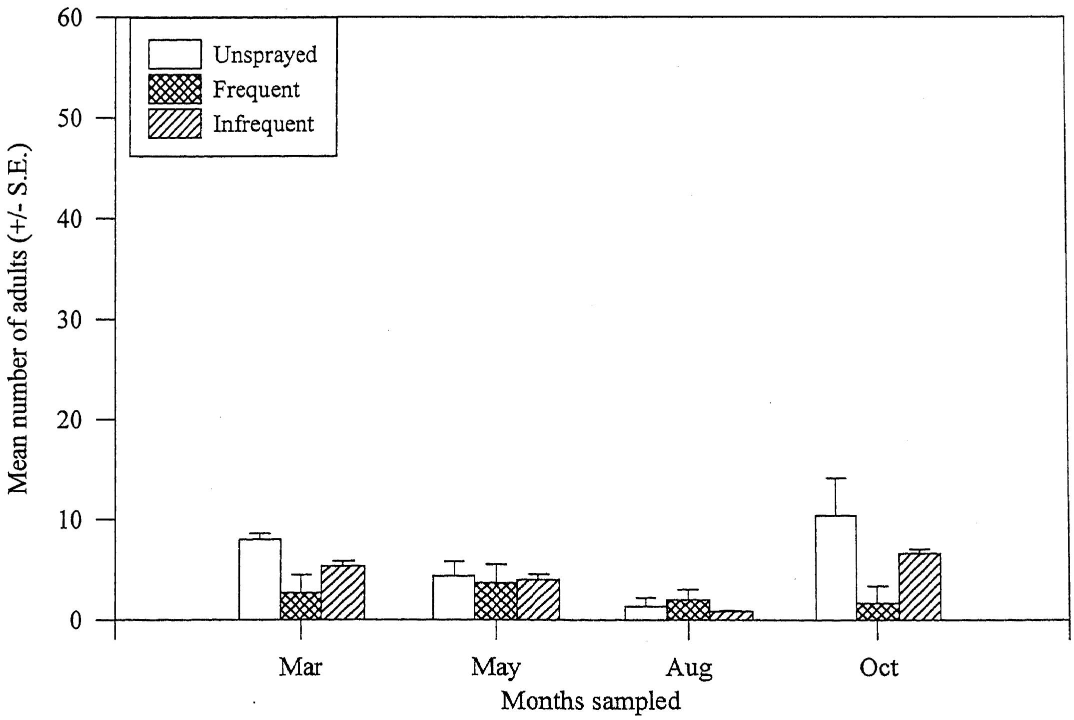


Figure 4.4: Mean number of adult spiders collected from unsprayed, frequently and infrequently sprayed mango orchards in March to October, 1994 (n=3,3,6 respectively).

August and October, 1994 in the three orchard types were analysed using a three-factor ANOVA. There were more immature spiders collected in these orchards than adults (F=64.976, P<0.001). There was no significant difference in the month sampled (F=0.974, P=0.410) or the orchard types (F=2.232, P=0.115) and no significant interactions (see Tables 4.5).

Table 4.5: Summary of three-factor ANOVA for mean numbers of immature and adult spiders (March, May, August and October, 1994).
***P<or=0.001, NS not significant

Characteristic	Significance
Age (immature / adults)	***
Months	NS
Orchard	NS
Age x Months	NS
Age x Orchard	NS
Months x Orchards	NS
Age x Months x Orchards	NS

The number of immature and adult spiders in frequently sprayed and un-sprayed orchards over the 14 sampled months (December, 1994 to January, 1995) is shown in Figure 4.5 and 4.6. The three way ANOVA indicated that there were more immature than adult spiders (F=166.944, P<0.001) collected and more spiders in unsprayed orchards than frequently sprayed orchards (F=54.238, P<0.001). There was no significant difference in the number of adult and immature spiders at the different months sampled. There was one significant interaction that between spider age and orchard type (F=13.171, P<0.001). There tends to be a relatively greater reduction of adult than immature spiders in sprayed orchards. The results of these analyses are summarised in Table 4.6.

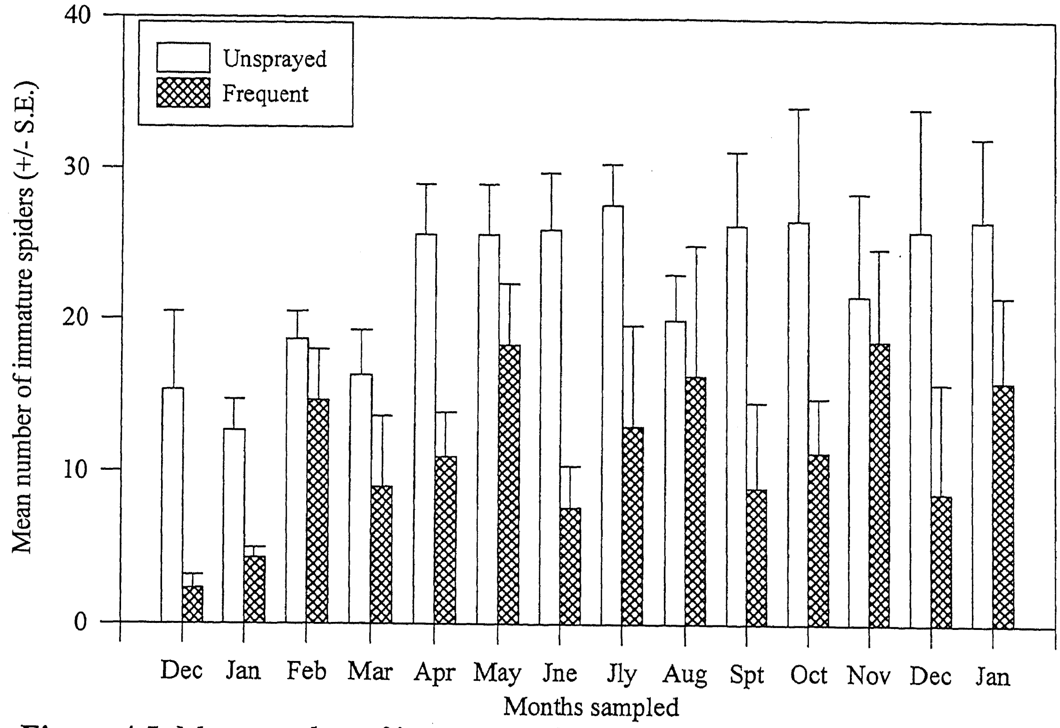


Figure 4.5: Mean number of immature spiders collected from unsprayed and frequently sprayed mango orchards in December, 1994 to January, 1996 (n=3,3 respectively).

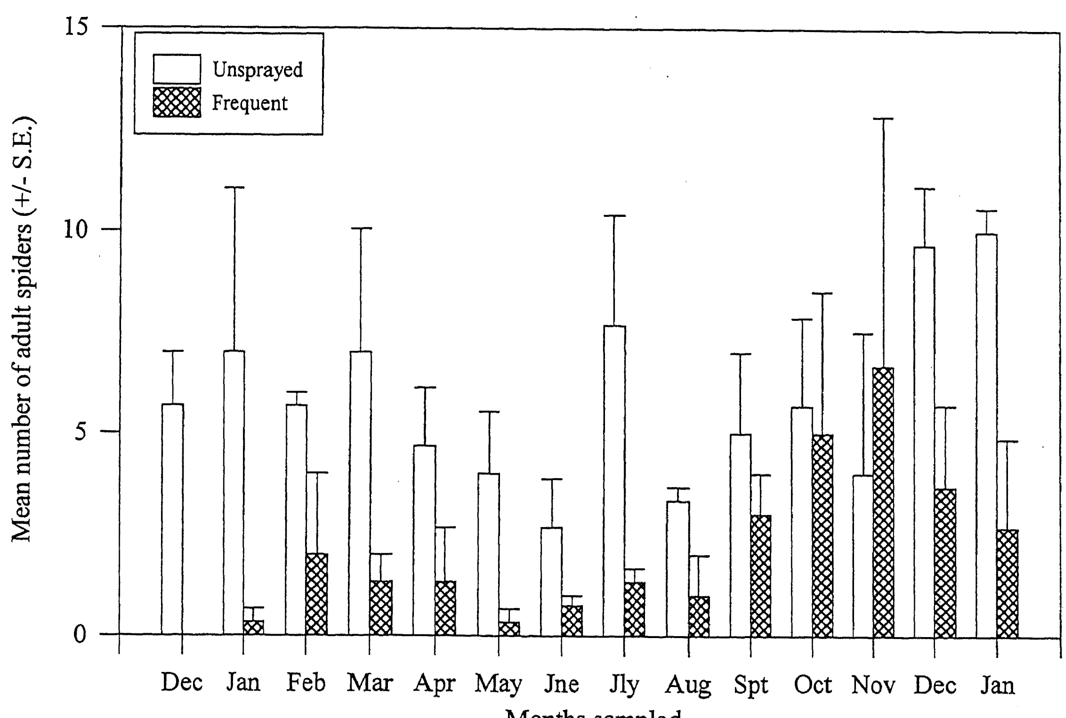


Figure 4.6: Mean number of adult spiders collected from unsprayed and frequently sprayed mango orchards in December, 1994 to January, 1995 (n=3,3 respectively).

Table 4.6: Summary of three-factor ANOVA's for mean numbers of immature and adult spiders (December, 1994 to January, 1996).
***P<or=0.001, NS not significant

Characteristic	Significance
Age (immature / adults)	***
Months	NS
Orchard	***
Age x Months	NS
Age x Orchard	***
Months x Orchards	NS
Age x Months x Orchards	NS

An evaluation was made of the effect pesticides had on the number of species present in frequently, infrequently and un-sprayed orchards (Figure 4.7). There were significant differences in the number of species present in the three types of orchard (F=12.775, P<0.001). The Bonferroni test showed that there were less species in frequently sprayed than unsprayed orchards (P<0.001); and in frequently than infrequently sprayed orchards (P=0.001). However, the number of species did not change significantly over the months sampled (F=1.361, P=0.244) and there was no interaction (F=1.483, P 0.155). These results are summarised in Table 4.3. Similar results were found when comparing monthly data (December,1994 to January,1995) of frequently sprayed and unsprayed orchard types (see Figure 4.8). There were less spider species in frequently sprayed orchards than unsprayed and no difference in the numbers between sampling times (orchard type F=86.825, P<0.001, months F=1.671, P=0.093) and there was no interaction (F=0.709, P=0.747) (Table 4.4).

Shannon-Wiener diversity indices for frequently, infrequently and unsprayed orchards for each of the 7 months sampled was calculated (Figure 4.9). There were no significant differences between orchard types (F=1.775, P=0.178) or months sampled (F=0.866, P=0.525) and there was no interaction (F=1.128, P=0.354). A

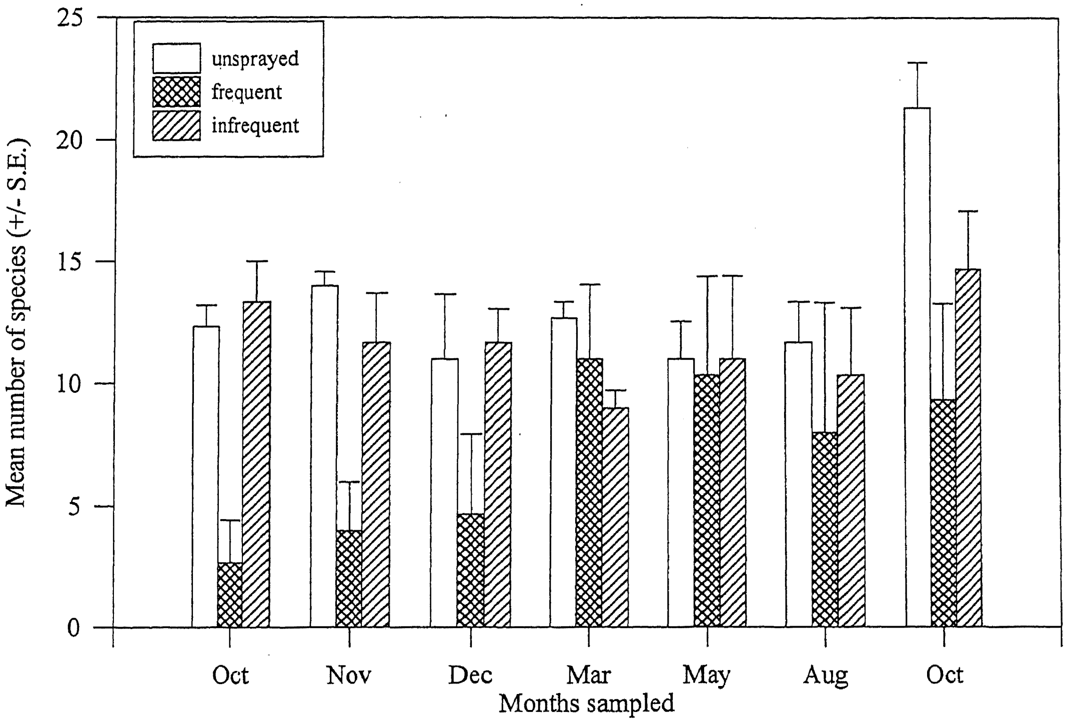


Figure 4.7: Mean number of spider species for unsprayed, frequently and infrequently sprayed mango orchards in October, 1993 to Octobber, 1994 (n=3,3,6, respectively).

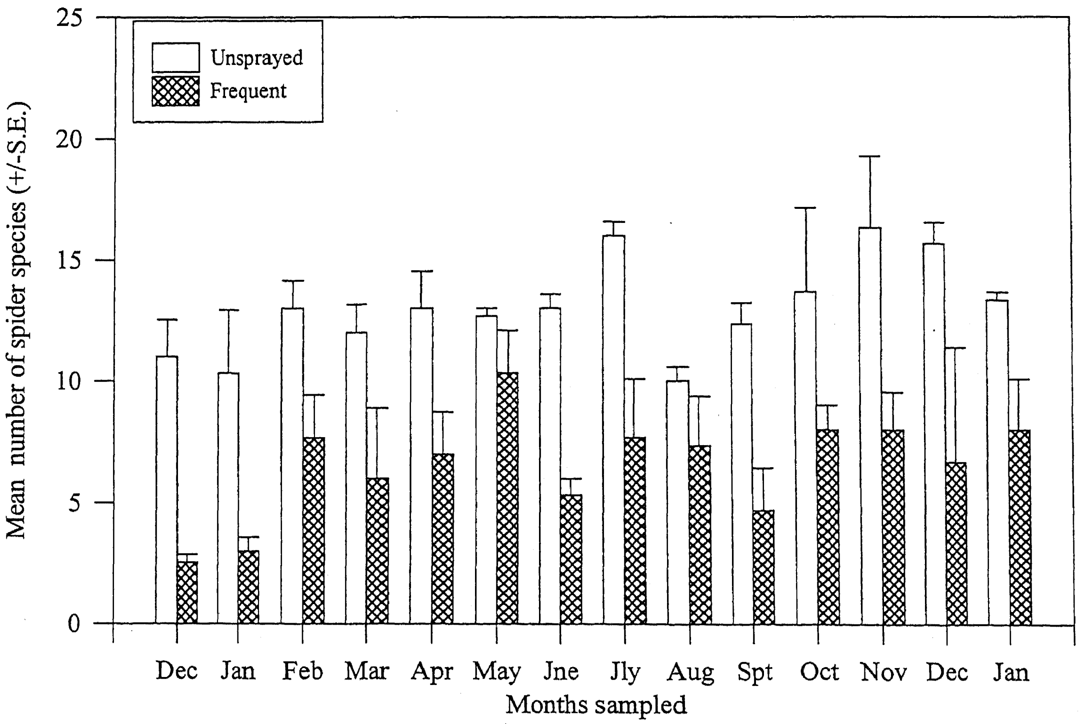


Figure 4.8: Mean number of spider species collected in unsprayed and frequently sprayed mango orchards from December, 1994 to January, 1996 (n=3,3,6, respectively).

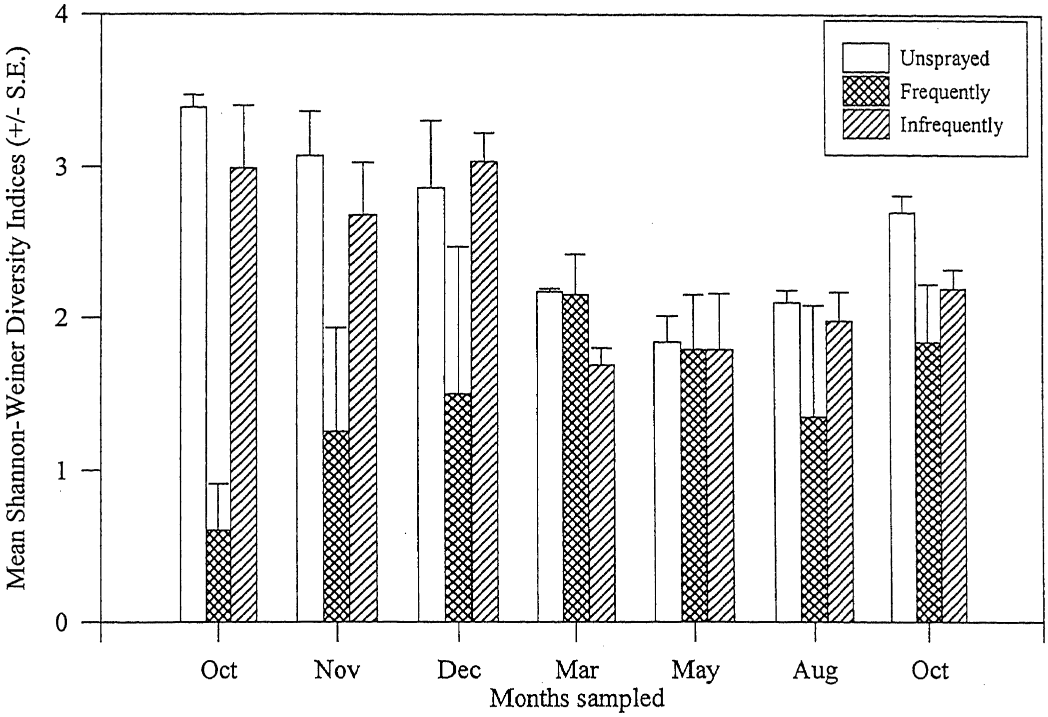


Figure 4.9: Mean Shannon-Wiener Diversity Indices for unsprayed, frequently and infrequently sprayed mango orchards in October,1993 to October, 1994 (n=3,3,6 respectively).

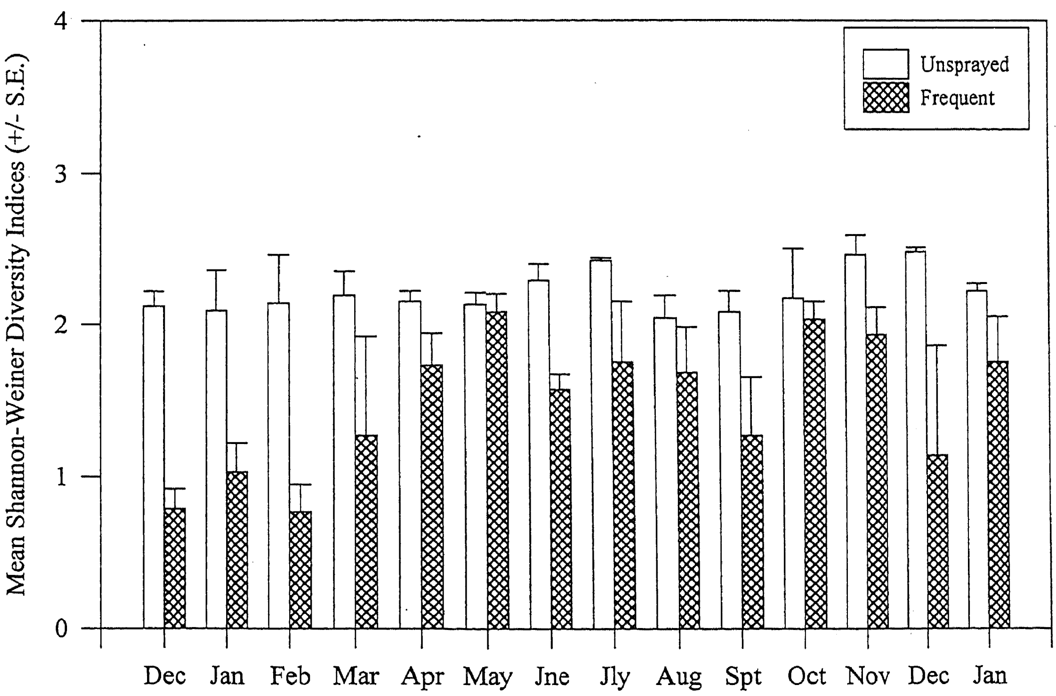


Figure 4.10: Mean Shannon-Weiner Diversity Indices for spiders collected in unsprayed and frequently sprayed mango orchards from December, 1994 to January, 1996 (n=3,3 respectively).

summary of the two-factor ANOVA's for unsprayed, frequently and infrequently sprayed orchards for the 7 months sampled from October, 1993 to October, 1994 is shown in Table 4.3.

The Shannon-Wiener diversity indices were calculated for frequently sprayed and unsprayed orchards and evaluated for a 14 month sampling period (December, 94 to January, 96) (Figure 4.10). Shannon-Wiener diversity indices were lower in frequently sprayed than infrequently sprayed orchards (F=41.740, P<0.001). There were no differences in the diversity of spiders collected monthly from December, 94 to January, 95 (F=1.303, P=0.239) and there was no interaction (F=1.107, P=0.373). A summary of the univariate analysis for frequently sprayed and unsprayed orchards over the 14 months sampled are shown in Table 4.4.

Figure 4.11 shows the mean number of spiders collected for the first survey in each guild, and orchard type during the first sampling period. A three-factor ANOVA with factors guild, orchard type and sampling month indicated differences in the number of spiders between in each guild (F=34.245, P<0.001). The Bonferroni test showed that there were more orb-weaving spiders than; tangle-weaving (P<0.001), cribellate (P<0.001) and hunting spiders (P<0.001). There was a difference in the number of spiders between the 7 months sampled (October, 1993 to October, 1994) (F=2.805, P=0.012). A Bonferroni test found that there were significantly more spiders in October, 1993 than in October, 1994 (P=0.014); and more in December, 1993 than in October, 1994 (P=0.026). There were also differences between the type of orchards (F=5.993, P=0.003). The Bonferroni analysis showed that there were significantly less spiders in frequently sprayed than unsprayed orchards (P=0.006), and frequently

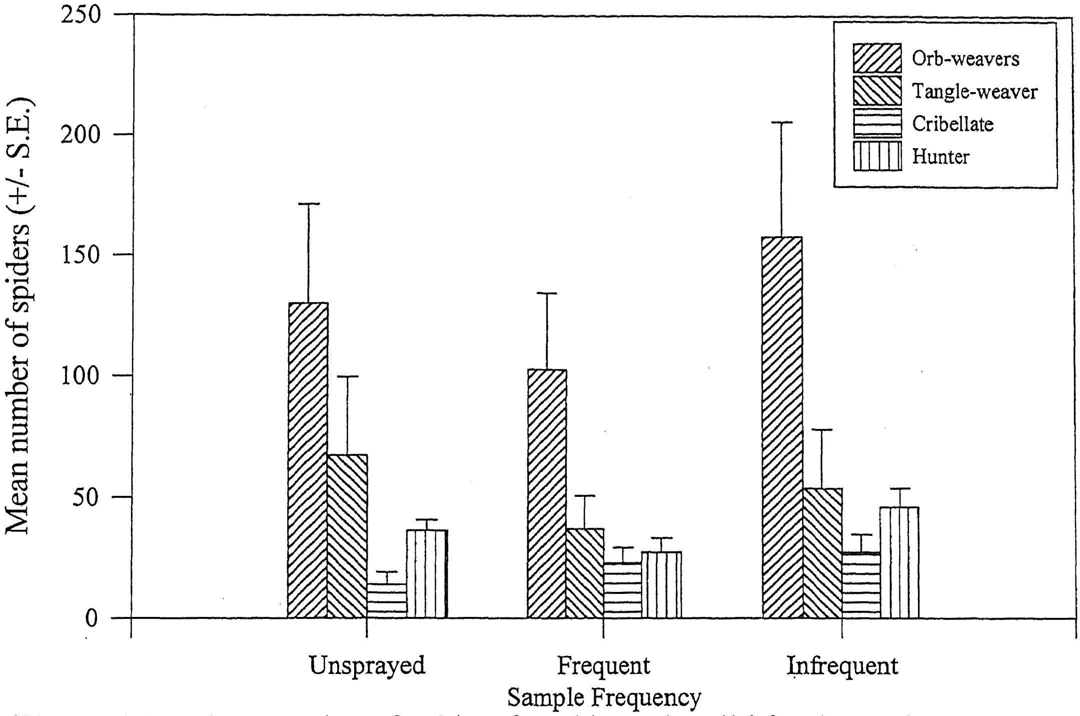


Figure 4.11: Mean number of spiders found in each guild for the total number in unsprayed, frequently and infrequently sprayed mango orchards from October, 1993 to October, 1994 (n=3,3,6 respectively).

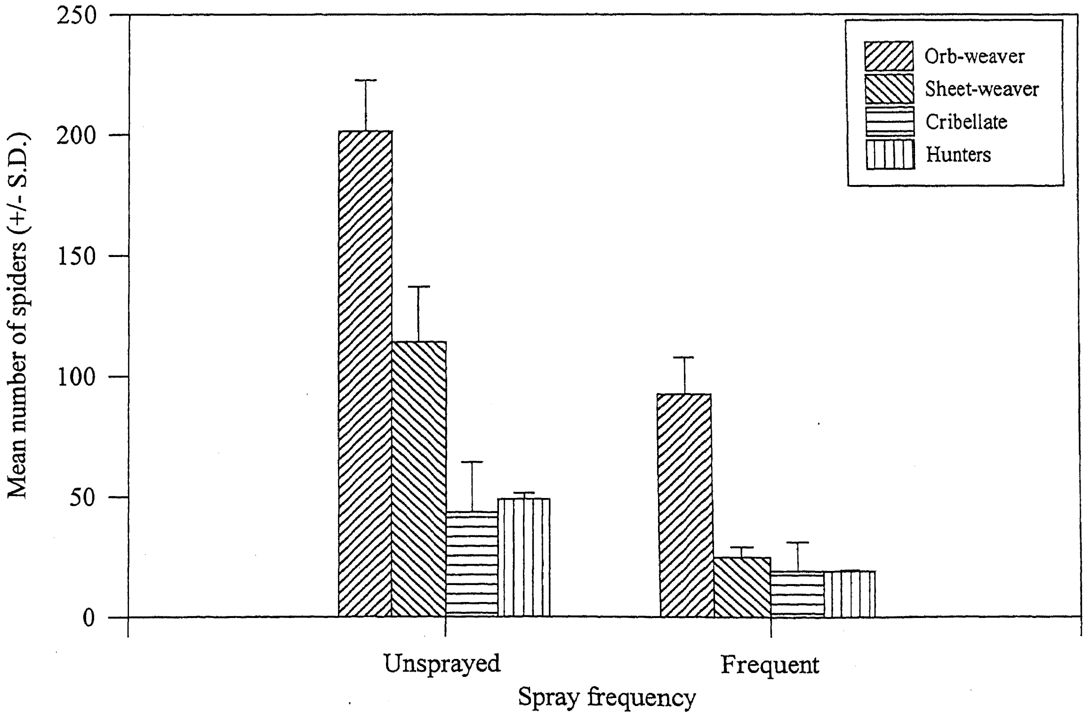


Figure 4.12: The mean number of spiders in each guild collected during sampling of unsprayed and frequently sprayed mango orchards from December, 1994 to January, 1996 (n=3,33 respectively).

sprayed than infrequently sprayed orchards (P=0.008). These results are summarised in Table 4.7. There were significant differences in the interactions between guilds and orchard types (F=2.958, P=0.008), and guilds and sampling months (F=2.211, P=0.004). These results are summarised in Tables 4.7A and 4.7B (respectively).

The Bonferroni results for the interaction between guilds and orchard types (see Table 4.7A) suggest that orb-weaving spiders are reduced relatively more than other guilds in sprayed orchards but are increased in infrequently sprayed orchards compared to unsprayed orchards. Cribellate spiders increased in frequently and infrequently sprayed orchards compared to unsprayed orchards.

The Bonferroni results for the interaction between guilds and sampling months are shown in Table 4.7B. These results primarily indicate that the orb-weaving guild varied between sampling times more than the other guild.

An analysis was performed to find the difference in the number of spiders in the four guilds (orb-weavers, tangle-weavers, cribellate and hunting) in unsprayed and frequently sprayed orchards for fourteen sampling months (December, 1994 to January, 1996). Figure 4.12 shows the pooled data for the 14 months comparing the mean number of spiders in unsprayed and frequently sprayed orchards. A three-factor ANOVA suggested that there were differences in the number of spiders amongst guilds (F=72.228, P<0.001). The Bonferroni test showed that there were more orb-weaving than tangle-weaving (P<0.001), cribellate (P<0.001) and hunting spiders (P<0.001) and more tangle-weaving than cribellate (P<0.001) and hunting spiders (P=0.005). There were also more spiders in unsprayed than frequently sprayed

Table 4.7: Results of three-factor ANOVA for numbers of spiders in guilds, orchard types and sampling times (October, November, December, 1993; March, May, August and October, 1994).
*P<or=0.05, ** P<or=0.01, ***P<or=0.001, NS not significant

Characteristic	Significance	Results of Bonferroni
Guilds	***	orb-weavers more than tangle-weavers*** P<0.001 orb-weavers more than cribellates*** P<0.001 orb-weavers more than hunters*** P<0.001
Orchard type	**	frequently sprayed less than unsprayed** P=0.006 frequently sprayed less than infrequently sprayed** P=0.008
Sampling months	*	October, 93 less than October, 94 * P=0.014 December, 93 less than October, 94* P=0.026
Guild x Orchard type	**	SEE Table 4.6A
Guild x Sampling months	**	SEE Table 4.6A
Orchard type x Sampling months	NS	
Guilds x Orchard type x Sampling months	NS	

Table 4.7A: The Bonferroni test results for guild x orchard interaction for three-factor ANOVA of frequently, infrequently and un-sprayed orchards for October, November, December, 1993; March, May, August and October, 1994.

Interaction	P=
unsprayed / orb-weaver x unsprayed / tangle-weaver	0.011
unsprayed / orb-weaver x unsprayed / hunter	0.009
unsprayed / orb-weaver x frequently / orb-weaver	0.000
unsprayed / orb-weaver x frequently / tangle-weaver	0.000
unsprayed / orb-weaver x frequently / cribellate	0.000
unsprayed / orb-weaver x frequently / hunter	0.000
unsprayed / orb-weaver x infrequently / orb-weaver	0.000
unsprayed / orb-weaver x infrequently / tangle-weaver	0.000
unsprayed / orb-weaver x infrequently / cribellate	0.000
unsprayed / orb-weaver x infrequently / hunter	0.000
unsprayed / tangle-weaver x unsprayed / cribellate	0.005
unsprayed / cribellate x unsprayed / hunter	0.004
unsprayed / cribellate x frequently / orb-weaver	0.000
unsprayed / cribellate x frequently / tangle-weaver	0.000
unsprayed / cribellate x frequently / cribellate	0.000
unsprayed / cribellate x frequently / hunter	0.000
unsprayed / cribellate x infrequently / orb-weaver	0.000
unsprayed / cribellate x infrequently / tangle-weaver	0.000
unsprayed / cribellate x infrequently / cribellate	0.000
unsprayed / cribellate x infrequently / hunter	0.000

Table 4.7B: The Bonferroni test results for guild x months interaction for three-factor ANOVA of frequently, infrequently and un-sprayed orchards for October, November, December, 1993; March, May, August and October, 1994.

Interaction	P=
orb-weaver / November, 93 x hunter / December, 93	0.013
orb-weaver / November, 93 x hunter / May, 94	0.018
orb-weaver / March, 94 x cribellate / December, 93	0.013
orb-weaver / March, 94 x cribellate / March, 94	0.029
orb-weaver / March, 94 x cribellate / August, 94	0.002
orb-weaver / March, 94 x cribellate / October, 94	0.001
orb-weaver / March, 94 x hunter / December, 93	0.003
orb-weaver / March, 94 x hunter / March, 94	0.008
orb-weaver / March, 94 x hunter / May, 94	0.004
orb-weaver / March, 94 x hunter / August, 94	0.009
orb-weaver / May, 94 x tangle-weaver / October, 93	0.00
orb-weaver / May, 94 x tangle-weaver / November, 93	0.00
orb-weaver / May, 94 x tangle-weaver / December, 93	0.00
orb-weaver / May, 94 x tangle-weaver / March, 94	0.01
orb-weaver / May, 94 x tangle-weaver / August, 94	0.03
orb-weaver / May, 94 x cribellate / October, 93	0.00
orb-weaver / May, 94 x cribellate / November, 93	0.00
orb-weaver / May, 94 x cribellate / December, 93	0.00
orb-weaver / May, 94 x cribellate / March, 94	0.00
orb-weaver / May, 94 x cribellate / May, 94	0.00
orb-weaver / May, 94 x cribellate / August, 94	0.00
orb-weaver / May, 94 x cribellate / October, 94	0.00
orb-weaver / May, 94 x hunter / October, 93	0.00
orb-weaver / May, 94 x hunter / November, 93	0.00
orb-weaver / May, 94 x hunter / December, 93	0.00
orb-weaver / May, 94 x hunter / March, 94	0.00
orb-weaver / May, 94 x hunter / May, 94	0.00
orb-weaver / May, 94 x hunter / August, 94	0.04
orb-weaver / August, 94 x cribellate / December, 1993	0.027
orb-weaver / August, 94 x cribellate / May, 1994	0.037
orb-weaver / October, 94 x cribellate / December, 93	0.014
orb-weaver / October, 94 x cribellate / March, 94	0.030
orb-weaver / October, 94 x cribellate / August, 94	0.002
orb-weaver / October, 94 x cribellate / October, 94	0.001
orb-weaver / October, 94 x hunter / December, 94	0.003
orb-weaver / October, 94 x hunter / May, 94	0.004
orb-weaver / October, 94 x hunter / August, 94	0.009
hunter / October, 94 x tangle-weaver / December, 93	0.04
hunter / October, 94 x cribellate / October, 93	0.04
hunter / October, 94 x cribellate / December, 93	0.007
hunter / October, 94 x cribellate / March, 94	0.016
hunter / October, 94 x cribellate / August, 94	0.00
hunter / October, 94 x cribellate / October, 94	0.001
hunter / October, 94 x hunter / December, 93	0.001
hunter / October, 94 x hunter / March, 94	0.00
hunter / October, 94 x hunter / May, 94	0.002
hunter / October, 94 x hunter / August, 94	0.005

orchards (F=91.425, P<0.001). An interaction between guilds and orchard types was found (F=10.213, P<0.001). A summary of the univariate analysis for the guilds from December, 1994 to January, 1996 is shown in Table 4.8. The Bonferroni test results are summarised in Table 4.8A. In this survey all guilds were reduced in frequently sprayed compared to unsprayed orchards. Orb-weavers and tangle-weavers guild were reduced relatively more than the other two guilds.

Table 4.8: Results of three-factor ANOVA for numbers of spiders in guilds, orchard types and sampling times(October, 1993 to October, 1994).
***P<or=0.001, NS not significant

Characteristic	Significance	Results of Bonferroni
Guilds	***	orb-weavers more than tangle-weavers*** P<0.001 orb-weavers more than cribellates*** P<0.001 orb-weavers more than hunters*** P<0.001 tangle-weavers more than cribellates*** P<0.001 tangle-weavers more than hunters** P=0.005
Orchard type	***	
Sampling months	NS	
Guild x Orchard type	***	SEE Table 4.6A
Guild x Sampling months	NS	
Orchard type x Sampling months	NS	
Guilds x Orchard type x Sampling months	NS	

Table 4.8A: The Bonferroni test results for guild x months interaction for 3-way ANOVA of frequently and un-sprayed orchards for December, 1994 and January, 1996.

Interaction	P=
orb-weaver / unsprayed x orb-weaver / frequently	0.000
orb-weaver / unsprayed x tangle-weaver / unsprayed	0.000
orb-weaver / unsprayed x tangle-weaver / frequently	0.000
orb-weaver / unsprayed x cribellate / unsprayed	0.000
orb-weaver / unsprayed x cribellate / frequently	0.000
orb-weaver / unsprayed x hunter / unsprayed	0.000
orb-weaver / unsprayed x hunter / frequently	0.000
orb-weaver / frequently x tangle-weaver / frequently	0.000
orb-weaver / frequently x cribellate / unsprayed	0.001
orb-weaver / frequently x cribellate / frequently	0.000
orb-weaver / frequently x hunter / unsprayed	0.029
orb-weaver / frequently x hunter / frequently	0.000
tangle-weaver / unsprayed x tangle-weaver / frequently	0.000
tangle-weaver / unsprayed x cribellate / unsprayed	0.000
tangle-weaver / unsprayed x cribellate / frequently	0.000
tangle-weaver / unsprayed x hunter / unsprayed	0.000
tangle-weaver / unsprayed x hunter / frequently	0.000

4.3.3 Multivariate analysis of the chronic effects of pesticides

The effects of pesticides on the relative abundance of all the spider species collected, was assessed through the use of a non-parametric multivariate analysis. The 'Primer' program was used to produce multi-dimensional scaling map. The scaling map calculated for frequently and unsprayed orchards in the 14 months sampling period (December, 1994 to January, 1994) is shown in Figure 4.13. Analysis of Similarities (ANOSIM) was performed to test the null hypothesis that there was no significant difference in the relative abundance of species in two sets of data (Clarke 1993). The differences were performed on the monthly data from December, 1994 to January, 1996 for three unsprayed and three frequently sprayed orchards. The Global 'R' was calculated at 0.153 ($P<0.001$) indicating a significant difference between unsprayed and frequently sprayed orchards.

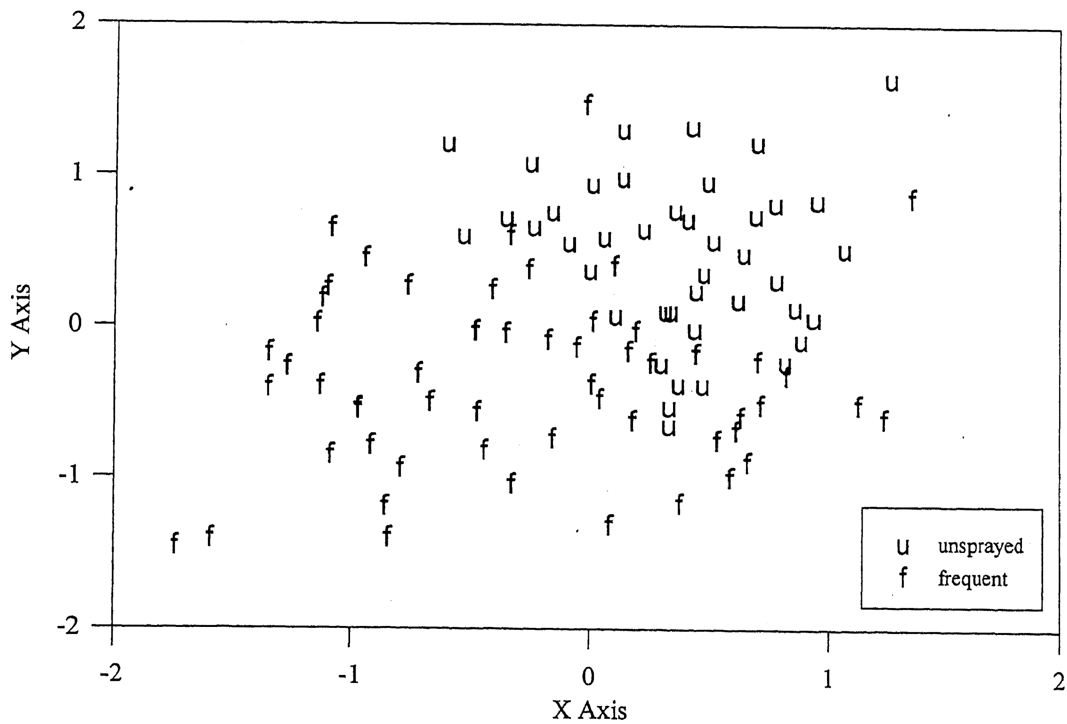


Figure 4.13: Multidimensional Scaling for unsprayed and frequently sprayed orchards (October, 1994 to October, 1995).

4.3.4 Acute effects of pesticides

Figure 4.14 shows the relative abundance of spiders before, 4 days and 11 days after spraying with methidathion in sprayed and unsprayed trees. These results suggest that there was a decrease in the number of spiders 4 days after spraying, in both the unsprayed and sprayed trees. It appears from Figure 4.14 that the decrease in abundance is greater in the sprayed trees than the unsprayed trees four days following spraying. However, one-tailed Wilcoxon non-parametric pair sample test indicated that the change in spider abundance four days after spraying was not significantly greater in sprayed than unsprayed at the 5% level of significance ($0.1<P<0.05$). After 11 days the spiders appear to increase in number in both sprayed and unsprayed trees. The increase was not significantly different between sprayed and unsprayed trees (one tailed Wilcoxon, $P=0.40$).

The calculated mean Shannon-Wiener diversity indices were plotted in Figure 4.15. The graph shows that there is less diversity of spiders 4 days after spraying and diversity increased after 11 days in both sprayed and unsprayed trees. The decrease in spider diversity was greatest in sprayed trees after four days (one tailed Wilcoxon paired sample test, $P=0.05$). There was no difference in the increase in diversity after 11 days between the sprayed and unsprayed trees.

Figure 4.16 shows the number of spiders collected in each guild in sprayed and unsprayed trees before, 4 days after and 11 days after spraying. Both the orb-weavers and tangle-weavers in sprayed and unsprayed trees have less spiders 4 days after spraying, and more 11 day after spraying than 4 days after. Again, the recovery of guilds after 11 days is similar for both sprayed and unsprayed trees.

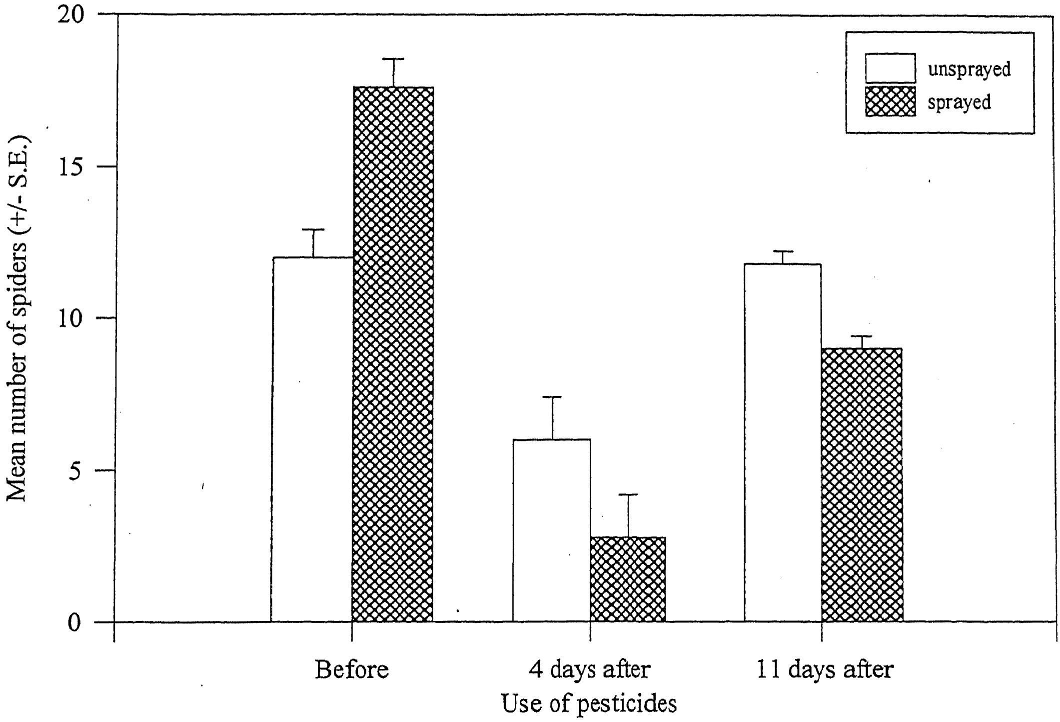


Figure 4.14: Total number of spiders collected from sprayed and unsprayed trees before, 4 and 11 days after spraying with methidathion.

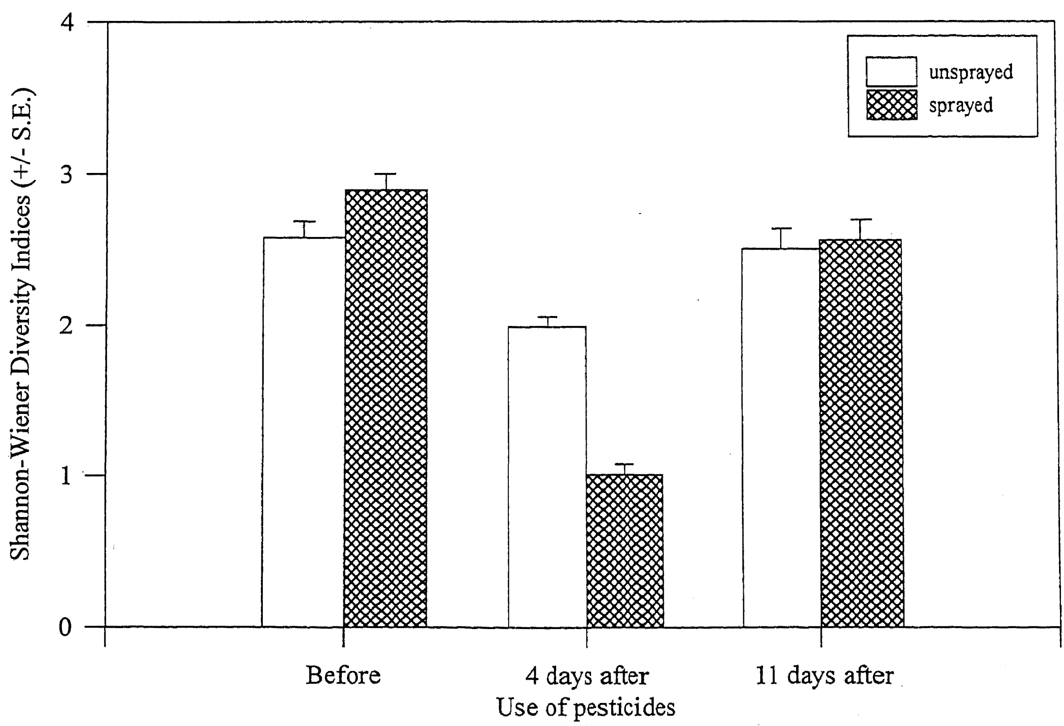


Figure 4.15: Shannon-Wiener Diversity Indices from sprayed and unsprayed trees before, 4 and 11 days after spraying with methidathion.

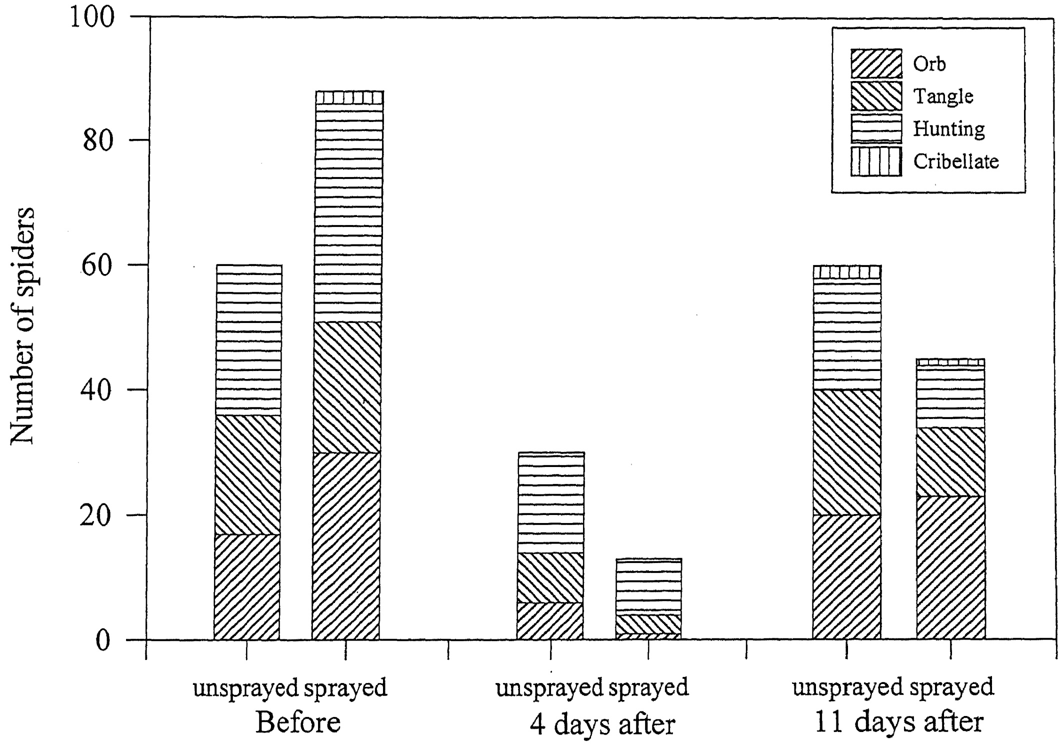


Figure 4.16: Number of spiders in each guild in unsprayed and sprayed trees before, 4 days and 11 days after spraying with Mehtidathion.

4.4 DISCUSSION

Many researchers have found that pesticides can reduce the number of spiders in orchards and crops. For example, a number of different pesticides are recorded as having varying effects on spiders found in agroecosystems (Mansour *et al.*, 1981; Mansour 1987A and 1987B; Van Den Berg *et al.*, 1990). The most commonly used insecticides in the mango orchards were endosulfan and methidathion. Both of these pesticides were found to kill *Chiracanthium mildei*, (a commonly occurring spider in Israel apple orchards) in two days (Mansour *et al.*, 1981). The endosulfan was tested under laboratory conditions and was found to be the most toxic of three pesticides tested (endosulfan, azinphos-methyl and cyhexatin) against *C. mildei*. The methidathion was also tested under field conditions in an apple orchard and was found to kill *C. mildei* plus another seven species of spider found in the orchard. It is possible that the solvent or carrier solution used in some of these insecticides may also kill spiders. Whatever the case spiders are know to be killed by the process of using these chemicals.

Initial observations in the mango orchards suggest that there were less spiders in orchards where pesticides had regularly been used. Of the 3102 individual spiders collected from three unsprayed and three frequently sprayed orchards during both surveys, only 36.6% of the total were collected in frequently sprayed orchards (Table 4.1 and 4.2). An analysis comparing unsprayed, frequently and infrequently sprayed orchards found that there were significantly less spiders in frequently sprayed, than unsprayed and infrequently sprayed orchards (Table 4.3). A similar result was found during the second survey over a 14 month period. There were less spiders in frequently sprayed than unsprayed orchards (Tables 4.4). This suggests that pesticides produce chronic or long-term effects in the spider communities by reducing the overall abundance of spiders in the orchards. This reduction may delay predatory response to insect outbreaks if spiders are found to be effective biocontrollers of mango pests.

For reasons discussed previously, an important aspect of the spider community is species richness. A species rich spider community offers a large variety of capturing techniques. In their simulations using computer models of individual spiders, Provencher and Riechert (1994) found that increases in the number of spider species and the variability of prey body sizes contribute significantly to greater prey limitation and spider survival. Riechert and Lawrence (1997) found that the spider assemblage in their study did approximately two times as well in limiting prey than did any given predatory species by itself. Therefore, the loss of species may reduce the ability of the spider community as a whole to act as beneficial predators in mango orchards. There were less species present in frequently sprayed than unsprayed and infrequently sprayed orchards in the first survey (Table 4.3) and less spiders in frequently sprayed compared to unsprayed orchards in the fourteen months of the second survey (Tables 4.4).

There was no difference in the Shannon-Wiener diversity indices of spiders in the first survey (Table 4.3). But in the second survey (December, 1994 to January, 1996) the Shannon-Wiener diversity indices were less in the frequently sprayed orchards than the unsprayed orchard (Table 4.4). There does not appear to be any obvious reason for this difference. Climatically and seasonally the two survey periods were similar with two weeks separating them. The multivariate results suggest that the use of pesticides in orchards caused changes in the spider assemblages (Figure 4.13). There were significant differences between unsprayed and frequently sprayed orchards ($P<0.001$).

The conservation of these potentially beneficial predators was addressed by Riechert and Lockley (1984) in a review of spiders as biological control agents. They suggested the restriction of insecticide treatments during the crucial periods in the life cycle of pest species and limitation of spraying to midday when spiders are inactive and in sheltered locations. If spiders prove to be important in integrated pest management then restrictions of pesticides will be required as they clearly have a negative impact on the spider community.

A greater understanding of the effects of pesticides on the spiders can be obtained by comparing the common species present in frequently sprayed and unsprayed mango orchards. There was a total of 124 spider species collected from 15 families; 82 species in the frequently sprayed and 107 species in unsprayed orchards (see Table 4.1 and 4.2). The dominant family in frequently sprayed orchards was Araneidae with a total of 339 individuals spiders collected from 30 species. This family was also numerically dominant in unsprayed orchards with a total of 794 individuals collected from 32 species. This family is common in central Queensland mango orchards and has a large number of species in both unsprayed and frequently sprayed orchards. The Araneidae is a very diverse group which shows a large variety of capturing techniques which may prove to be important as part of the beneficial group of predators in these orchards. The study in section 3.3.1 also found that this was the most common spider family both nocturnally and diurnally. Further investigation into the types of insects this spider family capture and their potential to capture orchard pests could give an indication of their potential as beneficial predators. This family may also warrant investigation into its conservation as it is a numerically dominant component of the spider assemblage.

Araneus sp.15 was the common spider (253) in unsprayed orchards. However, their numbers were much less in frequently sprayed orchards (9). *Argyrodes antipodiana* and *Argyrodes rhobopheid* also showed large differences in the number of individuals from 124 and 124 (respectively) in unsprayed to 36 and 0 (respectively) in frequently sprayed orchards (see Table 4.1). It appears that these species were susceptible to the use of pesticides. This may be due to *Araneus* sp.15's behaviour of building silken retreats on top of the leaf where they would be exposed to the direct affects of the sprays. *A. antipodiana* and *A. rhobopheid* with their cleptoparasitic existance in orb webs would be exposed to the direct affects of pesticides. Many of the other Theridiidae appear to be susceptible to pesticides as they build tangle-webs between branches. This would expose them to the direct effects of the pesticides when the trees are sprayed. The effects of pesticides were also reflected in several of the spider species. Eighty-four species out of 124 spider species recorded in these orchards were found to be less abundant in frequently sprayed than unsprayed orchards (see Table 4.1).

One of the most common species in this study was *Badumna* sp. 56. This species was common in unsprayed orchards (137) and numerically dominant in frequently sprayed orchards (206). *Argiope aethera* was common in unsprayed (136) and occurred in frequently sprayed orchards in high numbers (119) (see Table 4.1). Due to their numerical dominance and apparent resistance to pesticides these two species have potential as pest controllers in mango orchards in central Queensland. Four other spider species (*Deliochus humulus, Oxyopes maculensis,* immature specimen 25 and *Archaearanea mundula*) were found in higher numbers in frequently sprayed orchards and require further investigation. These species may have the ability to either withstand the impact of pesticides or return to the orchards quite soon after the direct effects of the pesticides have subsided, or both. In these cases, they may be relevant in augmentation studies where spiders and/or egg sacs may be distributed through out large areas of orchard. Riechert and Lockley (1984) suggested augmentation of spiders into large agroecosystems where immigration to the center of these large areas is low. This is an area that requires further investigation. Consideration should be given to enhancing spider activity which will maintain predatory pressure within these pesticide disturbed orchards.

Each family was placed into a guild that was associated with the type of capturing techniques used by the family. Araneidae were placed in the orb-weaving guild with the Tetragnathidae. This guild was the most numerically dominant in unsprayed orchards compared to tangle-weavers, cribellates and hunters (Figure 4.11 and 4.12). The number of orb-weavers in unsprayed orchards was greater than the other three guilds in all orchards (unsprayed, frequently and infrequently sprayed) orchards (see Table 4.7). As previously discussed in section 2.2.3 orb-weavers offer a great variety of capturing techniques. They appear to be disproportionately reduced by spraying which probably results in substantial loss in over all capturing ability of the spider community.

The types of insects taken by tangle-weavers warrants further investigation. There were large numbers of tangle-weavers present in unsprayed orchards, however like orb-weavers, the numbers appeared much lower in frequently sprayed orchards. If they are important predators then consideration should be given to the conservation of this group.

Cribellate spiders were not as common in any of the orchards compared to the other three guilds. Their low numbers in unsprayed orchards suggest that they may not be an important component of the unsprayed orchards. However, the numbers were higher in frequently and infrequently sprayed orchards. Therefore, further investigation is warranted into the type of prey captured by this group, their potential as biocontrollers and the effects of pesticide use.

The hunting spiders in October, 1994 were in greater number than cribellate and hunting spiders during the other months sampled (see Table 4.7B). At this time of the year the mango trees are in flower. The increase in hunting spiders could be associated with this event. Thomisidae (crab and flower spiders) are specialised hunters and are likely to move into the orchards during the flowering season. Species such as *Thomisus spectabilis* tend to sit on flowers and wait for prey that come to the flowers. While, *Xysticas* sp. was camouflaged in the dead flowers after flowering where small beetles and other insects were observed. Some of the hunting spiders may have a negative effect on insects by preying upon pollinators (personal observations). Further investigation is required particularly during the flowering season to establish this impact. Investigation into alternative methods of counting these spiders are also required. While the branches of these trees were diligently searched it is possible that some hunting spiders were undetected due to their secretive nature. It may be possible to use sticky traps along branches and in the foliage to detect this group to five a more comprehensive understanding of hunting spider abundances in mangoes.

The tentative results from the analysis of guilds found in mango orchards suggests that all the groups except cribellates are reduced in number by the frequent use of pesticides. Each of the four guilds requires further investigation into the type of prey they capture and their relative importance as biocontrollers of pest insects.

Investigations into the movement of spiders into the mango orchards may increase the understanding of the types of spiders that are important in re- colonisation of the areas after disturbance. The ability of spiders to move into an area is dependent upon their techniques of migration. Weyman (1993) suggested that spiders with high mobility are often the first to arrive in a crop newly infested with pests, and have a role in controlling pest outbreak until more specific predators arrive. Many species balloon into an area by releasing a silken thread and catching air currents. Bishop and Riechert (1990) found the majority of the spiders entering the garden plots arrived via ballooning. Approximately, 50% of these spiders were not found in nearby 'natural habitat'. Generally, it is the immature stage that has the ballooning capabilities.

The number of immature and adult spiders present in these orchards was also investigated and will be discussed briefly. In the first study over four sampling months (March, May, August, October, 1994), there was no difference between the number of immature spiders in unsprayed, infrequently and frequently sprayed orchards. The results from the fourteen months sampling found that there were more immature spiders in unsprayed than frequently sprayed orchards. The number of adult spiders in each survey was also investigated. The results from both surveys suggest that there were more adults in unsprayed than frequently sprayed orchards. (Table 4.5). Therefore, both immature and adult spiders appear to be reduced by the use of pesticides.

When the immature and adult spiders were compared, more immatures were collected than adult spiders. It is likely that immature spiders balloon into the area and establish themselves quickly after the effects of the pesticides have subsided. Immature spiders are often ignored by researchers. This is due to the difficulty in identifying them to species level. In many cases, the reproductive structures which spiders develop only on maturity are required for their identification. Immature spiders may be very important in these types of agroecosystems. They are in constantly higher numbers than the adults and are the first colonise orchards after disturbances. Therefore, they are more likely to offer immediate protection against pests in the orchard.

This study has shown that there were chronic effects of pesticides experienced by the spider community when sprayed frequently with pesticides. The number of individual spiders and the species richness were reduced in frequently sprayed orchards, while species diversity as measured by the Shannon-Wiener index was less in frequently sprayed compared to unsprayed orchards. Infrequently sprayed orchards were similar to unsprayed orchards that suggests that the minimal use of pesticides decreases the risk of disrupting spider assemblages in this type of agroecosystems probably because of the scope for rapid re-colonisation.

Further investigations are required into the immediate or acute effects of pesticides upon these spiders. The initial study suggests that the number of spiders and species diversity are reduced but after 4 days the number of spiders present in the orchard increases and begins to re-colonise. Investigation into spider re-colonisation could reveal that this occurs relatively quickly and that immature spiders are very important in this process.

In the experiment on the acute effects of spraying (although not significant at the 5% level ($0.1<P<0.05$) for abundance) it appears that the immediate decrease in both abundance and diversity was greater in sprayed than unsprayed trees, as expected (Figure 4.14 and 4.15). However, recovery from spraying was similar in both sprayed and unsprayed trees. A similar result was obtained for spider guilds (Figure 4.16). These results from this experiment require further investigation. As spray drift is likely to have occurred it would be more efficient to use a randomised block design and spray the trees in block rather than as separate trees. This would reduce the possibility of spray drift contaminating other trees. The experiment could be designed to investigate the effects of pesticides before and the next day after spraying. This would answer the question 'Do pesticides kill spiders within the first day after spraying?' Another experiment could examine the colonisation by spdiers after spraying has occurred.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY.

Mangoes are an important commercial crop in central Queensland. Like many crops insects and disease are a major problem. Therefore, pesticide use varies from high (for export market) to low (for organic market). As public awareness of environmental and human health risks from pesticides increases, there is demand upon farmers to produce crops that do not use large quantities of pesticides. The role of naturally occurring predators is being considered as part of an alternative approach to intensive pesticide use. The aims of this study were to investigate spiders as naturally occurring predators in mango orchards and the effects pesticides have on these predator communities.

Species richness and diversity play an important role in spider communities. The community of spiders in mango orchards appeared to have high species richness and diversity. Species richness and diversity give an indication of the range of hunting techniques used by spider assemblages. The most common guild found in both frequently sprayed and unsprayed orchards was the orb-weavers that have a wide range of capturing techniques. However intensive investigations into the abundance of hunting spiders and their role as pest controllers requires more study. Assessment of the capacity of spiders to be predators of pest insects was not conclusive. They appear to be present in relatively large numbers day and night and throughout the seasons. Therefore, they are likely to be available as predators when insects are active. Spiders made up 98% of the arthropod predators found in the orchards.

However, it appears from these initial results that spiders do not capture large numbers of prey. This requires more intensive investigation where the numbers and type of insect preyed upon are monitored over several seasons. No significant pest species were caught in these sticky traps during the October and November surveys. Investigations over the spring and summer period when pest insects are prevalent may show predator pest interactions and provide some insight into the potential of spiders as biocontrollers in mango orchards.

The long-term effects of pesticide use in mango orchards indicate a substantial reduction in abundance, diversity and guild structure. Several spider species including *Cytrophora exanthematica, Argiope aethera, Badumna* sp. 56 and *Araneus* sp. 15, were common in unsprayed orchards. However, *Araneus* sp. 15 was greatly reduced in frequently sprayed orchards. This indicates that the species was particularly susceptible to pesticides. By contrast, four species that were *Deliochus humulus, Oxyopes maculensis,* immature specimen 25 and *Archaearanea mundula* were found in greater numbers in frequently sprayed orchards. This may be because these species are resistant to the pesticides and/or they were advantaged by the removal of competitors. Further investigation into the predatory behaviour of these species may identify some species which are active predators and that can resist the impact of pesticide use. These species may be used to augment spider communities after the use of pesticides. This may ensure that there is a predatory assemblage present as pest insects move back into the orchards.

This study has increased the knowledge of spider communities in a commercially important agroecosystem in tropical Australia. Spiders are abundant in mango orchards and the community is rich and diverse. In general the spider community appears to fulfil at least three of the four essential requirements of biocontrollers. Spiders are present in large numbers, have a range of capturing techniques and are active during all seasons and at most times during the day and night. These results are inconclusive as the spiders were not shown to capture a significant proportion of the pest insects present in the mango orchards. Pest species were not recorded in significant numbers to evaluate the effect spider have on pest species. Pesticides were found to decrease the number of spiders present and change the spider assemblage. Frequently sprayed orchards show significant changes in community structure. There are some species that appear to be resistant to pesticide use. These may be possible biocontrollers in IPM where minimal pesticide use may still be required.

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APPENDIX 1

The location and site codes of each mango orchard used in this study and the intensity of pesticides used from October, 1993 to January, 1995 in Central Qld.

Site Code	Spray intensity*	Location
A	Unsprayed	Kinka Beach, Capricorn Coast
B	Unsprayed	Limestone Ck Rd, Yeppoon
C	Unsprayed	Evan's Rd, Bungendarra
D	Frequent	Limestone Ck Rd, Yeppoon
E	Frequent	Tamby Rd, Capricorn Coast
F	Frequent	Limestone Ck Rd, Yeppoon
G	Infrequent	Grove's Rd, Bungendarra
H	Infrequent	Evan's Rd, Bungendarra
I	Infrequent	Evan's Rd, Bungendarra
J	Infrequent	Evan's Rd, Bungendarra
K	Infrequent	William's Rd, Bungendarra
L	Infrequent	Millview Rd, Farnborough
M	Frequent	Limestone Ck Rd, Yeppoon

* Unsprayed orchards had not been sprayed with pesticides during the sampling period.
Frequently sprayed orchards were regularly sprayed with pesticides see Appendix 2A and 2B.
Infrequently sprayed orchards were sprayed with pesticides but at least two sampling times did not have any spraying between them see Appendix 2A.

APPENDIX 2A

The months that each frequently and infrequently sprayed orchard was sampled are listed below. The times given are the events pesticides were sprayed before sampling occurred. (The location of each site code is explained in Appendix 1 and illustrated in Figure 2.1.)

X no spray since last sampled

Site Code	Dates orchards were sampled for spiders						
	Oct, 93	Nov, 93	Dec, 93	Mar, 94	May, 94	Aug, 94	Oct, 94
D	5 days	1 wk	4 days	1 wk	1 wk	2 days	Same day
E	4 wks	2 wks	2 wks	Approx. 7 wks	X	approx 3 wks	3 days
F	3 wks	2 wks	4 wks	X	approx. 8 wks	1 wk	approx 4 wks
G	several wks	4 wks	X	X	approx 2 wks	1 wk	approx 3 wks
H	1 wk	4 wks	X	X	1 wk	X	X
I	12 mths	5 days	3 wks	10 wks	X	4 wks	1 wk
J	2 wks	2 wks	X	2 wks	X	3 wks	X
K	10 days	X	4 wks	2 wks	2 wks	7 wks	X
L	11 wks	X	1 wk	X	X	2 wks	X

APPENDIX 2B

The months that each frequently sprayed orchard was sampled are listed below. The times given are the events pesticides were sprayed before sampling occurred. (The location of each site code is explained in Appendix 1 and illustrated in Figure 2.1.)

X - no spray since last sampled

	Site Codes		
Months sampled	D	E	F
Dec, 94	approx. 5 days	5 days	approx. 5 days
Jan, 95	X	X	X
Feb, 95	approx. 4 wks	approx. 5 wks	approx. 3 wks
Mar, 95	approx. 1 wk	approx. 3 wks	X
Apr, 95	X	approx. 3 wks	X
May, 95	X	X	X
Jne, 95	approx. 4 wks	approx. 5 wks	approx. 4 wks
Jly, 95	approx. 4 wks	X	X
Aug, 95	X	X	X
Spt, 95	approx. 2 wks	approx. 3 wks	X
Oct, 95	X	X	X
Nov, 95	approx. 4 wks	approx. 3 wks	X
Dec, 95	approx. 1 wk	AM	X
Jan, 96	3 wks	2 wks	3 wks

APPENDIX 3

The species list of specimens collected from unsprayed, frequently and infrequently sprayed mango orchards from October, 1993 to January, 1996.

F. Araneidae
Araneus praesignis
Araneus sp.
Araneus sp.
Araneus sp.
Araneus sp.
Araneus sp.
Araneus sp.
Araneus sp.
Araneus sp.
Araneus sp.
Argiope aethera
Ariope probata
Arkys clavatus
Cytophora exanthematica
Cytophora hirta
Gasteracanthus mimax
Gasteracanthus sp.
Gasteracanthus sp.
Gasteracanthus sp.
Gasteracanthus sp.
immature 131b
immature 58a
immature 58b
immature 61
immature 93
immature 100
immature 1114
immature 142
immature 152
immature 157
immature 164
immature 175
immature 184
immature 185
immature 193
immature 196
Neoscona sp.
Nephila sp.
Nephila sp.
Nephila sp.
Poltys sp.
Ordgarius sp.
F. Clubionidae
Clubiona sp.
Clubiona sp.
Clubiona sp.
Cheiracanthium sp.
immature 83
immature 137
immature 149
immature 162
F. Desidae
Badumna sp.
Badumna sp..
Badumna sp.
immature 154
F. Heteropodidae
immature 62
immature166
immature183
immature 198
F. Linyphiidae
immature 183
F. Oxyopidae
Oxyopes maculensis
Psuedohostus squamous
immature 98
F. Pisauridae
Dolomedes sp.
F. Salticidae
Myrmarachne sp.
Bavia sp.
Bavia sp.
Cosmophasis bitaeniata
Cytaea sp.
Cytaea sp.
Cytaea sp.
Cytaea sp.
Helpis sp.
Lycidas sp.
Mopsus sp.
Opisthoncus sp.
Tara sp.
Immature S1
Immature S4
Immature S5
Immature S7
Immature S7
Immature S10
Immature S12
Immature S13
Immature S15
Immature S16
Immature S20
Immature S22
Immature S28
Immature S30
Immature S33
Immature S39
Immature S41
Immature S42
F. Scytodidaae
Scytodes fusca
F. Tetragnathidae
Deliochus humulus 119
Leucage sp. 8
Phonognatha sp. 121
unidentified immature 25
unidentified immature 32
unidentified immature 79
unidentified immature 86
unidentified immature 103
unidentified immature 109
unidentified immature 165
F. Theridiidae
Ariannes sp.
Archearania mundula
Archearania sp.
Argyrodes antipodiana
Argyrodes rhobopheid
Deliochus humulua
Euryopis sp.
Euryopis sp.
immature 3
immature 20a
immature 28e
immature 29b
immature 30
immature 55
immature 94
immature 112
immature 112b
immature 116
immature 120
immature 127
immature 133
immature 144
immature 151
immature 153
immature 170
F. Thomisidae
Dianea sp.
Dianea sp.
Thomisus spectabilits
Xyssticus sp.
immature T2
immature T10
immature T11
immature T12
immature T14
immature T15
immature T16
immature T21
immature T23
F. Uloboridae
Philoponella sp.
Philoponella sp.
Miagrammopes bradleyi
F. Zodariidae
immature 134

Total	**147**