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Spider ecology in pistachio orchards in South Africa

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Spider ecology in pistachio orchards in South Africa

By

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**Free my heart to feel again
Free my mind to understand
To run unfettered
Pull the blinders from my eyes
Let me see the endless skies
And drown here where I stand
In the beauty of the land**

- *Todd Nichols*



The Green Valley Nuts estate on the Orange river



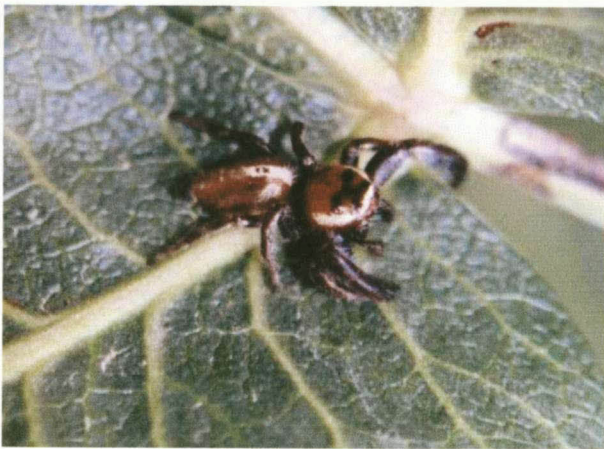
Orange River Nama Karoo grassland (veld)



Collecting arboreal spiders from white sheets



The pistachio stinkbug pest *Atelocera raptoria* Germar



The jumping spider *Thyene inflata* (Gerstaecker)



The ground spider *Setaphis bilinearis* Simon

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ABSTRACT

As part of a larger biomonitoring project on pistachio nuts, *Pistaciae vera* L. (Anacardiaceae), a new crop in South Africa, spiders (Arachnida: Araneae) were surveyed over a 2-year period (January 2001 to December 2002) at orchards on the farms Green Valley Nuts (GVN) and Remhoogte (REM) in the Prieska district, Northern Cape Province, South Africa. This study aimed to determine the diversity of spiders in the tree canopies, ground covers, and soil surface, and aspects of the biology and pest control potential of common species present. The various studies were conducted in the orchards GVN 1 (8 yrs old, 16 ha), GVN 19 (5 yrs old, 16 ha), and REM (9 yrs old, 1.5 ha).

A review was conducted to assess the effects of pesticide management on the spider fauna of orchards. It was found IPM, organic and unsprayed orchards supported a much greater diversity and abundance of spiders than conventionally managed orchards. The effects of particular pesticides on spiders were also assessed. Since the present study was conducted in IPM orchards one could expect spiders to play an important role as predators of arthropod pests.

During the 2-year survey of arboreal spiders, 200 trees were sampled per orchard primarily using insecticide fogging with dichlorvos as a knockdown agent. A total of 18 families and 87 species were collected. Numbers and diversity were highest in REM (n=2202, 70 spp.), followed by GVN 1 (n=2051, 64 spp.) and GVN 19 (n=1550, 47 spp.). Orchard age has a significant effect on spider abundance and diversity. The jumping spider, *Heliophanus pistaciae* Wesolowska (Salticidae), was strongly dominant, comprising an average of 53.8% of the fauna. Field observations on three common spiders, *H. pistaciae*, *Cheiracanthium furculatum* Karsch (Miturgidae) and *Neoscona subfusca* (C. L. Koch) (Araneidae), found them to prey on minor pest aphids (Aphididae), false chinch bugs (Lygaeidae), leafhoppers (Cicadellidae), thrips (Phlaeothripidae) and leaf beetles (Chrysomelidae), indicating that they have potential as biological

control agents. Endosulphan and parathion applications apparently had a minimal impact on the arboreal spiders, but further research is necessary to clarify this.

In the ground covers, 55 species in 14 families were collected between July 2001 and July 2002 (10 samples, 2000 sweeps/orchard). Numbers and diversity were highest in GVN 1 (n=631, 40 spp.), then REM (n=580, 35 spp.) and GVN 19 (n=549, 36 spp.). Ground cover composition significantly affect spider abundance, but not diversity. The lynx spider, *Peucetia viridis* (Blackwall) (Oxyopidae), dominated the fauna (29.3%), and *H. pistaciae* was also common (23.4%). Common spiders also preyed on the same pest organisms listed above in the ground covers, indicating that predation in this stratum may limit pest populations before they can reach damaging levels on the main crop.

In a comparison of the epigeic fauna of the three orchards and undisturbed grassland ("veld"), pitfall traps (all sites) and active searching (orchards only) were used to determine the diversity and abundance of spiders from August 2001 to July 2002. Pitfall catches were highest and most diverse in the veld (n=1112, 56 spp.), followed by REM (n=704, 35 spp.), GVN 1 (n=560, 26 spp.) and GVN 19 (n=428, 25 spp.). The dominant species in the orchards was the sheet-weaver, *Ostearius melanopygius* (O. P.-Cambridge) (Linyphiidae, 30% in the orchards), and the ground spider, *Asemesthes lineatus* Purcell (Gnaphosidae) in the veld (29.1%). Orchard disturbances had a significant negative effect on the abundance and diversity of epigeic spiders. Families dominating the pitfall trapping (Linyphiidae, Gnaphosidae, Lycosidae and Salticidae) also dominated active searching, but their relative abundance varied between methods.

In regard to its high abundance in pistachio orchards, the biology of *H. pistaciae* was studied to create a better understanding of its role in pest control. Arboreal populations peaked between December and March, depending on the year of sampling. Ground cover populations peak in early summer (December-January), which suggests a vertical migration to the tree canopies early in summer. Various aspects of the feeding and reproductive behaviour of this

species were observed in the laboratory, and described. Egg production in the field was greatest in early summer, but declined in subsequent months. An average of 12.6 eggs are produced per egg sac ($n=88$). An egg parasite, *Odontacolus* sp. (Scelionidae), and an undetermined polysphictine ichneumonid wasp, parasitic on adult females of *H. pistaciae* only, were associated with this spider.

The predation potential of *H. pistaciae* on the minor pest *Nysius natalensis* Evans (Lygaeidae) was assessed in laboratory and field tests. Predation rates were compared with vinegar flies, *Drosophila melanogaster* Meigen (Drosophilidae). Predation rates were significantly higher for both male and female spiders on *D. melanogaster* than *N. natalensis* during both days of the 48-hour-long tests. Predation of *N. natalensis* increased significantly for both sexes during the second day of the tests. Preference tests indicated a high preference of *D. melanogaster*, with increasing capture of *N. natalensis* with time. In the field, female *H. pistaciae* ($n=8$) preyed on a mean of 1.38 *N. natalensis* in 24 hrs. Factors affecting prey capture rates may be prey size, palatability and activity.

The present study showed spiders to be a diverse and abundant group of generalist predators in pistachio orchards, with 143 species representing 31 families collected in the surveys of the three strata. They may play an important role in the suppression of minor pests before they reach levels that may be damaging to pistachio trees and nuts. Further research is needed to clarify their predatory impact on pests, effects of pesticides, and the relative abundance and diversity of spiders in other orchard crops in the Prieska district.

UITTREKSEL

As deel van 'n groter biomoniteering projექ op pistachio neute, *Pistachio vera* L. (Anacardiaceae), 'n nuwe gewas in Suid-Afrika, was spinnekoppe (Arachnida: Araneae) versamel oor 'n 2-jaar periode (Januarie 2001 tot Desember 2002) in boorde op die plase Green Valley Nuts (GVN) en Remhoogte (REM) in die Prieska distrik, Noord-Kaap Provinsie, Suid-Afrika. Hierdie studie se hoofdoele was om die diversiteit van spinnekoppe in die bome, in grondbedekkings en op die grond te bepaal, en aspekte van die biologie en plaagbeheer potensiaal van algemene spesies wat voorkom. Die verskillende studies was in die boorde GVN 1 (8 jaar oud, 16 ha), GVN 19 (5 jaar oud, 16 ha) en REM (9 jaar oud, 16 ha) unitgevoer.

'n Literatuur studie was unitgevoer om die effekte van bestuurstrategie op spinnekoppe in boorde te bepaal. Daar is gevind dat spinnekop diversiteit en voorkoms baie hoer is in GPB, organise en onbesproeide boorde as in konvensioneel bestuurde boorde is. Die effekte van verskillende plaagdoders op spinnekoppe is ook ondersoek. Aangesien die huidige studie uitgevoer is in GPB pistachio boorde, kan daar verwag word dat spinnekoppe 'n belangrike rol as predatore sal speel.

Gedurende die 2-jaar studie van boom spinnekoppe was daar op 200 bome per boord versamel, primer met bespuiting van dishlorvos as 'n afslaan agent. 'n Totaal van 28 families en 87 spesies is versamel. Aantalle en diversiteit van spinnekoppe was hoogste in REM (n=2202, 70 spp.), gevolg deur GVN 1 (n=2051, 64 spp.) en GVN 19 (n=1550, 47 spp.). Boord ouderdom het 'n merkwaardige effek gehad op die aantalle en diversiteit van spinnekoppe versamel. Die springspinnekop, *Heliophanus pistaciae* Wesolowska (Salticidae), was baie numeries dominant, en het 'n gemiddeld van 53.8% van die fauna bygedra. Veld obserwasies op drie algemene spesies, *H. pistaciae*, die langbeensakspinnekop, *Cheiracanthium furculatum* Karsch (Miturgidae), en die

wawielwebspinnekop, *Neoscona subfusca* (C. L. Koch) (Araneidae), het gevind dat hulle op verskeie plaë, insluitend plantluise (Aphididae), besies (Lygaeidae), bladspringers (Cicadellidae), blaaspootjies (Phlaeothripidae) en blaar kewers (Chrysomelidae) voed, wat aandui dat spinnekoppe moontlik 'n rol speel as biologiese beheer agente. Toedienings van die plaagdoders endosulfaan en parathion het blykbaar 'n onmerkwaardige effek op die fauna gehad, maar verder navorsing is nodig om vas te stel of dit wel die geval is.

In die grond bedekkings was 55 spesies in 14 families tussen Julie 2001 en Julie 2002 versamel (10 monsters, 2000 swaaie/board). Nommers en diversiteit was hoogste in GVN 1 (n=631, 40 spp.), gevolg deur REM (n=580, 35 spp.) en GVN 19 (n=549, 36 spp.). Die komposisie van die grondbedekking het 'n merkwaardige effek op aantalle spinnekoppe gehad, maar nie op diversiteit nie. Die groen tierspinnekop, *Peucetia viridis* (Blackwall) (Oxyopidae), was die vollopste spesie (29.3%), gevolg deur *H. pistaciae* (23.4%). Algemene spinnekoppe was gesien om op die bogenoemde plaë in die grondbedekking te groei, wat aandui dat predasie in hierdie stratum kan plaagaantalle beperk, en keer dat hulle skadelike vlakke op die pistachio bome bereik.

In 'n vergelykende studie van die grondelewende fauna van die drie boorde en onversteurde veld, was putvalle (alle "sites") en aktiewe soektogte (boorde alleen) gebruik om die diversiteit en vollopheid van spinnekoppe te bepaal. Die studie is uitgevoer tussen Augustus 2001 en Julie 2002. Aantalle was hoogste in putvalle in die veld (n=1112, 56 spp.), gevolg deur REM (n=704, 35 spp.), GVN 1 (n=560, 26 spp.) en GVN 19 (n=428, 25 spp.). Die dominante spesie in die boorde was die rooistert hangmatwebspinnekop, *Ostearius melanopygius* (O. P.-Cambridge) (Linyphiidae, 30% in die boorde), en die muisspinnekop, *Asemesthes lineatus* Purcell (Gnaphosidae), in die veld (29.1%). Versteuringe in die boorde het 'n merkwaardige negatiewe effek op die vollopheid en diversiteit van grondelewende spinnekoppe. Families wat vollopste in die putvalle was (Linyphiidae, Gnaphosidae, Lycosidae en Salticidae) was ook

dominant in die soektogte, maar hulle relatiewe vollopheid het verskil tussen metodes.

Die biologie van *H. pistaciae* was bestudeer in aanmerking van dié spesie se vollopheid in pistachio boorde. Dit was gemik om die rol van dié spesie in plaagbeheer beter te verstaan. Populasies in die bome het gepiek tussen Desember en Maart, aanhangende van die jaar. In die grondbedekkings het populasies in vroeg somer gepiek (Desember-Januarie), wat 'n vertikale trek die bome in aandui. In die laboratorium was verkeie aspekte van die reprodktiewe- en voedingsgedrag bestudeer en beskryf. Eier produksie in die veld is hoogste in Januarie, en daal af in die maande wat volg. 'n Gemiddeld van 12.6 eiers is geproduseer per eier sak ($n=88$). 'n Eier parasite, *Odontacolus* sp. (Scelionidae), en 'n polysphictine ichneumonid wesp, wat net op wyfie spinnekoppe parasiteer, was geassosieër met dié spesie.

Die predasie potensiaal van *H. pistaciae* on die plaag *Nysius natalensis* Evans (Lygaeidae) was in laboratorium en veldtoetse bepaal. Predasie tempos was vergelyk met asynvlieë, *Drosophila melanogaster* Meigen (Drosophilidae). Predasie tempos was merkwaardig hoër op *D. melanogaster* deur altwee dae van die 48-uur studie. Predasie op *N. natalensis* het merkwaardig verhoog gedurende die tweede dag van die studies. Voorkeur toetse het 'n hoë voorkeur vir *D. melanogaster* bewys, maar die proporsie *N. natalensis* gevang het verhoog met tyd. In die pistachio bome het wyfie *H. pistaciae* ($n=8$) 'n gemiddeld van 1.38 *N. natalensis* in 24 ure gevang. Prooi grootte, smaaklikheid en ektiwiteit kan predasie rates beïnvloed.

Hierdie studie het gewys dat spinnekoppe is 'n diverse en algemene groep predatore in pistachio boorde, met 143 spesies van 31 families versamel in die drie strata. Hulle mag 'n belangrike rol speel om plae te beheer voordat hulle vlakke mag raak wat skade aan die bome en neute aanrig. Verdere navorsing is benodig om hulle predatoriese impak op plae te verstaan, effekte van plaagdoders op spinnekoppe, asook die relatiewe vollopheid van spinnekoppe op ander boord gewasse in die Prieska distrik.

CHAPTER 1



**Effects of pesticide management
practices on the spider fauna of
orchards: a review**

1.1 ABSTRACT

The effects of pesticides on spiders inhabiting orchards are briefly reviewed. Different management practices are discussed, and a list of pesticides used in orchards is provided. From the literature it appears that the broad-spectrum insecticides used in conventional management have a strong negative impact on orchard spiders, while integrated pest management (IPM) practices using selective insecticides support spider populations and possibly increase their role in biological control programs. The negative effects of pesticides on spider community structure and growth, may reduce their impact on pests. Vegetal management of ground covers, hedgerows and orchard boundaries may play an important role in supplementing the arboreal fauna, providing a resource from which tree canopies can be recolonised following pesticide applications.

1.2 INTRODUCTION

The central aim in the production of orchard crops is to optimise production and profitability without compromising product quality. This depends largely on effective management strategies to reduce damage by pests and diseases. Orchard management practices are likely to affect all organisms in the ecosystem, either by direct and/or indirect effects. Toxic effects on predators and/or prey could result in shifts in equilibria between predators and prey, and consequently affect natural control of pest organisms. Chemical control measures are often a necessary intervention to prevent pests from causing damage to orchard crops (AliNiazee 1998). However, management action should only be taken if one or more target pests are present in sufficient numbers that exceed economic threshold levels, and only if the action taken will significantly reduce or remove that threat (Harris & Jackman 1991).

Numerous management strategies exist for controlling pests in orchards. These can be divided into four main categories: 1) conventional management, which relies largely on the use of broad-spectrum pesticides for pest control; 2) IPM, including the use of selective pesticides, biological control, mating disruption and vegetation management; 3) organic management, which involves spraying of organic pesticides, biological

control, vegetative management and mating disruption; and, 4) unsprayed orchards, which rely on the latter three aspects for pest control.

In orchards not treated with pesticides, which are to a certain degree comparable to forest ecosystems, spiders can be abundant predators (Nyffeler & Benz 1987), and may be effective biological control agents (*e.g.* Mansour *et al.* 1985; Mansour & Whitcomb 1986). Diversity studies in orchards are essential to determine the dominant species present and their spatial distribution, as well as the guild structure of spider communities, both of which will affect predatory effects on pests (Green 1996; Marc & Canard 1997).

The effect of pesticides on spiders is an aspect that needs to be considered before their role in biological control programs can be established (Dippenaar-Schoeman 1998). As such, reducing pesticide use may be a necessary strategy to increase populations of spiders and other natural enemies (Riechert 1999). According to Marc *et al.* (1999), accumulated experience in the use of chemical treatments has shown that some treatments induce an increase in some species of pests (usually non-target species), as well as a decrease in the density and diversity of spiders in orchards.

Numerous reviews have been published on the management practices in different orchards (*e.g.* Blommers 1994; Peña *et al.* 1998; AliNiazee 1998). These works have all provided detailed accounts of the pesticides used in the respective cropping systems and their impact on target pests. However, gaps exist in the knowledge of the effects of pesticides on certain natural enemy groups, especially spiders, in orchards. Stark *et al.* (1995) reviewed the effects of pesticides on spiders, but most studies dealt with spiders in field crops. Aspects that were discussed in the latter review include laboratory toxicity, metabolism of pesticides, effect of exposure to pesticides on spiders, resistance, and toxicology at the population level. Due to the paucity of knowledge of pesticide effects on spiders more ecotoxicological studies are needed (Sunderland & Greenstone 1999).

The aim of this review was to analyse the effects of different management practices on the spider fauna in orchard ecosystems. Aspects that are discussed include influences of pesticide management on the faunistic composition of different orchard strata, effects of particular pesticides on individual spider species and spider communities, possible effects on pest control by spiders, pesticide resistance and the

positive role that ground covers may play in recovery of spider populations following pesticide applications.

1.3 CATEGORIES OF PEST MANAGEMENT

In this section background is given on the basic principles of each pest management system is presented along with the execution of these principles, and the pesticides used in each system. The pesticides used vary from crop to crop, depending on the pest species present, extent of damage and the economic viability of application. Certain pesticides are sometimes used even in both conventional and IPM orchards. Examples of these include dimilin (Samu *et al.* 1997) and azinphos-methyl (Prokopy *et al.* 1980; Brown & Schmitt 2001).

1.3.1 Conventional pest management

Conventional pest management practices are based on the use of broad-spectrum insecticides, known as conventional chemical control, which may control a variety of pests with a single pesticide, but usually cause severe mortality of orchard natural enemies in orchards (Mansour *et al.* 1980; Madsen & Madsen 1982; Mansour 1984; Longley 1999; Brunner *et al.* 2001; Wakgari & Giliomee 2001; Michaud 2002; Heunis & Pringle 2003). Consequently, there is a strong dependence on the pesticides applied for effective control of pests in systems under conventional management, while natural enemies play a reduced role due to the mortality effects of pesticides (Brunner *et al.* 2002). Conventional management results in the presence of low numbers of insects during the season and little damage at harvest. However, increasing insecticide resistance problems and changing market requirements put the sustainability of such systems in doubt (Hoy 1995; Suckling *et al.* 1999).

A wide variety of broad-spectrum insecticides and acaricides are used in conventionally managed orchards (Table 1).

TABLE 1: active ingredients of some pesticides for arthropods used in orchard crops, with examples of studies in which they were used (I- insecticide, A- acaricide, 1-used in conventional management systems, 2- used in IPM, 3- used in organic farming, ?- no indication other than “sprayed orchards”).

ACTIVE INGREDIENT	TYPE	SYSTEM	CROPS	REFERENCES
abamectin	A,I	2	Apple, pear	Horton <i>et al.</i> (2001)
acephate	I	?	Mango	Peña <i>et al.</i> (1998)
aldrin dust	I	?	Mango	Peña <i>et al.</i> (1998)
amitraz	I	2	Pear	Rieux <i>et al.</i> (1999)
azinphos-methyl	I	1	Apple, hazelnut	Prokopy <i>et al.</i> (1980), AliNiazee (1998), Gurr <i>et al.</i> (1999), Suckling <i>et al.</i> (1999), Brown & Schmitt (2001)
<i>Bacillus thuringiensis</i>	I	2,3	Apple	Samu <i>et al.</i> (1997), Bogya & Markó (1999), Jenser <i>et al.</i> (1999), Suckling <i>et al.</i> (1999)
barium polisulfide		1	Apple	Bogya & Markó (1999), Jenser <i>et al.</i> (1999)
buprofezin	I	2	Apple	Suckling <i>et al.</i> (1999)
carbaryl	I	1	Apple, hazelnut, mango	AliNiazee (1998), Peña <i>et al.</i> (1998)
chlorpropylate	I	1	Apple	Jenser <i>et al.</i> (1999)
chlorpyrifos	I	1,2	Hazelnut, apple,	AliNiazee (1998), Brown & Schmitt (2001), Horton <i>et al.</i> (2001)
cyhexatin	A	1	Apple	Prokopy <i>et al.</i> (1980)
A-cypermethrin	I	1	Apple	Pekár (1999a)
cyromazine	I	?	Mango	Peña <i>et al.</i> (1998)
deltamethrin	I	1,2	Apple, pear	Samu <i>et al.</i> (1997), Bogya & Markó (1999), Rieux <i>et al.</i> (1999)
diazinon	A,I	?	Mango	Peña <i>et al.</i> (1998)
dichlorvos	I	?	Mango	Peña <i>et al.</i> (1998)
diflubenzuron	I	1,2	Apple	Pekár (1998), Bogya & Markó (1999), Jenser <i>et al.</i> (1999), Pekár (1999a)
dimecron	I	1	Apple	Samu <i>et al.</i> (1997)
dimethoate	I	?	Apple, mango	Samu <i>et al.</i> (1997), Peña <i>et al.</i> (1998), Bogya & Markó (1999)
dimilin	I	1,2	Apple	Samu <i>et al.</i> (1997)
dinitro-orthoecresol	I	2	Pear	Rieux <i>et al.</i> (1999)
dodine	I	2	Apple	Suckling <i>et al.</i> (1999)
endosulphan	A,I	?	Hazelnut, mango	AliNiazee (1998), Peña <i>et al.</i> (1998)
esfenvalerate	I	1	Hazelnut	AliNiazee (1998)
etrimphos	I	1,2	Apple	Pekár (1999a)
fenazaquin	A	1	Apple	Vesselin (2001)
fenbutatin oxide	I	2	Apple	Bogya & Markó (1999)
fenpyroximate	A	1	Apple	Vesselin (2001)
fenthion	I	?	Mango	Peña <i>et al.</i> (1998)
fenithrothion	I	1,2	Apple, mango	Peña <i>et al.</i> (1998), Pekár (1999a)
fenoxycarb	I	2	Apple	Jenser <i>et al.</i> (1999)
fluvalinate	I	?	Mango	Peña <i>et al.</i> (1998)
flucycloxuron	I	2	Pear	Pekár (1998)
formetanate hydrochloride	A,I	?	Apple	Brown & Schmitt (2001)
formothion	I	1	Apple	Pekár (1999a)
hexaflumuron	I	2	Pear	Pekár (1998)
hydrated lime	I	2	Apple	Suckling <i>et al.</i> (1999)
imadacloprid	I	1	Various	James & Price (2002)
lead arsenate	I	?	Apple	Dondale <i>et al.</i> (1979)

TABLE 1- continued.

ACTIVE INGREDIENT	TYPE	SYSTEM	CROPS	REFERENCES
leptophos	I	?	Apple	Dondale <i>et al.</i> (1979)
lime sulphur	I	2,3	Apple	Jenser <i>et al.</i> (1999), Horton <i>et al.</i> (2001)
lufenuron	I	2	Apple	Samu <i>et al.</i> (1997), Bogya & Markó (1999)
malathion	I	1	Hazelnut, mango	AliNiazee (1998), Peña <i>et al.</i> (1998)
methidathion	I	1	Apple	Pekár (1999a)
methomyl	I	?	Apple	Brown & Schmitt (2001)
methyl parathion	I	1	Apple	Samu <i>et al.</i> (1997), Bogya & Markó (1999), Brown & Schmitt (2001)
mineral oils	I	2	Apple, pear	Rieux <i>et al.</i> (1999), Suckling <i>et al.</i> (1999)
monocrotophos	I	?	Mango	Peña <i>et al.</i> (1998)
nitrothal-isopropyl	I	1,2	Apple	Suckling <i>et al.</i> (1999)
oils	A,I	2,3	Apple	Prokopy <i>et al.</i> (1980), Brown & Schmitt (2001), Horton <i>et al.</i> (2001)
parathion	I	1	Apple	Jenser <i>et al.</i> (1999)
permethrin	I	1	Apple, hazelnut	AliNiazee (1998), Pekár (1999a)
phenoxycarb	I	2	Apple	Samu <i>et al.</i> (1997), Bogya & Markó (1999)
phenthoate	I	?	Mango	Peña <i>et al.</i> (1998)
phosalone	I	1,2	Apple, mango	Samu <i>et al.</i> (1997), Peña <i>et al.</i> (1998), Pekár (1999a)
phosmet	I	2	Apple	Dondale <i>et al.</i> (1979), Prokopy <i>et al.</i> (1980)
phosphamidon	I	1	Apple, mango	Peña <i>et al.</i> (1998), Bogya & Markó (1999), Jenser <i>et al.</i> (1999), Pekár (1999a)
pirimicarb	I	2	Apple	Bogya & Markó (1999), Jenser <i>et al.</i> (1999)
pirimor	I	2	Apple	Samu <i>et al.</i> (1997)
prebloom oil	I	3	Apple	Suckling <i>et al.</i> (1999)
propargite	A,I	1	Apple	Prokopy <i>et al.</i> (1980), Bogya & Markó (1999), Pekár (1999a), Suckling <i>et al.</i> (1999), Brown & Schmitt (2001), Jenser <i>et al.</i> (1999)
propilate	I	1	Apple	Vesselin (2001)
pyridaben	A	1	Apple	Peña <i>et al.</i> (1998)
quinalphos	I	?	Mango	De Maeyer <i>et al.</i> (2002)
spirodiclofen	A	2	Apple, pear	Bogya & Markó (1999)
sulphur+vaseline oil	I	2	Apple	Suckling <i>et al.</i> (1999)
tebufenozide	I	2	Apple	Pekár (1998)
tefluhexuron	I	2	Pear	Bogya & Markó (1999)
trichlorphon	I	1	Apple	Prokopy <i>et al.</i> (1980)
vendex	A	1	Apple	

Most of the compounds used in conventional management can be classified as organophosphates, organochlorines, carbamates and thiocarbamates. Some broad-spectrum insecticides (particularly organochlorines) are environmentally persistent, and the negative effects of application on organisms in an ecosystem may continue for a prolonged period as a consequence of residues (WWF-Canada 2001).

1.3.2 Integrated pest management

IPM systems aim to use a wide range of control methods for pests, including a reduction in spraying frequency, and preferential use of selective pesticides (Suckling *et al.* 1999). IPM practices necessitate the use of selective insecticides and acaricides to control pests without causing harm to the resident natural enemies. Selective pesticides typically have a minimal effect on non-target arthropods (most importantly predators and parasitoids), which results in natural enemies playing a much greater role in pest control (*i.e.* biological control). Manipulation of vegetative characteristics of the orchard landscape by ground cover, field margin and leaf litter management also impacts the phenology of pests and natural enemies, and may aid in pest control (Brown *et al.* 1997; Bogya *et al.* 2000). IPM ideally aims to rely only on the natural enemies for pest control, as this would eliminate the need to apply pesticides, and in doing so, amongst others, reduces the costs of food production. Pesticides should only be applied when biological control efforts have failed to suppress pests.

Prokopy *et al.* (1994) discussed different levels of IPM. For our purposes the most important, *i.e.* first- and second-level IPM, will be discussed here. They regarded first-level IPM as management practices that integrate chemically and biologically based management techniques for a single class of pests, such as arthropods, diseases, weeds and vertebrates. Second-level IPM integrates multiple management tactics across all classes of pests. Their approach for second-level IPM was to use chemically based control measures for pests during the early part of the growing season only, after which exclusively biologically-based control tactics were used (*i.e.* cultural, behavioural and biological). This resulted in a 30% reduction in the use of insecticides, with a minimal increase in fruit damage.

Various synthetic and organic products are used in IPM strategies for pest control (Table 1). These include organophosphates, pyrethroids, insect growth regulators, imidates, phenylpyrrazoles, and various natural and organic products (*e.g.* *Bacillus thuringiensis* and plant oils). Suckling *et al.* (1999) found that the insect growth regulator (IGR) tebufenozide used in IPM apple orchards provides excellent control with little impact on natural enemies. Mycoinsecticidal effects on pear psylla showed that inclusion of such pesticides could be a useful component in IPM programs for pear orchards (Puterka 1999), as can selective acaricides such as spiroticlofen for control of mites in pome fruit orchards (De Maeyer *et al.* 2002).

Mating disruption using pheromone traps has potential for use in IPM programs, as well as in organic farming. Brunner *et al.* (2002) and Pringle *et al.* (2003) reported on the use of mating disruption in apple orchards. Mating disruption used together with reduced pesticide applications may not provide as effective control of codling moths as broad-spectrum insecticide use alone. However, increases in natural enemies once pesticide applications have decreased reduces secondary pest problems (Brunner *et al.* 2002). Mating disruption alone may significantly reduce the percentage of damaged fruits at harvest time (Pringle *et al.* 2003).

If proper IPM practices are followed, then spiders may be the most abundant generalist predators in IPM orchards, for example on apples in Hungary (Jenser *et al.* 1999), implying that they may play an important role in biological control programs. Augmentative releases of natural enemies (*e.g.* ladybirds and parasitoids) may form part of biological control programs in orchards. Such introductions have been found to have variable success rates, for example on avocados in California (McMurtry 1992), making pest suppression by the endemic fauna a more important consideration from a financial and ecological viewpoint.

1.3.3 Organically managed orchards

Organic farming practices have recently received a great amount of interest. Such systems rely almost entirely on natural enemies and habitat manipulation for pest control. If necessary, only naturally derived pesticides (so-called “green products”), with low or

no toxicity to non-target arthropods are used to aid pest suppression. Examples include oils, *Bacillus thuringiensis*, and neem products (Table 1).

Additional control measures can be carried out in organic orchards by mating disruption (Witzgall 2001; Brunner *et al.* 2002), and augmentative releases of natural enemies into the orchard system (*e.g.* Wyss *et al.* 1999). Various cultural controls can be carried out, for example, unmowed ground covers, and providing refugia and alternative food sources for natural enemies. Organically produced products are more marketable, since no synthetic chemical pesticide residues are present, making them a more aesthetically attractive and healthy product for consumers.

Detrimental health effects, environmental issues, insect resistance to pesticides, as well as marketing opportunities for organically produced food, are well-known arguments against the use of pesticides (Witzgall 2001). Such factors have made methods such as mating disruption of pests by means of synthetic pheromone releases a possible, and effective alternative to insecticide sprays.

1.3.4 Unsprayed orchards

Unsprayed orchards are characterised by the total absence of any insecticide, fungicide, herbicide or other pest control applications. Such orchards aim to rely entirely on biological control, mating disruption, and cultural control practices for pest suppression. This includes manipulation of ground covers, and orchard sanitation (*e.g.* removal of fallen fruit from the ground, AliNiazee 1998).

1.4 EFFECTS OF PESTICIDE MANAGEMENT ON ORCHARD SPIDERS

1.4.1 *Effects pesticide management on the spider fauna of different orchard strata*

Berres & Sechser (2001) found the sensitivity of spiders to pesticides to vary minimally over a testing period of five months, which suggests that populations may be afflicted to similar degrees by regular applications of pesticides through the season. The susceptibility of spider populations to pesticides (insecticides and acaricides) is likely to vary from tree canopy (high level), where applications are concentrated, to the ground (low level), where residues from spray drift and dripping may accumulate (Burnip *et al.*

1998). Herbicides are primarily directed at weedy growth in the tree rows, and are likely to have the greatest effects on the epigeic and ground cover faunas.

1.4.1.1 Arboreal spiders

The reduced use of broad-spectrum insecticides may not immediately increase spider numbers. Miliczky *et al.* (2000), working on apples in Washington State, found that reduced use of broad-spectrum insecticides in mating disruption orchards a year prior to the commencement of a 2-year study did not result in arboreal spider densities comparable to that of organic orchards during the period of sampling. They deduced that the time taken for spiders to recover from broad-spectrum insecticides may be lengthy, as most species are univoltine (Dondale 1961), and consequently populations may not recover in the season of particular management application (Miliczky *et al.* 2000).

Specht & Dondale (1960) found spider densities to be nearly three times higher in unsprayed apple orchards in New Jersey than in orchards sprayed with ryania, lead arsenate and nicotine bentonite. They also found a much higher proportion of spiders to total predators in unsprayed orchards, indicating a high sensitivity of spiders to pesticides, than was the case for other natural enemies. In most samples in unsprayed orchards, spiders comprised more than 50% of the total predators, reaching a maximum of 95.7%. In a 6-year study on apples in Quebec, Dondale *et al.* (1979) attributed a two-thirds decline in spider numbers in the final year of the survey to various factors, which included multiple applications of broad-spectrum insecticides (phosmet and leptophos) for plum curculio control.

Conflicting accounts exist on the effects of IPM and conventional practices on arboreal spiders. Generally, IPM spraying (selective pesticides) increases numbers and diversity of arboreal spiders, compared to conventional practices in apple orchards in the Czech Republic and Hungary (Pekár 1999a; Bogya *et al.* 2000). The former author also showed that IPM practices maintained the seasonal abundance of the spider population at a balanced level, while plots under conventional spraying displayed violent fluctuations. However, Samu *et al.* (1997), had results contrasting with the abovementioned. These authors found no significant differences in the numbers of canopy spiders between apple

orchards under conventional control and individual orchards under two different IPM management strategies in Hungary.

In addition, Miliczky *et al.* (2000) found that organic orchards contained significantly higher spider densities in the tree canopies than mating disruption or conventional orchards, while Madsen & Madsen (1982) found spider numbers to be nearly 100 times greater in the tree canopies of an organic orchard than in a conventionally sprayed orchard. In this latter study, the organic orchard had previously been maintained under a pesticide management program, but following conversions to organic management numbers steadily increased over two seasons, and were 4-6 times greater in corresponding months during the second season of the study.

In a yearlong study on spiders in apple orchards in Israel, Mansour *et al.* (1980) found the density and diversity of spiders to be more than twice as much in unsprayed orchards than in orchards treated with chemicals. Spider populations in the chemically treated plots were strongly affected by the pesticide treatments and were occasionally eliminated altogether. However, spider communities were able to recover when the time between applications was long enough. According to Amalin *et al.* (2001), the lower number of spiders in sprayed versus unsprayed lime orchards in Florida demonstrates the possible non-target effects on spiders of the different pesticides used in the orchards.

1.4.1.2 Ground cover spiders

The published knowledge of pesticide effects on the fauna of ground covers in orchards is minimal. Organic and IPM orchards contain significantly higher spider densities in the ground covers than mating disruption or conventional orchards (Bogya *et al.* 2000; Miliczky *et al.* 2000). Madsen & Madsen (1982) also found spiders to be nearly 100 times more abundant, and considerably more diverse, in ground covers of an organic apple orchard compared to a regularly sprayed orchard in British Columbia, which indicates that broad-spectrum insecticides have a strongly negative influence on ground cover spiders.

Also on this topic, Pekár (1999a) found that spider abundance could be dramatically affected by the species composition of ground cover plantings. Abundance

and diversity was higher in IPM plots in the Czech Republic planted with grasses and herbs than in conventional orchards with a weedy ground cover.

Spiders dwelling in the ground covers assist in supplementing the arboreal fauna, particularly in the recovery of arboreal populations following pesticide applications (see Section 1.4.1). A reduction in their numbers in this stratum may reduce numbers recolonising the canopy, diminishing their capability as biological control agents of arboreal pests.

1.4.1.3 Epigeic spiders

Only a few studies are known, which established effects of conventional spraying on the epigeic spider fauna of orchards. One would expect the effects of residues that accumulate on the soil surface to be minimal, as the bulk of the spray volume is directed at and absorbed by the foliage. Consequently, pesticide run-off dripping from the trees, and residues from spray drift, would be minimal. The amount of this residue can be effectively reduced by using the proper nozzle size for a particular crop, and by applying pesticides under minimal wind conditions.

In apple orchards in Hungary, Bogya & Markó (1999) found no significant differences in the species richness, species composition, density or diversity of epigeic spiders in a comparison of conventionally managed orchards and IPM orchards in Hungary. Pekár (1999b), working in apple orchards in the Czech Republic, reported that epigeic spiders and harvestmen were on average more abundant in a conventionally managed orchard compared to two IPM orchards over a 4-year period. He attributed this to the differences in ground cover plantings in the three orchards sampled, with the conventional plot having the lowest plant density. Furthermore, herbicide applications had a much more pronounced effect on epigeic spiders than applications of pesticides to the tree canopy, in both conventional and IPM plots (Pekár 1999b).

Miliczky *et al.* (2000) found the high densities of epigeic spiders in a conventional orchard puzzling, despite the insecticide output being higher than in mating disruption orchards, and ground covers being sparse in two conventional orchards, which would have reduced any shielding effects of the vegetation against spray residues. Mean densities of epigeic spiders were similar or higher in three conventional orchards than in

three mating disruption orchards, and densities in one of the conventional orchards was only exceeded by one of three organic orchards. It seems that no clear conclusions can be drawn from these studies, other than that pesticides seem to have a minimal effect on epigeic populations.

1.4.1.4 Overwintering spider populations

Pekár (1999c), in studying the overwintering spider fauna under cardboard bands in the Czech Republic, found the fauna of IPM apple orchards to be dominated by small species that appear to be tolerant of pesticides (Theridiidae and Dictynidae), while the fauna of an abandoned orchard was dominated by larger, more pesticide-susceptible species of Clubionidae and Philodromidae. Numbers were nearly three times higher in the abandoned orchards than in the commercial orchards. Horton *et al.* (2001), working in orchards in Washington, also found more spiders overwintering under cardboard bands in unmanaged and organically managed orchards than from apple and pear orchards that received insecticides during the growing season. Numbers and species composition varied between the two crops, as well as at all three heights on the tree boughs at all three sites that were sampled. From these results it appears that the typically higher number of arboreal spiders in unmanaged or abandoned orchards directly relates to the abundance of overwintering spiders.

1.4.2 Effects of particular pesticides on spider populations in orchards

Foliar applications of the broad-spectrum insecticide diazinon for control of apple leafcurling midge, *Dasineura mali* Kieffer, caused significant mortality of arboreal spiders, whilst neither foliar applications nor drench applications had a significant effect on the abundance of epigeic spiders (Burnip *et al.* 1998). Foliar applications of malathion were found to have no effect on spider populations in grapefruit orchards, but a mixture of formothion and carbaryl dramatically reduced the abundance of arboreal spiders (Mansour & Whitcomb 1986).

Different selective pesticides used in pear orchards for control of pear psylla, *Psylla pyri* (L.), affect the resident spiders to varying degrees (Pekár 1998). Arboreal spider populations were most severely affected in the week following applications, and

effects of pesticides also varied between years. Flucycloxuron was highly toxic to spiders, but failed to control *P. pyri*. Teflubenzuron and hexaflumuron were most efficient in the control of *P. pyri*, and were less harmful to spiders than flucycloxuron. Diflubenzuron performed poorly in pest control, but also did not harm spiders.

Bajwa & AliNiazee (2001) conducted a study on common spiders (two species of Salticidae, and one each of Linyphiidae, Clubionidae, Philodromidae and Theridiidae) of apple. They showed that the microbial pesticide *Bacillus thuringiensis*, the insect growth regulator diflubenzuron, and the organophosphate phosmet were generally harmless to spiders. The organophosphate azinphos-methyl and the carbamate carbaryl were moderately harmful, while the pyrethroids esfenvalerate and permethrin were found to cause moderate to high mortality in the same spider taxa. Similarly, Gurr *et al.* (1999) found that applications of azinphos-methyl significantly reduced spider numbers in apple orchards compared to either of two orchards treated with insect growth regulators (tebufenozide and fenoxycarb). An additional negative consequence was the increase in numbers of the two-spotted mite, *Tetranychus urticae* Koch, in the azinphos-methyl-treated orchard.

Examples are reported of herbicides and fungicides that caused significant reductions in spider and predacious mite populations following applications in orchards and tomato crops (Bower *et al.* 1995; Yardim & Edwards 1998). Although certain acaricides (*e.g.* pirimiphos-methyl and flufenoxuron) are highly toxic to spiders (Pekár 2002), others (*e.g.* Neemgard and spiroticlofen) have no or minimal toxic effects on spiders and other natural enemies (Mansour *et al.* 1997; De Maeyer *et al.* 2002; Wolf & Schnorbach 2002).

1.4.3 Influence of pesticides on individual species and guilds

Knowledge of the toxic effects of pesticides on individual spider species is poor except for studies by Mansour (1984), Mansour & Nentwig (1988) in Pekár (2002), Mansour *et al.* (1992) in Pekár (2002), Sekar & Shunmugavelu (1992), Sunderland & Greenstone (1999), Amalin *et al.* (2000), and Pekár (2002). This makes it difficult to project the effects of pesticide applications on spider populations and species composition in the field, as well as whether to attribute fluctuations in abundance and

diversity to pesticides or to other factors such as climate. Different spider species are not all affected in the same way by different chemical treatments (Van den Berg *et al.* 1990; Marc *et al.* 1999).

Analysis of studies in various orchards has shown the species and guild composition of orchard spiders to vary considerably between different tree species (Putman 1967; Jennings 1976; Mansour *et al.* 1982; Liao *et al.* 1984; Pekár 1998; Costello & Daane 1999; Miliczky *et al.* 2000; Amalin *et al.* 2001; Dippenaar-Schoeman *et al.* 2001). In this respect, habitat complexity has a strong influence on guild structure of spiders in crops (Uetz *et al.* 1999). This will affect the species composition, activity patterns, and prey capture methods of spiders, and the consequent susceptibility to applications of pesticides. If a large proportion of the resident species are active when the pesticides are applied, mortality may be greater than for species displaying different activity patterns, which may only be affected by residues. This will decrease the spider population and its possible role in pest control.

A study by Bogyá *et al.* (1999) found that spider assemblages at the family level in canopies of apple trees in the Holarctic Region were largely influenced by latitude. In Europe, the genus and species composition also changed along a north-south gradient. The vegetation structure of the tree canopy, bark and ground covers, as well as spacing between trees often varies between tree species, and between orchards of the same crop in different geographical locations. This will affect guild structure, susceptibility of the resident spider population to pesticides, and ultimately, influence its impact on pests.

Aspects of the foraging mode of spiders that influences their susceptibility to pesticides are whether the species is diurnal or nocturnally active, a web-builder or an active hunter (Pekár 1999d). Furthermore, spider species may either have univoltine or bivoltine life cycles (Dondale 1961), which may have an influence on the prevalence of different life stages during the season, and influence the relative sensitivity of a species to pesticides. The various studies consulted below provide conflicting evidence as to the susceptibility of wandering and web-building spiders to pesticides.

1.4.3.1 Effects of pesticides on wandering spiders

Bostanian *et al.* (1984) found that densities of wandering spiders were significantly lower than densities of web-builders in Quebec apple orchards receiving insecticide and fungicide treatments, compared with those receiving fungicides only. From this, they deduced that wandering spiders were more susceptible to insecticides than web-builders.

Mansour (1984) demonstrated in laboratory toxicity tests that malathion was significantly less toxic to citrus orchard-dwelling *Cheiracanthium mildei* L. Koch than chlorpyrifos, even when concentrations of the latter pesticide were much lower. Hodge & Vink (2000) determined that mortality of *Lycosa hilaris* Koch, a common ground-dwelling hunting spider in green beans, was not affected by applications of chlorpyrifos or diazinon at recommended rates. From this, they deduced that *L. hilaris* might not be an ideal bioindicator of organophosphate contamination. However, similar responses in abundance of other predatory arthropods would suggest residues on the soil surface to be insufficient to cause significant predator mortality. The differences in the effects on the two species treated with chlorpyrifos in these studies could be attributed to their habitat preferences, with *C. mildei* being arboreal, where the spray application is concentrated, while *L. hilaris* is a ground-dwelling species that is exposed to residues only.

Pekár (1999d) studied the effects of three pesticides on a variety of spiders representing different guilds. The diurnal hunting spiders, *Philodromus cespitum* (Walckenaer) and *Pardosa agrestis* (Westring), and the nocturnal hunter, *Clubiona neglecta* O. P.-Cambridge, were severely affected by permethrin. Phosalone was toxic to *P. agrestis* and *C. neglecta*, but to a lesser degree than permethrin. This insecticide was not significantly toxic to *P. cespitum*. The insect growth regulator hexaflumuron was not significantly toxic to any of these species. In this context, hunting spiders (Thomisidae, Philodromidae and Salticidae) were most severely affected by applications of flucycloxuron in pear orchards (Pekár 1998).

Amalin *et al.* (2000) found broad-spectrum insecticides (*i.e.* azinphosmethyl, chlorpyrifos, ethion, carbaryl and dicofol) to be highly toxic to the hunting spider, *Hibana velox* (Becker), causing 100% mortality even at the lowest concentrations. Avermectin, and imidacloprid applied as a spray, had moderate toxicity. Imidacloprid

applied as a drench caused low mortality, as did azadirachtin, *Bacillus thuringiensis* and diflubenzuron.

Neemgard, an acaricidal and fungal extract from neem tree seed kernels, was found to cause very high mortality of red spider mites, *Tetranychus cinnebarinus* (Boisduval) (Mansour *et al.* 1997). This botanical pesticide had no toxic effect on *C. mildei* and the predacious mite, *Phytoseiulus persimilis* Anthias-Henriot, which makes it an ideal selective acaricide to include in an integrated pest control program (Mansour *et al.* 1997).

1.4.3.2 Effects of pesticides on web-building spiders

Spider webs may be efficient collectors of pesticide sprays (Samu *et al.* 1992 in Miliczky *et al.* 2000). Since certain web-building spiders periodically consume their webs they may therefore be at increased risk of taking in pesticides (Miliczky *et al.* 2000).

In a study in apple orchards, Mansour *et al.* (1980) found considerably fewer web-builders in an IPM orchard (14%) compared to 31% in an unsprayed orchard. Wiesniewska & Prokopy (1997) found significantly fewer web-building Theridiidae in second-level IPM apple orchards compared to unsprayed orchards in Massachusetts. They attributed this to the consumption of webs by the spiders. Bogyá *et al.* (1999) also found that most members of the Theridiidae and Araneidae decreased considerably in apple and pear orchards treated with pesticides.

These results conflict with those of Pekár (1999d), who found that hunting spiders (listed above) were generally more severely affected by pesticides (*i.e.* permethrin, phosalone and hexaflumuron) than web-builders with webs. In this study, mortality of web-builders was noticeably lower for *Araniella opistographa* (Kulczynski), *Dictyna uncinata* Thorell and *Theridion impressum* (L. Koch) when the spiders were allowed to construct webs compared to when webs were removed. This suggests that webs provide some protection from pesticide residues. Permethrin was much more toxic than phosalone for all the web-builders, and hexaflumuron didn't cause significant mortality to any species, whether the spiders had webs or not.

Sekar & Shunmugavelu (1992) evaluated the toxicity of four pesticides on four species of spiders representing different guilds. These were the orb-weaver, *Cyrtophora cicatrosa* Stoliczka, the space web-builder, *Crossopriza semiringopus* (Blackwall), the retreat web-builder, *Stegodyphus sarasinorum* Karsch, and the wandering jumping spider, *Marpissa calcutaensis* (Tikader). All four pesticides tested (*i.e.* tallux, malathion, monocrotophos and endosulphan) were highly toxic to all the spiders. Endosulphan was comparatively the least toxic of the four.

Pekár (2002) evaluated the effects of 17 pesticides used in orchards on the gum-foot web-builder *Theridion impressum*. Mortality was highest for broad-spectrum insecticides (*i.e.* cypermethrin+chlorpyrifos, α -cypermethrin and deltamethrin) and acaricides (pirimiphos-methyl, flufenoxuron, τ -fluvalinate+thiometon and bifenthrin). Selective pesticides (pirimicarb, *Bacillus thuringiensis* ssp. *tenebrionis*, and trizamate) were much less harmful than broad-spectrum insecticides, causing average mortalities of 11% and 60%, respectively. Of four fungicides and three herbicides tested, only the fungicide dithianon was significantly toxic.

1.4.4 Effects of pesticides on the body lengths of spiders and their role in pest control

Nentwig & Wissel (1986) assessed the effects of prey length on capture rates by thirteen species of spiders. Prey (*i.e.* crickets) that were 50-80% of the spiders' body length yielded the highest capture rates (up to 100%). Six species were capable of subduing prey up to 150% of their body length, while *Xysticus* could subdue prey up to 200% of their body length. Because body lengths of spiders are related to the sizes and therefore the types of prey consumed, the negative effects of pesticides on mean body length of visual hunting and web-building spiders may affect their role as predators of different types of arthropod pests (Wisniewska & Prokopy 1997).

A likely consequence of the difference in body size of spiders found in sprayed and unsprayed orchards can be seen in terms of their impact on populations of prey insects (Miliczky *et al.* 2000). In apple orchards, it was found that the relative scarcity of large spiders and prominence of smaller species (*e.g.* Linyphiidae) in conventionally managed and mating disruption orchards, compared to organic orchards, probably

reduces the potential contribution of spiders in controlling larger pests, such as prepupal larvae and adults of codling moth.

Bostanian *et al.* (1984) found that spider populations in insecticide-treated orchards peaked a month later than in untreated orchards. They felt that this insecticide-induced delay might hinder the contribution that spiders play in controlling apple pests during early summer (August), when several species of pests may cause significant economic damage.

1.5 OTHER FACTORS AFFECTING EFFECTS OF PESTICIDES ON SPIDERS

1.5.1 Role of ground covers and hedgerows in recovery of spider populations following pesticide applications

There is often a considerable overlap in the species composition of tree canopies and ground covers (Bogya *et al.* 1999, 2000; Miliczky *et al.* 2000). The nature and density of the ground covers seem to play a very important role determining the composition of the spider fauna in the pistachio orchards. Brown *et al.* (1997) found that there was an increase in biological control in apples in five countries by using selective pesticides and a variety of weedy ground covers.

The vertical movement of the spider fauna from the epigeal and ground covers to the tree canopies (Pekár 1999a,b) assists in the recolonisation of the canopy, after chemical applications have diminished numbers (Bogya *et al.* 2000). An overlap in species composition between the strata is thus a strongly positive ecosystem attribute in orchards where this phenomenon is encountered.

Rieux *et al.* (1999), analyzing the arthropods in pear orchards, determined that interactions are likely to occur between the faunas of pear trees and hedgerows, and pear trees and ground covers. They suggested that manipulation of beneficial arthropods through vegetal management may assist in optimizing IPM. Hedgerows and ground covers, when containing similar beneficial faunas, may be sources of beneficials to recolonise trees following pesticide applications.

1.5.2 Pesticide resistance and effects on spiders

The development of pesticide resistance by pests can severely compromise effective control and limitations of pest damage. Such resistance necessitates the development of new pesticides for control of the pests, a process that is a great financial burden to the producer, and subsequently the consumer. Because spiders form such an integral part of the natural enemy complex in most orchards, the development of new formulae should consider the impacts on spiders and other beneficials.

Orchard pests that don't develop resistance have an added benefit, as the pesticide can be repeatedly used in successive seasons, with the possibility of the natural enemies developing resistance. This would reduce the toxic mortality effects on spiders, and other predators and parasitoids, which could increase the impact of biological control on pests.

Mansour (1984) provided a good example of the development of pesticide resistance in spiders. In comparing the pesticide susceptibility of the sac spider, *Cheiracanthium mildei*, from citrus orchards and cotton, he demonstrated that the citrus populations were 3.3 times less susceptible to malathion than populations from cotton. He attributed this to the extensive use of malathion for a number of years in the citrus orchards, which subsequently resulted in the development of resistance in *C. mildei* and *Theridion* sp. with increased exposure to the chemical (Mansour & Whitcomb 1986).

1.6 CONVENTIONAL OR IPM: WHICH SYSTEM IS BEST?

There is convincing evidence of the negative effect of traditional chemical applications on orchard crops when compared to IPM practices. The bulk of comparative studies have indicated that conventional practices dramatically impact spider diversity and abundance, as well as populations of other natural enemies, minimising the chance of natural enemies being effective biological control agents. Spiders are most abundant and diverse in organic and unsprayed orchards. IPM practices stimulate natural enemy effectiveness by reduced chemical applications and disturbance, using softer pesticides that target specific pests, and providing a habitat with greater prey diversity. These factors all contribute to increasing spider numbers, improving the likelihood that they will play a role in pest suppression.

While broad-spectrum pesticides reduce natural enemy populations, IPM practices and cultural methods often result in increased biological control, although this may not always be successful, leading to chemical intervention with selective pesticides. However, secondary pest problems may also develop as a consequence of reduced use of broad-spectrum insecticides (Brown *et al.* 1997; James & Price 2002).

Orchards converted from conventional to IPM or organic management have shown promising increases in spider diversity and abundance (Madsen & Madsen 1982; Miliczky *et al.* 2000). The dramatic reduction in pesticide and application costs (*e.g.* Stewart *et al.* 2002) of IPM and organic practices makes them more cost effective, even if pest damage is slightly higher. Biodiversity is greater in the latter management systems, and control by natural enemies may often be adequate to avoid chemical intervention. In the present commercial environment where pesticide-free products are preferred, spending the money necessary for conversion to IPM or organic management may bring greater returns with product sales. This will ultimately result in greater ecological sustainability through decreased disturbance of orchard ecosystems, and greater profitability provided high levels of production and food quality can be maintained.

Brown (1999) proposed that an ecological approach to IPM be used, whereby ecological processes are used and manipulated to increase production and product quality to levels encountered in conventional management. His approach may be ideal when establishing new orchards, *i.e.* to begin with an almost natural system, and gradually add inputs (starting with horticultural practices, then ground covers, then mating disruption and finally pest control), only as they become needed. Additions should be done with the least disruptive effects to achieve long-term sustainability of the system.

This review has indicated that there is a great need for further research into the toxicological effects of pesticides on spiders. Particular focus should be on laboratory work to assess the effects of pesticides on individual spider species, especially the dominant species in orchards, as these species are the most likely to play the greatest role as predators of pests. Research should also intensify on effects of pesticides used in organic farming, both in the laboratory and field, in consideration of the expansion of this management practice in agriculture.

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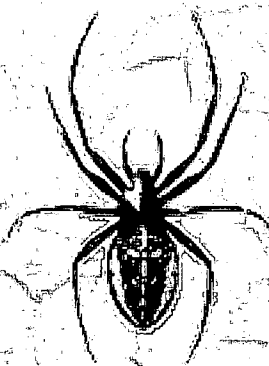
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CHAPTER 2



**The arboreal spider (Araneae)
fauna in pistachio orchards in
South Africa: patterns of
diversity and abundance, and
biological control potential**

2.1 ABSTRACT

As part of a biomonitoring program on pistachio orchards in South Africa, spiders were collected from tree canopies in three orchards from January 2001 to December 2002, using an insecticide mist blower and dichlorvos as a knockdown agent. Sampling was conducted in two orchards on the farm Green Valley Nuts, namely GVN 1 and GVN 19, and a third orchard on the farm Remhoogte (REM). In total, 5803 spiders were collected, representing 18 families and 87 species. Numbers and diversity were highest in REM (n=2202, 70 spp.), followed by GVN 1 (n=2051, 64 species) and GVN 19 (n=1550, 47 species). Three species dominated the spider fauna: the jumping spider, *Heliophanus pistaciae* Wesolowska (53.8%), the sac spider, *Cheiracanthium furculatum* Karsch (12.8%), and the orb-web spider, *Neoscona subfusca* (C. L. Koch) (6.4%). Orchard age was found to have a significant influence on the abundance of spiders (Chi-squared test), while linear regression on various spider abundance data sets showed mixed results. Sørensen's Quotient values indicated a high similarity between the faunas of the two older orchards compared to the similarity between the older orchards and the young orchard, which indicates that orchard age has a significant effect on diversity. An assessment of field predation by three species of spiders showed that they prey on minor pests, including aphids (Aphididae), leafhoppers (Cicadellidae), false chinch bugs (Lygaeidae) and thrips (Phlaeothripidae), as well as two natural enemy groups (Chalcidoidea and Coccinellidae). Spiders are the most abundant generalist predators on pistachio orchards, outnumbering Coccinellidae, Chrysopidae, Staphylinidae and predatory bugs, and probably play a role in pest suppression.

2.2 INTRODUCTION

Pistachio nuts, *Pistacea vera* L., are presently being established as a new crop in South Africa. The introduction of a new crop into a country foreign to its origin always carries the risk of unknown pest and pathological threats that may hinder the establishment of the crop. As part of a continued integrated pest management (IPM) program on pistachio, research is presently being conducted to determine the insect and

arachnid fauna in these orchards, with the aim of identifying target pest species and the natural enemies that will play a role in their control.

Spiders have recently received an increased amount of attention regarding their role as predators in agroecosystems (reviewed in Nyffeler & Benz 1987), and the implications that this has on pest control. Spiders seem to form an important part of the predatory guild in many agroecosystems (*e.g.* Specht & Dondale 1960; Carroll 1980; Liao *et al.* 1984; Nyffeler & Benz 1987; Van den Berg & Dippenaar-Schoeman 1991; Knight *et al.* 1997; Costello & Daane 1999; Amalin *et al.* 2001a; Yee *et al.* 2001), and may be the dominant predators present. According to Greenstone (1999) the primary role of studying predation by spiders should be to determine their role in suppression of pest populations. It has been suggested that single spider species might not be capable of controlling a specific pest species, but rather that the spider complex of a crop may collectively be able to suppress a pest species (Riechert & Lawrence 1997). Several functional groups can be identified in orchards. Each differs with regard to their hunting strategies, biological cycles, activity patterns and localisation in the environment, which affects the type of prey consumed and the effect of pest populations (Marc & Canard 1997). A high prevalence and diversity of spiders in orchards suggests that they may have a role in regulating the increase of arthropod pest populations (Amalin *et al.* 2001a).

Comprehensive surveys to determine species diversity and abundance are necessary before experiments can be carried out to determine the effectiveness of spiders as biological control agents (Green 1996). Diversity studies enable us to determine numerically dominant species on a crop, the guilds and phenology of different species, their spatial distribution, and the mechanisms by which prey, especially pests, are captured.

Surveys of spiders in South Africa have received an increased amount of attention as the role of these organisms as predators in agricultural landscapes is recognised. Work has been carried out on strawberries (Dippenaar-Schoeman 1976, 1979), cotton (Van den Berg & Dippenaar-Schoeman 1991; Dippenaar-Schoeman *et al.* 1999), citrus (Van den Berg *et al.* 1992; Stephen *et al.* 2001) and macadamia nuts (Dippenaar-Schoeman *et al.* 2001a). Locally, the role of spiders as biocontrol agents of mites in strawberries and cotton (Dippenaar-Schoeman 1976; Van den Berg & Dippenaar-Schoeman 1991), and of

citrus pests (Van den Berg *et al.* 1987, 1992; Dippenaar-Schoeman 1998) has been recognised, but no attempt has been made to quantify their predatory effects in other crops such as wheat, maize and deciduous orchards other than those mentioned above.

This study focused on determining the diversity and abundance of arboreal spiders in three pistachio orchards differing in age, size, and location, with the aim of determining factors influencing their diversity and abundance, as well as their role as natural control agents of pistachio pests. The first step towards achieving the latter objective were done by studying the diet of the three numerically dominant spider species in the field. This served to provide baseline information for a more specific study on the biological control potential of the dominant spider species present.

2.3 MATERIAL & METHODS

2.3.1 Study area and period

The study was carried out in two orchards at the Green Valley Nuts Estate (GVN, 22°56'41"S, 29°35'11"E), and a third on the farm Remhoogte (REM, 23°00'06"S, 29°31'55"E) in the Prieska district, Northern Cape Province, South Africa. The farms fall within the arid region of South Africa, with annual rainfall averaging between 200 and 300mm. The natural vegetation in the region is classified as Orange River Nama Karoo (Hoffman 1996). Characteristics of each orchard, as at the start of the study in January 2001, are summarised in Table 1.

TABLE 1: Parameters of three pistachio orchards surveyed at Green Valley Nuts Estate (GVN) and the farm Remhoogte (REM) in the Prieska district, Northern Cape Province, at the start of the survey in January 2001.

	GVN 1	GVN 19	REM
Orchard age	8 years	5 years	9 years
Orchard size	16 ha	16 ha	1.5 ha
Ground covers	Dominated by low-growing weeds	Alternate rows of grass and weeds	Dense mixture of grass and weeds
Other characteristics	Bordered by riverine bush and irrigated fields	Surrounded by other pistachio orchards	Bordered by riverine bush and irrigated fields

Trees were sampled once a month during 2001 and 2002, with the exception of June and August. Winter sampling was only done during July, as all trees lost their leaves during May, and there were consequently a negligible number of arthropods present in the trees during the cold months. Most arthropods found during the winter period were overwintering under bark or dead leaves in the tree canopy.

All orchards were subject to applications of various chemicals. Plant growth stimulants (*e.g.* Bladbuff™, Commodobuff™, Optibor™, Compliment™, etc.) were used for promotion of pistachio nut growth, budding and flowering. Roundup™ was applied to weeds beneath the tree canopies to prevent encroachment on the trees. The only insecticides applied were parathion during April, and endosulphan during December of both seasons, for the control of stinkbugs and other hemipterans. Benlate™ was applied as a fungicide to control infections of various fungal pathogens in trees.

2.3.2 Sampling method

Ten trees were randomly selected in each orchard on each study date. Thirty-six square metres of white sheeting were spread beneath each tree prior to sampling, which was done using a motorised knapsack mistblower (Stihl® SR 420). Dichlorvos (15ml/10l water) was used as a knockdown agent. While walking around the circumference of the trees, all foliage, branches and bark were sprayed with the dichlorvos solution until drenched. After 5 minutes had passed (to allow the insecticide to take effect) the trees were shaken vigorously to dislodge any arthropods that had not yet fallen onto the sheets. All arthropods were then collected by hand and preserved in 70% ethanol. A total of 200 trees were sampled in each orchard over the two-year survey.

After sampling from the sheets had been completed, all loose bark, dead leaves (usually curled leaves affected by *Altenaria* fungal infections), biotags (plastic strips supporting branches), and webs constructed in crevices were removed and searched thoroughly for any organisms sheltering in them. These were also preserved in the alcohol together with the other specimens for each tree.

The trees were sampled using a beating sheet at REM (during September 2001) and GVN 19 and REM (December 2002), due to extremely windy conditions, which made fogging impossible. In these cases the branches in the lower half of two trees were

beaten to account for the branches in a single tree. A beating sheet 0.5m by 0.5m was used and all spiders collected on the sheet were sampled. The additional sampling described above by searching was carried out as usual.

2.3.3 Guilds

Spiders were separated into known guilds for each genus or family, although this information wasn't included in the species list (Appendix 1). Wandering spiders were separated into plant-wanderers and ground-wanderers. Web building spiders were divided into the gumfoot-web builders, hackle-web builders, orb-web builders, retreat-web builders, sheet-web builders and space-web builders.

2.3.4 Predation events

Field observations on spiders actively foraging on foliage and bark (wanderers), or hunting in webs (web builders) were carried out during the day and at dusk. All predation events observed in the field were noted, and the spider and its prey were preserved in 70% ethanol for identification in the laboratory. No time was specifically allocated to this procedure, and therefore no attempt was made to quantify prey capture or relate it to season, plant physiology or prey abundance.

2.3.5 Statistical analysis

All calculations were done using the program GraphPad InStat version 3.05. Total spider catches in the three orchards were compared using a Chi-square test with Yate's correction at $P < 0.05$ and $P < 0.001$, to determine whether differences in abundance could be attributed to orchard age. This analysis was performed on two data sets, namely 1) on paired combinations of the total spider abundance over the two-year sampling period, and 2) on the monthly totals of spiders in each of the three orchards. Paired combinations of orchards during each month were compared.

A second analysis was performed on the spider abundance using linear regression, with spider numbers and orchard age at the end of the sampling periods as the two variables. This analysis was performed on three data sets, namely 1) the total spider abundance in the three orchards over the 2-year sampling period, 2) the annual totals of

the three orchards, and 3) the 6-month totals of the three orchards. Orchard age at the end of each sampling period was used in the calculations.

Species richness of the three orchards was determined to project the effect of orchard age and location on diversity. Species richness was determined as the number of species in an orchard divided by the total species in all three orchards found in the study. The qualitative Sørensen's Quotient of similarity was used to compare the similarity of the spider faunas of the three pistachio orchards: $QS=2j/(a+b)$, where a and b are the number of species captured at the two sites, and j the number of species common to both samples (Gajdoš & Toft 2000). A higher value (closer to 1) indicates greater similarity between the faunas at the two sites, while a value closer to 0 indicates a more unique fauna.

2.4 RESULTS

2.4.1 Diversity and abundance

The complete species list and their abundance in the three orchards throughout the survey is given in Appendix 1. A total of 5803 spiders represented by 18 families and 87 species were collected in the three orchards during the course of this study. This includes five new species and four possibly new species.

Total numbers of spiders were highest in REM ($n=2202$), followed by GVN 1 ($n=2051$) and GVN 19 ($n=1550$). Only three species comprised more than 5% of the total spider fauna each (Appendix 1), namely the jumping spider *Heliophanus pistaciae* Wesolowska (Salticidae, 53.8%), the sac spider *Cheiracanthium furculatum* Karsch (Miturgidae, 12.8%), and the orb-weaver *Neoscona subfusca* (C. L. Koch) (Araneidae, 6.4%). Family abundance showed a very skewed dominance, with the Salticidae most common in all three orchards. In GVN 1 they comprised 66.1% of the total catch, in GVN 19 they contributed 61.2%, and at REM, 52.4% (Table 2). Among the remaining families only the Miturgidae (10.0%; 15.9%; 14.0%, respectively) and Araneidae (7.0%; 4.1%; 11.6%, respectively) represented, on average, more than 5% of the fauna.

TABLE 2: Family abundance in three pistachio orchards at Green Valley Nuts (GVN) and Remhoogte (REM), collected during a 2-year sampling period (January 2001 to December 2002) conducted in the Prieska district, Northern Cape Province.

FAMILY	GVN 1	%	GVN 19	%	REM	%	TOTAL	%
Araneidae	144	7.02	63	4.06	255	11.58	462	7.96
Corinnidae	10	0.49	6	0.39	30	1.36	46	0.79
Dictynidae	35	1.71	30	1.94	62	2.82	127	2.19
Gnaphosidae	21	1.03	25	1.61	37	1.67	83	1.43
Linyphiidae	75	3.66	25	1.61	76	3.45	176	3.03
Lycosidae	10	0.49	7	0.45	14	0.64	31	0.53
Mimetidae	0	0	0	0	1	0.05	1	0.02
Miturgidae	204	9.95	247	15.94	309	14.03	760	13.10
Oxyopidae	22	1.07	8	0.52	30	1.36	60	1.03
Philodromidae	65	3.17	63	4.06	105	4.77	233	4.02
Pholcidae	0	0	1	0.06	0	0	1	0.02
Pisauridae	1	0.05	0	0	6	0.27	7	0.12
Salticidae	1355	66.07	948	61.16	1154	52.41	3457	59.57
Segestriidae	0	0	0	0	1	0.05	1	0.02
Tetragnathidae	0	0	0	0	1	0.05	1	0.02
Theridiidae	91	4.44	122	7.87	96	4.36	309	5.32
Thomisidae	18	0.88	5	0.32	22	1.00	45	0.78
Uloboridae	0	0	0	0	3	0.14	3	0.05
Σ	2051	~100.00	1550	~100.00	2202	~100.00	5803	~100.00

TABLE 3: Family composition (species diversity) of spiders in three pistachio orchards at Green Valley Nuts (GVN) and Remhoogte (REM), collected during a 2-year sampling period (January 2001 to December 2002) conducted in the Prieska district, Northern Cape Province.

FAMILY	GVN 1	%	GVN 19	%	REM	%	TOTAL	%
Araneidae	6	9.38	4	8.51	5	7.14	9	10.34
Corinnidae	5	7.81	3	6.38	5	7.14	7	8.05
Dictynidae	1	1.56	1	2.13	1	1.43	1	1.15
Gnaphosidae	8	12.50	8	17.02	10	14.29	11	12.64
Linyphiidae	8	12.50	6	12.77	8	11.43	10	11.49
Lycosidae	1	1.56	1	2.13	1	1.43	1	1.15
Mimetidae					1	1.43	1	1.15
Miturgidae	2	3.13	2	4.26	2	2.86	2	2.30
Oxyopidae	3	4.69	2	4.26	3	4.29	3	3.45
Philodromidae	4	6.25	3	6.38	3	4.29	5	5.75
Pholcidae			1	2.13			1	1.15
Pisauridae	1	1.56			1	1.43	1	1.15
Salticidae	11	17.19	11	23.40	13	18.57	15	17.24
Segestriidae					1	1.43	1	1.15
Tetragnathidae					1	1.43	1	1.15
Theridiidae	4	6.25	3	6.38	5	7.14	5	5.75
Thomisidae	10	15.62	2	4.26	8	11.43	11	12.64
Uloboridae					2	2.86	2	2.30
Σ	64	~100.00	47	~100.00	70	~100.00	87	~100.00

Species diversity was highest in REM (70 spp.), followed by GVN 1 (64 spp.) and GVN 19 (47 spp.) (Table 3). In addition to being the most abundant family, the Salticidae was also the most diverse, comprising 17.2% of the total species in the pistachio trees. This family was the most diverse in all three orchards. Other diverse families include the Gnaphosidae and Thomisidae (11 spp., 12.6% each), and Linyphiidae (8 spp., 11.5%).

2.4.2 Guilds

The plant-wandering spiders (79.2%) were strongly dominant in the pistachio trees, largely due to the dominance of *H. pistaciae* and *C. furculatum*. Ground-wandering spiders only occasionally wandered onto trees and formed a small proportion of the population (2.2%). Many of these ground dwellers were found foraging on bark on the tree trunk or resting under bark or in dry leaves. Web building spiders formed only a relatively small proportion of the spider population in the trees. Orb-weavers (Araneidae, Tetragnathidae, Uloboridae) were dominant (8.0%), followed by gumfoot-web builders (Theridiidae, 5.3%), sheet-web builders (Linyphiidae, 3.0%), hackle-web builders (Dictynidae, 2.2%), space-web builders (0.02%) and retreat-web builders (Segestriidae, 0.02%).

In terms of species diversity, guilds were comprised of plant-wanderers, which dominated with 37.5% of the species, followed by the ground-wanderers (27.3%). Web-building spiders comprised smaller proportions of the species present, with orb-weavers (13.6%), sheet-web builders (11.4%), gum-foot web builders (5.7%), space-web builders, hackle-web builders and retreat-web builders (1.1% each).

2.4.3 Seasonal abundance and phenology

Arboreal spider populations in the three orchards appeared to follow relatively similar seasonal fluctuations (Figure 1). During the summer 2001 season, populations peaked in March-April, with a sharp decrease in the months following through autumn and winter. Spider populations in the following season peaked in December-January. However, populations in all three orchards decreased in February-March 2002. Numbers in the last season remained low following winter.

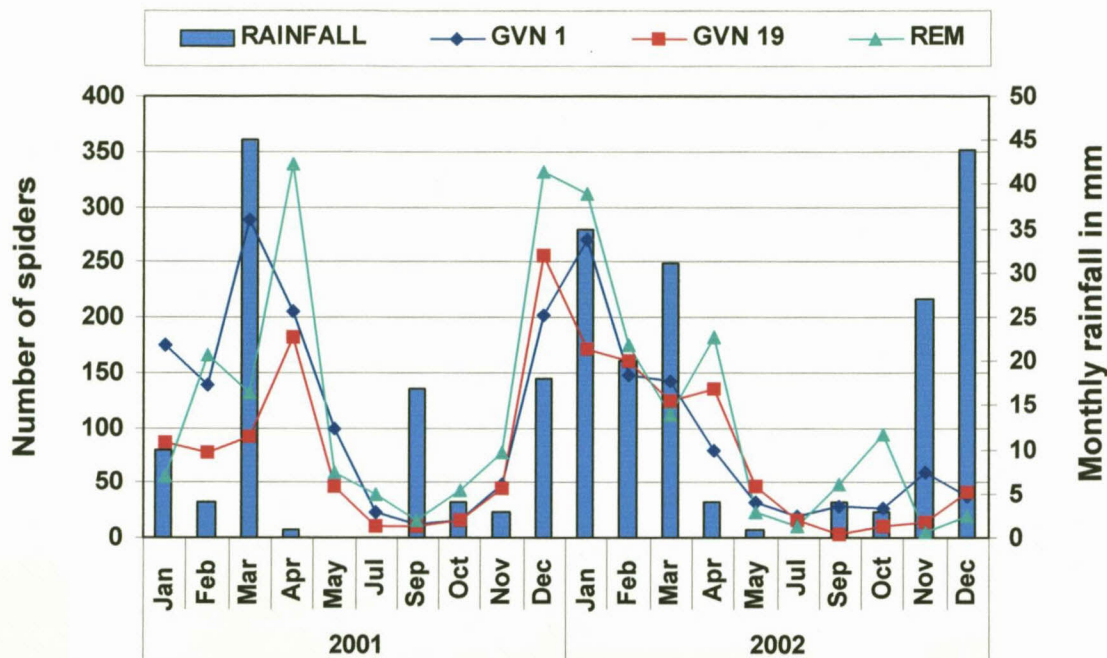


FIGURE 1: Seasonal fluctuations of spider populations in three pistachio orchards in the Prieska district, Northern Cape Province.

The unexpectedly low spider numbers compared to previous months at GVN 1 (February 2001) and REM (March 2001) (Figure 1) could be attributed to very windy conditions during the sampling, which may have blown many spiders beyond the sampling sheeting. The use of beating as a method in September 2001 (REM) and December 2002 (GVN 19 and REM) due to windy conditions may also have underestimated the spider fauna. Harvesting at REM and GVN 1 decreased numbers of spiders collected in March in both years.

Heliophanus pistaciae is a small (<6mm), sexually dimorphic, diurnally active jumping spider. Males are black with a white median stripe on the abdomen, occasionally extending onto the black-brown cephalothorax; females are pale grey throughout with darker speckles on the abdomen. When not active, spiders rest in silk cocoons in protected sites, such as under bark and in tree knots, in dead leaves in the tree canopy,

and in biotags. Numbers peaked in February-March during the summer 2001 season, but during the 2001/2002 season the peak was in December-January (Figure 2). Peak abundance was nearly double in the summer of 2002 than in the summer of 2001. The rainfall of September 2001 (Figure 1) may have been responsible for the large peak in the *H. pistaciae* population in December. Immatures consistently formed 50% or more of the population of this species.

Cheiracanthium furculatum is one of numerous species of sac spiders with nocturnal activity. This species can be distinguished from other spiders in pistachio trees by their large size (<15mm in length), pale yellow colour of the entire body and legs, and the dark chelicerae. Egg sacs were found in a cocoon enclosing the female, during February and March, in dried leaves and under loose bark. When not active, this species constructs retreats in dead leaves in the canopy and under bark.

The *C. furculatum* collected from the pistachio trees were mainly immatures, with very few adults collected in any particular month (Figure 2). The build-up of *C. furculatum* early in the season appears to be slow, with populations peaking in early autumn (April) during both years. Their large numbers in summer could be attributed to the dispersal of second instar spiderlings from egg sacs. Numbers decreased sharply in May and remained low until the start of summer.

The orb-weaving genus *Neoscona* was well represented in the pistachio trees, with five species collected. The dominant species was *N. subfusca*, a small (<5mm), light brown spider that constructs its orb-web between leaves and branches in the tree canopy. It is a nocturnal species that begins web construction late in the afternoon, about an hour before sunset. During the day it rests beneath branches and leaves. Populations of *Neoscona* spp. peaked in April of the 2001 season, and remained low through autumn, winter and spring (Figure 2). There was a sudden increase in numbers in December 2001, and populations peaked in the following month. Abundance only decreased markedly in April, and remained low until the following season.

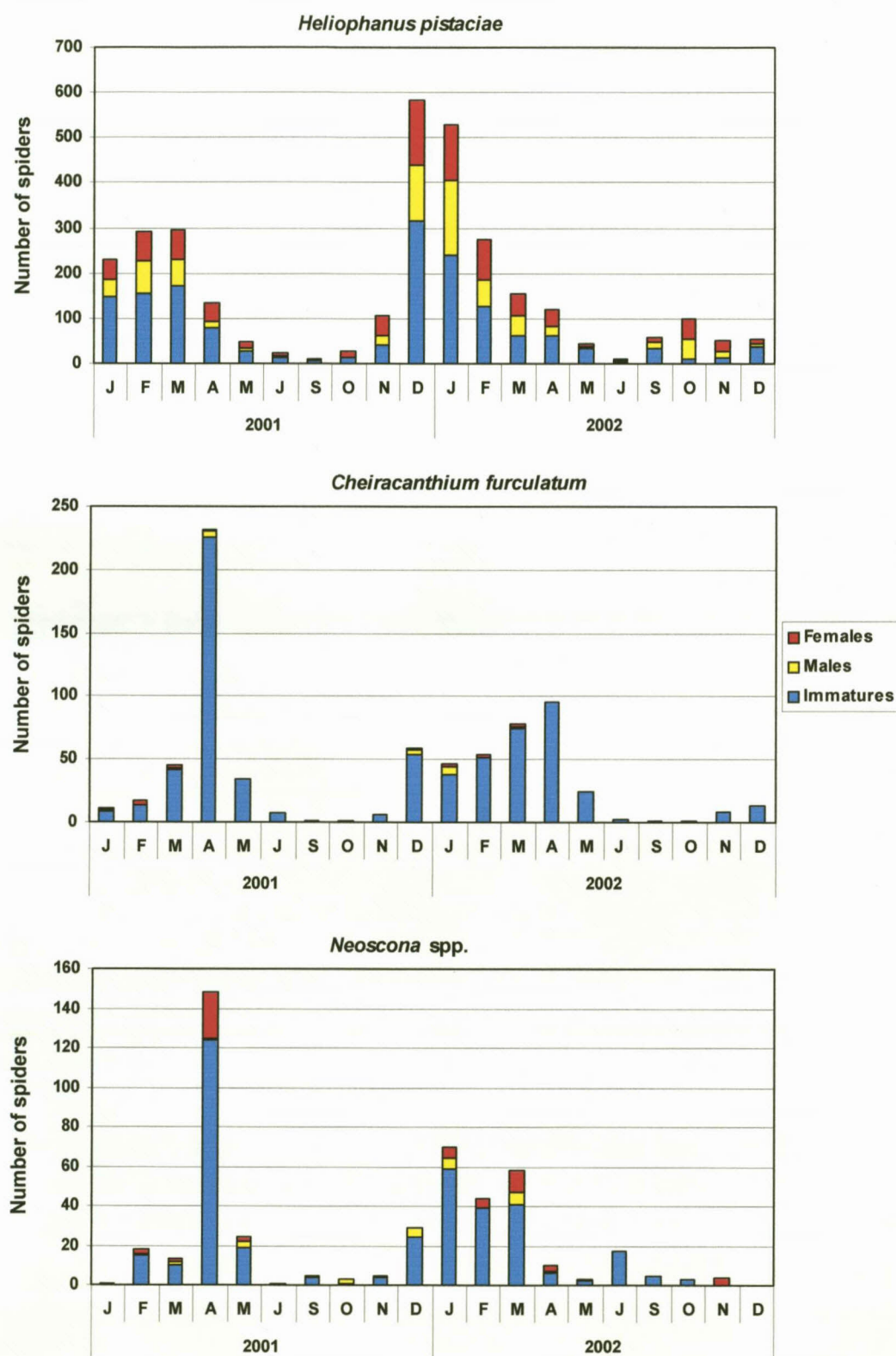


FIGURE 2: Seasonal fluctuations of three common spider taxa in the canopies of pistachio orchards in the Prieska district, Northern Cape Province.

2.4.4 Predation events

Field observations on the predatory behaviour of the three numerically dominant species in pistachio trees, *H. pistaciae*, *C. furculatum* and *N. subfusca*, yielded some interesting results (Table 4). These spiders were found preying on various minor and potential pests, including false chinch bugs, *Nysius natalensis* Evans (Hemiptera: Lygaeidae), aphids (Homoptera: Aphididae), leafhoppers (Homoptera: Cicadellidae), thrips (Thysanoptera: Phlaeothripidae), and leaf beetles (Coleoptera: Chrysomelidae). As these all pose a threat to the health and production potential of the crop, the role of spiders as predators of these pests should be regarded as positive. On one occasion a female *H. pistaciae* was found among an aggregation of aphids, feeding on an alate. The abdomen was distended, suggesting that numerous prey had already been consumed.

However, these three spider species also preyed on two important natural enemy groups: predatory ladybirds (Coleoptera: Coccinellidae: *Scymnus levaillanti* Mulsant) and parasitoid wasps (Hymenoptera: Chalcidoidea). Although these observations would suggest that spiders might harm populations of beneficials, both of these groups were very abundant and the impact of spiders on their populations may probably be small.

TABLE 4: Field observations of prey items of three common spiders in pistachio tree canopies.

PREY ITEMS	SPIDER SPECIES		
	<i>H. pistaciae</i>	<i>C. furculatum</i>	<i>N. subfusca</i>
Thysanoptera: Phlaeothripidae	x	x	x
Hemiptera: Lygaeidae	x	x	x
Homoptera: Aphididae	x	x	x
Homoptera: Cicadellidae	x	x	x
Coleoptera: Bruchidae		x	
Coleoptera: Coccinellidae	x	x	
Coleoptera: Chrysomelidae	x	x	
Diptera: Cecidomyiidae	x		x
Diptera: Muscidae	x	x	
Diptera: Tephritidae		x	
Lepidoptera larvae		x	
Hymenoptera: Chalcidoidea	x	x	x
Acari: Tetranychidae	x		

The results also demonstrated that spiders occupying different guilds and utilizing different hunting strategies and activity periods could prey on the same pest species: in this regard *H. pistaciae* is a visually dependent hunter, *C. furculatum* is a tactually dependent hunter, and *N. subfusca* constructs an orb-web between branches. This provides a good example of resource-use complementarity, which would support the idea that spider communities, as a unit, may have a greater impact on a pest species than a single species alone. Given the dominance of *H. pistaciae*, however, one could propose that this species might have a greater impact on certain diurnal pests than the spider community as a whole.

2.4.5 Statistical analysis

The Chi-square (χ^2) tests indicate that orchard age has a significant effect on spider abundance, but that this difference becomes less pronounced when orchards are of a similar age. Over the 2-year sampling period numbers were significantly higher in GVN 1 and REM than in GVN 19 ($P < 0.001$). Spider abundance in REM was higher than in GVN 1, but the difference was less significant ($P < 0.05$). This could be expected since REM is only a year older than GVN 1.

The Chi-square tests of the monthly totals indicated a general tendency for the older orchards to dominate the younger orchard regarding spider abundance (Table 5). However, the increase of spider populations with orchard age will ultimately reach a plateau, when the carrying capacity of the habitat is reached. Numbers should then fluctuate seasonally around an equilibrium level.

The second analysis, using linear regression, provided considerably different results. The 6-month totals were found to be insignificant ($r^2 = 0.00659$, $P = 0.8019$, $F = 0.06638$), as were the annual totals ($r^2 = 0.2395$, $P = 0.3245$, $F = 1.260$). However, the two-year totals were found to be highly significant ($r^2 = 0.9996$, $P = 0.0124$, $F = 2628.0$). These contrasting results could be attributed to seasonal and annual fluctuations in spider numbers, which provide a greater range of data points in this analysis. While the two-year totals have fewer data points, the influence of variation between seasons and years is greatly diminished.

Species richness (Appendix 1) was greatest at REM (0.805), and only slightly lower at GVN 1 (0.736). This could be expected, as REM is only a year older than GVN 1. Species richness was considerably lower at GVN 19 (0.540), which could be attributed to it being a younger orchard. Sørensen's Quotient values provided similar results. The similarity between the faunas of GVN 1 and REM was clearly higher (0.791) than between GVN 19 and GVN 1 (0.649) and between GVN 19 and REM (0.667).

TABLE 5: Results of a Chi-square test with Yate's correction, comparing paired combinations of monthly spider totals in three pistachio orchards. N.S. indicates that numbers in the two orchards compared were not significantly different in a particular month.

DOMINANCE	TOTAL	N.S.	TOTAL SIGNIFICANT	SIGNIFICANCE LEVELS				
				$P<0.00001$	$P<0.0001$	$P<0.001$	$P<0.01$	$P<0.05$
GVN 1 > REM	8	3	5			3	1	1
REM > GVN 1	12	5	7			5		2
GVN 1 > GVN 19	15	6	9	1	3	3		2
GVN 19 > GVN 1	5	3	2			1		1
REM > GVN 19	14	3	11		1	6	3	1
GVN 19 > REM	6	3	3				1	2

2.5 DISCUSSION

2.5.1 Faunal composition

Spiders were often the dominant order of predators in pistachio canopies in most months of this survey, usually exceeding numbers of beetles (Coleoptera: Coccinellidae, Staphylinidae) and lacewings (Neuroptera: Chrysopidae, Hemerobiidae). Their numerical abundance in pistachio orchards demonstrates that spiders are an important component of the natural enemy complex.

The results of this study compare well with the findings of spider abundance and diversity found by Van den Berg *et al.* (1992) on citrus and Dippenaar-Schoeman *et al.* (2001a) on macadamia nuts, where salticids also dominate the spider fauna on these

crops. This despite the present study occurring in an arid region compared to the subtropical biome of the macadamia survey. In other studies conducted in Europe and the United States, jumping spiders were also found to be common on apples (Samu *et al.* 1997; Wisniewska & Prokopy 1997; Bajwa & Aliniaze 2001) and in vineyards (Costello & Daane 1997; Nobre & Meierrose 2000). Maintaining a high diversity of natural enemies (including spiders) and creating an environment which supports such diversity may play an important role in the control of specific pests (Marc & Canard 1997; Wilby & Thomas 2002), as this increases the likelihood of finding suitable control agents for pests (Marc & Canard 1997).

There was strong dominance of wandering spiders in this study, which follows a pattern similar to numerous other studies in orchards (*e.g.* Specht & Dondale 1960; Jennings 1976; Miliczky *et al.* 2000; Bajwa & Aliniaze 2001). There were also considerably more web-builders collected in pistachio orchards than in architecturally similar macadamia orchards (Dippenaar-Schoeman *et al.* 2001a), probably due to the shaking of the trees and searching techniques carried out in the present study), which uncovered many sedentary web-builders. Dippenaar-Schoeman *et al.* (2001a) only sprayed the trees and collected spiders that fell on the sheets.

Even if web-builders are not abundant, they often form a substantial proportion of the species present in orchards (Dondale 1956; Dondale *et al.* 1979; Dippenaar-Schoeman *et al.* 2001a). Webs have additional benefits in biological control, since they indirectly add to the mortality of certain pests when the pest becomes trapped but is not fed on by the spider (Van den Berg *et al.* 1992; Riechert 1999; Sunderland 1999).

The prominence of *H. pistaciae* in pistachio orchards at GVN and other farms in the area, and other crops at GVN (figs, walnuts and pecan nuts), would support its classification as an agrobiont species, *i.e.* a species that reaches high levels of dominance in agroecosystems (Samu & Szinetár 2002), with the dominance sometimes reaching extremes. This despite that it was described only recently from material collected in the present study (Wesolowska 2003). This species occurs throughout the year and is an active hunter, occurring in high numbers on foliage in the trees in spring and summer. Downie *et al.* (2000) found that certain spider species appear to exhibit a preference for agricultural habitats over less-disturbed ones. The same preference could be prevalent in

H. pistaciae populations, a factor that may have had a strong influence on their progression to agrobiont status.

Cheiracanthium furculatum is a potential agrobiont, but was considerably less abundant than *H. pistaciae*. It was found in most trees sampled and during most months of the year (except winter). Another sac spider, *C. mildei* L. Koch, was found to be common in citrus and apple in orchards in Israel (Mansour *et al.* 1980; Mansour & Whitcomb 1986), and would qualify as an agrobiont. Favourable conditions may result in numbers of *C. furculatum* increasing to a level where it could be considered as an agrobiont.

It could be speculated that two other species, *N. subfusca* and *Thyene inflata* (Gerstaecker), could be targeted as future agrobionts, as they also reached relatively high numbers on rare occasions. Evidence in support of this is the two species of *Thyene* that dominated the spider fauna in macadamia orchards (Dippenaar-Schoeman *et al.* 2001a). Studies conducted in the future on spider abundance in pistachio orchards in the Prieska area may confirm whether this speculation has merit.

Orchard age (and possibly canopy size) has a significant effect on spider abundance, with older orchards with mature trees containing a greater number of spiders than more recently established orchards. The density of canopy spiders is typically correlated with an increase in the density of branches in trees (Rinaldi & Ruiz 2002), which is reflected in the age of the trees, as well as the cultivars sampled. Orchard age thus seems to influence the establishment of individual spider species, and probably increases the abundance of rare families.

Orchard age has a definite positive effect on spider diversity, which implies that with increasing age a greater number of spider species successfully colonise orchards and increase the total diversity as populations become established. There will be an upper limit where the maximum diversity capacity will be reached when most species in the area will have entered and established themselves in the orchards. Diversity indices carried out in surveys over a number of years will probably show diversity increasing rapidly during the early years of orchard establishment, before leveling out to a plateau as the total diversity from the surrounding habitats establish themselves in the orchards (see Wilmers *et al.* 2002). However, the disturbance effects in the orchards (chemical

applications, harvesting, ground cover mowing) may cause temporary local extinctions of rare species.

Smaller orchards, particularly those bordering on natural habitats, will probably be colonised more rapidly from the outside than larger orchards. This probably also influenced the abundance and diversity of spiders at REM, since it is an isolated orchard. Marshall *et al.* (2000) proposed that various factors were responsible for different colonisation rates of agroecosystems by spiders, including the presence of conspecifics, abundance and availability of prey, and interspecific competition and habitat structure. It would be very difficult (if not impossible) to quantify what proportion of individuals colonising orchards early in the season had overwintered under bark, in the ground covers, or in leaf litter, and how many entered orchards early in the season by ballooning from surrounding habitats.

Monthly spider abundance makes for useful comparison on the effects of rainfall on spider populations, with dramatic contrasts in the same period of consecutive years. Other studies have shown a positive correlation between spider numbers and numbers of potential prey (Nentwig 1982; Riechert & Lockley 1984; Bumroongsook *et al.* 1992). Thus, spider abundance increases with prey abundance, and is regarded as the numerical response to prey densities. The stimulatory effect that rainfall has on insect populations may play a role in spider increases, attracting them to the increasing prey numbers. Low prey availability may have a negative effect on spider population growth, as spiders may disperse to more profitable feeding sites when prey density becomes too low (Harwood *et al.* 2001). The deciduous nature of the trees and extremely cold conditions in winter may play a role in reducing the numbers of arboreal spiders. A similar pattern is evident in other crops in South Africa, including strawberries and macadamia nuts (Dippenaar-Schoeman 1977; Dippenaar-Schoeman *et al.* 2001b).

The results of this survey strongly support the proposed concept of the Green Oasis Hypothesis, whereby a favourable habitat (irrigated orchards) is created in a harsh environment (arid climate and vegetation), resulting in greater survival of arthropods than in the surrounding natural habitat (S. Louw, personal communication). In the case of predacious arthropods such as spiders, this is due to greater prey availability and a more

favourable microclimate inside the orchard ecosystem compared to the hot, dry surrounding environment, which together enhances survival of spider populations.

2.5.2 Seasonal abundance

An important factor to consider using spiders in biocontrol is that the spider populations fluctuate throughout the season and between years (Dippenaar-Schoeman 1977, 1979; Dippenaar-Schoeman *et al.* 2001b), and this is probably also true for pest species (*e.g.* Liao *et al.* 1984). Consequently the impact of spiders will vary seasonally regarding their density in the crop and, as such, will influence the capture frequency and the type of prey captured. Additionally, different developmental stages of spider species and their prey will occur in differing ratios throughout the year, and this may further affect the efficiency of a spider species in controlling a particular pest.

This study showed that climatic conditions, coupled with the deciduous nature of pistachio, have a significant effect on the abundance of spiders in the trees. In autumn (April and May) the trees lose their leaves, which is typically accompanied by a dramatic drop in arboreal spider numbers (Rinaldi & Ruiz 2002). Many arboreal arthropods fall to the ground and may overwinter in the ground covers and leaf litter, or survive the winter in the egg stage. Most of the arboreal spiders collected during winter were sedentary web-builders (mainly Theridiidae and Linyphiidae), or wanderers overwintering under loose bark and in dead leaves.

From the graphs of the seasonal abundance of spider populations and individual species, it appears that the applications of endosulphan had a minimal effect on the spider population during January 2002, following an application the previous month. The orchard that showed the greatest reduction was GVN 19 (approximately 30%), which could be a reflection of the less dense tree canopies of the younger trees. This would increase the susceptibility of the spiders to pesticides with a decrease in shielding effect of the vegetation. The applications of parathion resulted in more dramatic mortality of spider populations in May, but changing climatic conditions in autumn, and the falling of leaves from the trees could also have influenced these decreases. It would thus be unwise to attribute these population decreases solely to the pesticide. According to Van den Berg *et al.* (1990), working in South African cotton fields, endosulphan initially caused high

mortality of spiders (40.6%), but populations soon recovered. Sekar & Shunmugavelu (1992) also found endosulphan to have high toxicity to four species of spiders representing different guilds (orb-weavers, retreat-web and space-web builders, and wandering spiders). The effect of parathion on spiders is not presently known. It would thus be recommended that these two pesticides be tested on common spiders in pistachio to determine what their toxicity and likely effects on spider populations are.

2.5.3 Sheltering structures

Numerous natural and artificial structures in the pistachio trees were found to be important microrefugia for spiders and other prominent natural enemies (e.g. ladybird beetles). Plant wandering spiders such as *H. pistaciae* and *C. furculatum*, and most of the ground wandering species collected in the trees, were often found in silk retreats under loose bark, and in biotags and dead leaves when not active. Not only do the spiders rest here, females of both species were often found in summer together with egg sacs built in these structures. The females guard the young until they disperse from the egg sac. Numerous pests and potential pests (e.g. stink bugs, barklice, leaf beetles and seed weevils) were also found sheltering in these structures, and since it is unlikely that the spiders would feed while inactive, there is conflicting evidence as to the benefits of these structures. It must be noted, however, that spider numbers were notably higher in trees with dead leaves, loose bark and biotags than in those without. These structures, therefore, retain spiders in the trees and support the abundance of arboreal spiders.

In addition to providing shelter for wandering spiders when they are not active, these structures also serve as frames for gumfoot-web builders and hackle-web spiders to build their webs. *Theridion* spp. and a *Euryopis* sp. were regularly found in webs constructed in dry leaves and biotags, while an *Archaeodictyna* sp. appears to build its webs around buds and bases of both living and dead leaves.

Linyphiid spiders were more prevalent at REM because of plastic wrappings around the stem of some trees, which are used to protect the boughs from bursting in the heat of summer. These were wrapped low on the boughs of the trees and provide an ideal frame for the spiders to build their webs. *Heliophanus pistaciae*, *C. furculatum* and ladybirds were also commonly resting in the wrappings. Pekár (1999) and Horton *et al.*

(2001, 2002) showed that cardboard bands placed around tree trunks served as important overwintering sites for spiders, and increased their abundance in the trees during the following season. Thus, an additional benefit of these wrappings (over and above the protection of the tree) is that they support spider abundance in the trees. It is therefore strongly suggested that these structures are retained during the winter months to strengthen the natural enemy complex early in the following season, and also to include such wrappings in young orchards. This will assist in increasing spider abundance in these orchards during the years following orchard establishment, which will enable spiders to play an important role in pest control from an early stage in the development of the crop, particularly on pests feeding on vigorously growing plant parts, *e.g.* aphids.

2.5.4 Biological control potential

Spiders are often found to be the most abundant generalist predators in certain orchards (Carroll 1980; Liao *et al.* 1984; Knight *et al.* 1997), while other studies (*e.g.* Putman 1967) suggest that spiders only form part of the complex of minor predators that aid major predators in controlling pests. However, in reviews of pest management practices in certain orchard systems, it appears as if researchers have paid very little attention to the role spiders play in pest control (*e.g.* AliNiazee 1998; Peña *et al.* 1998).

The general biomonitoring program conducted to date in pistachio orchards has identified numerous key pests and minor pests. Two key pests are the woolly chafer *Sparrmannia flava* Arrow (Coleoptera: Scarabaeidae: Melolonthinae), which causes extensive defoliation of trees of the cultivar Shufra (Swart 2002), and the stinkbug *Atelocera raptoria* Germar (Hemiptera: Pentatomidae), which causes leaf damage to young trees and nut loss in older trees. This species also shows a selective feeding preference for the cultivar Shufra, and avoids feeding on foliage of the cultivars Sirora, Ariyeh, and others. The latter species has already been implicated as a pest of macadamia nuts in the Mpumalanga Lowveld (Van den Berg *et al.* 1999). However, both of these pests are large (>15mm in length), and spiders probably won't play a role in their control, with the possible exception of predation on stinkbug eggs and early-instar nymphs.

Consequently, the impact of spiders is likely to be greater on minor pests, such as the false chinch bug, *Nysius natalensis*, and unidentified aphids, leafhoppers, thrips, leaf

beetles and moth larvae (Lepidoptera). Aphids cause leaf wrinkling when feeding on the growth tips of young trees (personal observation), while *N. natalensis* not only transmits fungal pathogens to pistachio nuts, but also causes direct nut damage by its feeding (Swart 2002). Leaf beetles and moth larvae cause defoliation of pistachio trees.

Bumroongsook *et al.* (1992) and Mansour (1993) found spiders to be important biological control agents of blackmargined aphids on pecan nuts. Spiders are the most efficient aphid predators at densities of 1 or less aphids per leaf, while lacewings and ladybirds are more effective control agents at densities of 50 aphids per leaf (Bumroongsook *et al.* 1992). In the absence of spiders the populations of blackmargined aphids can increase at nearly an exponential rate (Liao *et al.* 1984). The example of the *H. pistaciae* female feeding on the aphids mentioned earlier provides strong evidence that this species may play an important role in the control of this pest, particularly since aphids were found in most trees sampled during spring and summer. Aphids also form a large proportion of the diet of web-building linyphiid (Nentwig 1980), theridiid (Pekár 2000) and dictynid spiders (Miliczky & Calkins 2001) in natural- and agroecosystems.

The role that spiders play in the control of the cotton fleahopper on cotton and woolly croton (Dean *et al.* 1987; Breene *et al.* 1988, 1989), supports the suggestion that that they may play an important role in the control of *N. natalensis*. Sterling *et al.* (1992) reported that spiders and other generalist predators all had some economic value in controlling cotton fleahoppers. It is proposed here that similar studies be conducted in the future, to determine potential economic benefits of spiders in controlling this pistachio pest, particularly in consideration of the feeding damage it inflicts on nuts (Swart 2002).

While leafhopper numbers are especially high in pistachio trees during the hot months of the year (October to March), nothing is known about the damage they cause. The three most abundant spider species all fed on leafhoppers, and may play a role in their control. Jumping spiders were also found to prey on leafhoppers in apple orchards (Marc & Canard 1997), while lycosids were found to be important biological control agents of leafhoppers in rice fields (Oraze & Grigarick 1989).

Various other studies have shown spiders to be important predators of key pests on several crops. These include citrus psylla (Van den Berg *et al.* 1987, 1992), citrus scale (Mansour & Whitcomb 1986), and citrus leafminer (Amalin *et al.* 2001b) on citrus,

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giant loopers on avocado (Mansour *et al.* 1985), leafrollers on apples (Miliczky & Calkins 2002), and spider mites on strawberries (Dippenaar-Schoeman 1976) and cotton (Van den Berg & Dippenaar-Schoeman 1991).

Spiders can be regarded as more effective predators than some specialist predators and parasitoids as they consume more than a single life stage of their prey (Lingren *et al.* 1968; Mansour *et al.* 1982; Guillebeau & All 1989; Nyffeler *et al.* 1990; Breene *et al.* 1993; Amalin *et al.* 2001b). Predation by spiders on eggs may be considerably less than that of other predators (Hilbeck *et al.* 1997; Pfannenstiel & Yeargan 2002), probably because most spiders depend on visual or vibratory cues for prey capture, resulting in a poor response to stationary food items such as eggs. Miliczky & Calkins (2002) found the tactile-dependent hunter *Cheiracanthium mildei* L. Koch to be the most effective spider predator of leafroller (Lepidoptera: Tortricidae) eggs and larvae in apple and pear orchards. Various salticids also fed extensively on eggs and larvae. One could expect *C. furculatum*, and to a lesser extent *H. pistaciae*, to play a role in the control of minor lepidopteran pests on pistachio, and play a supplementary role to the mortality effects of parasitic Hymenoptera on eggs and larvae. Spiders may also disturb lepidopteran larvae in the tree canopy, causing larvae to fall to the ground, where they may be consumed by epigeic predators, or die by not finding a suitable wild host plant (Mansour *et al.* 1981). Generalist predators may prey on specialists (Colfer & Rosenheim 2001; Heimpel *et al.* 1997), which may reduce the positive effects that other natural enemies have on pests.

According to Nyffeler (1999) information on how prey selection in the field operates is a prerequisite to a quantitative assessment of the spiders' potential as biological control agents in agroecosystems. In determining the prey items that spiders in agroecosystems consume, one cannot depend on laboratory test results alone to determine prey items that will be consumed in the field, since spiders behave differently in the field laboratory (Nyffeler & Benz 1987). However, potential prey species that are consumed in the laboratory will most likely be accepted in the field, provided the spider does encounter the prey. Predation can be tested using radio-isotope-labeled prey released in the crop, or analysis of stomach contents by enzyme-linked immunosorbent assay (ELISA) (Greenstone 1999).

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APPENDIX 1: Diversity and abundance of arboreal spiders collected in pistachio orchards from January 2001 to December 2002 († indicates a new species, ‡ indicates a possible new species, and ? indicates a dubious identification).

FAMILY/SPECIES	GVN 1	GVN 19	REM	TOTAL	% OF TOTAL
ARANEIDAE					
<i>Araneus</i> sp.		1		1	0.02
<i>Cyrtophora citricola</i> (Forskål, 1775)			2	2	0.03
<i>Hypsosinga</i> sp.		1		1	0.02
<i>Neoscona blondeli</i> (Simon, 1885)	30	15	25	70	1.21
<i>Neoscona moreli</i> (Vinson, 1863)?	1		1	2	0.03
<i>Neoscona rapta</i> (Thorell, 1899)	2			2	0.03
<i>Neoscona subfusca</i> (C. L. Koch, 1837)	105	46	222	373	6.43
<i>Neoscona</i> sp. 5	4			4	0.07
<i>Pararaneus cyrtoscapus</i> (Pocock, 1898)?	1		4	5	0.09
CORINNIDAE					
<i>Austrachelas</i> sp. imm.	1			1	0.02
<i>Cambalida</i> sp.†	2		1	3	0.05
<i>Castianeira fulvipes</i> Simon, 1896		3	10	13	0.22
<i>Castianeira</i> sp. 2		2		2	0.03
<i>Cetonana</i> sp. imm.	2		1	3	0.05
<i>Copa flavoplumosa</i> Simon, 1885	3	1	16	20	0.35
<i>Trachelas pusillus</i> Lessert, 1923	2		2	4	0.07
DICTYNIDAE					
<i>Archaeodictyna</i> sp.	35	30	62	127	2.19
GNAPHOSIDAE					
<i>Aneplasa nigra</i> Tucker, 1923	6	5	7	18	0.31
<i>Camillina cordifera</i> (Tullgren, 1910)	1	1	2	4	0.07
<i>Drassodes sesquidentatus</i> Purcell, 1908	8	11	5	24	0.41
<i>Echemus</i> sp.		1	1	2	0.03
<i>Latonigera</i> sp.			10	10	0.17
<i>Micaria</i> sp.	1	2	3	6	0.10
<i>Pterotricha auris</i> (Tucker, 1923)	1		3	4	0.07
<i>Setaphis subtilis</i> (Simon, 1897)	1		1	2	0.03
<i>Trichothyse</i> sp.	1	2	1	4	0.07
<i>Xerophaeus vickermani</i> Tucker, 1923		2		2	0.03
<i>Xerophaeus</i> sp. 2	2	1	4	7	0.12
LINYPHIIDAE					
<i>Eperigone fradeorum</i> (Berland, 1932)	14	2	23	39	0.67
<i>Erigone</i> sp.		1	2	3	0.05
<i>Meioneta habra</i> Locket, 1968	8	3	9	20	0.35
<i>Meioneta</i> sp. 2†	1	2	2	5	0.09
<i>Meioneta</i> sp. 3	1	2	2	5	0.09
<i>Metaleptophantes familiaris</i> Jocqué, 1984	1			1	0.02
<i>Microlinyphia sterilis</i> (Pavesi, 1883)	1		2	3	0.05
<i>Ostearius melanopygius</i> (O. P.-Cambridge, 1879)	49	15	37	101	1.74
<i>Pelecopsis janus</i> Jocqué, 1984			1	1	0.02
<i>Tybaertiella</i> sp.	1			1	0.02

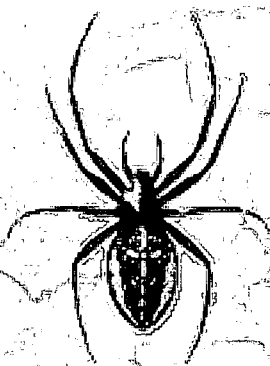
APPENDIX 1- continued.

FAMILY/SPECIES	GVN 1	GVN 19	REM	TOTAL	% OF TOTAL
LYCOSIDAE					
<i>Pardosa crassipalpis</i> Purcell, 1903	10	7	14	31	0.53
MIMETIDAE					
<i>Mimetes</i> sp.†			1	1	0.02
MITURGIDAE					
<i>Cheiracanthium furculatum</i> Karsch, 1879	202	240	302	744	12.83
<i>Cheiracanthium vansoni</i> Lawrence, 1936	2	7	7	16	0.28
OXYOPIDAE					
<i>Oxyopes bothai</i> Lessert, 1915?	1	1	1	3	0.05
<i>Oxyopes hoggi</i> Lessert, 1915	1		1	2	0.03
<i>Peucetia viridis</i> (Blackwall, 1858)	20	7	28	55	0.95
PHILODROMIDAE					
<i>Hirriusa arenacea</i> (Lawrence, 1927)			2	2	0.03
<i>Philodromus browningi</i> Lawrence, 1952	13	1	15	29	0.50
<i>Philodromus</i> sp. 2	48	60	88	196	3.38
<i>Suemus</i> sp. ‡	3			3	0.05
<i>Thanatus</i> sp.	1	2		3	0.05
PHOLCIDAE					
<i>Smeringopus</i> sp.		1		1	0.02
PISAURIDAE					
<i>Rothus vittatus</i> Simon, 1898	1		6	7	0.12
SALTICIDAE					
<i>Heliophanus charlesi</i> Wesolowska, 2003†	14	8	3	25	0.43
<i>Heliophanus pistaciae</i> Wesolowska, 2003†	1230	860	1028	3118	53.79
<i>Heliophanus trepidus</i> Simon, 1910	6	2		8	0.14
<i>Mogrus</i> sp.?			1	1	0.02
<i>Myrmarachne</i> sp.		5	1	6	0.10
<i>Natta horizontalis</i> Karsch, 1879	8	3	4	15	0.26
<i>Pellenes</i> sp.	2	4	5	11	0.19
<i>Phintella</i> sp.	1	1	4	6	0.10
<i>Phlegra</i> sp.	4	7	8	19	0.33
<i>Pseudicius</i> sp. 1†	3		3	6	0.10
<i>Pseudicius</i> sp. 2	5	3	5	13	0.22
<i>Pseudicius</i> sp. 3			1	1	0.02
Salticidae sp. (undetermined genus)		2		2	0.03
<i>Thyene inflata</i> (Gerstaecker, 1873)	78	53	89	220	3.80
<i>Tusitala barbata</i> Peckham & Peckham, 1902	4		2	6	0.10
SEGESTRIIDAE					
<i>Ariadna</i> sp.			1	1	0.02
TETRAGNATHIDAE					
<i>Tetragnatha</i> sp. imm.			1	1	0.02

APPENDIX 1- continued.

FAMILY/SPECIES	GVN 1	GVN 19	REM	TOTAL	% OF TOTAL
THERIDIIDAE					
<i>Enoplognatha</i> sp.	1		1	2	0.03
<i>Euryopis</i> sp.	15	77	52	144	2.48
<i>Latrodectus geometricus</i> C. L. Koch, 1841		1	3	4	0.07
<i>Theridion</i> sp. 1	73	44	35	152	2.62
<i>Theridion</i> sp. 2	2		4	6	0.10
THOMISIDAE					
<i>Diaea puncta</i> Karsch, 1884	1		2	3	0.05
<i>Heriaeus</i> sp. ‡	1		1	2	0.03
<i>Misumenops rubrodecoratus</i> Millot, 1942	4	2	7	13	0.22
<i>Monaeses austrinus</i> Simon, 1910			1	1	0.02
<i>Monaeses quadrituberculatus</i> Lawrence, 1927	2			2	0.03
<i>Oxytate</i> sp. ‡	1			1	0.02
<i>Runcinia depressa</i> Simon, 1906	1		1	2	0.03
<i>Thomisus kalaharinus</i> Lawrence, 1936	2		2	4	0.07
<i>Thomisus machadoi</i> Comellini, 1959	1			1	0.02
<i>Thomisus stenningi</i> Pocock, 1900	4	3	2	9	0.16
<i>Xysticus</i> sp.	1		5	6	0.10
ULOBORIDAE					
<i>Uloborus plumipes</i> Lucas, 1846?			3	3	0.05
Uloboridae sp.			1	1	0.02
Σ	2051	1550	2202	5803	~100.00
TOTAL SPECIES	64	47	70	87	-
SPECIES RICHNESS	0.736	0.540	0.805	-	-

CHAPTER 3



**Spiders (Araneae) in ground
covers of pistachio orchards in
South Africa**

3.1 ABSTRACT

As part of a larger study of arthropod diversity in pistachio orchards, spider (Araneae) populations were surveyed in ground covers in two orchards at the Green Valley Nuts Estate (GVN) and an orchard on the farm Remhoogte (REM) in the Prieska district, Northern Cape Province. Spiders were sampled from three different ground cover regimes in orchards to determine their diversity, relative abundance, and prey items of the numerically dominant species present. Sampling was undertaken using sweep nets (diameter 40cm), with 200 sweeps per orchard per month, in July 2001, September 2001 to April 2002, and July 2002, giving a total of 10 samples per site. In total, 1760 spiders representing 55 species were collected in the three pistachio orchards. Total spider numbers and diversity were highest in GVN 1 (n=631, 40 spp.), followed by REM (n=580, 36 spp.) and GVN 19 (n=549, 35 spp.). Two species, *Peucetia viridis* (Blackwall) and *Heliophanus pistaciae* Wesolowska, dominated the spider fauna, accounting for 29.3% and 23.4% of the total, respectively. Diversity was highest in the orchards with mixed ground cover consisting of herbs, weeds and grasses (GVN 1, 40 species), while 36 species were collected in the orchard with alternate rows of grasses and weeds (GVN 19). The third orchard (REM), dominated by herbs and grasses, contained 35 species. Plant composition and orchard age may have a significant effect on the abundance of spiders, but have a minimal influence on diversity. Predation events observed in the field for nine common spider species showed that they preyed on nine orders of insects, including minor pest thrips (Phlaeothripidae), false chinch bugs (Lygaeidae), leafhoppers (Chrysomelidae) and aphids (Aphididae). The presence of spiders in the ground covers may play a role in suppressing populations of minor pests before they reach damaging levels in pistachio canopies.

3.2 INTRODUCTION

Ground covers form an important structural component of many orchard ecosystems, influencing natural enemy populations by increasing overall habitat complexity, providing alternate food for predators and serving as trap crops for

potentially pestivorous herbivores (Cortesero *et al.* 2000). All three factors can positively influence the survival and consequent pest management effects of natural enemy populations on pest organisms on the main crop.

Ground covers have been shown to increase the biological control effects on pest populations in orchards (Bugg & Waddington 1994; Wyss *et al.* 1995; Brown *et al.* 1997a). However, they need to be carefully selected as different ground cover compositions may influence herbivore and predator populations in this vegetation, and in the tree canopies above (Bugg & Dutcher 1989; Bugg *et al.* 1991; Kaakeh & Dutcher 1993; Smith *et al.* 1994; Rieux *et al.* 1999). While cover crops and other floor vegetation can play a role in pest management, they cannot be relied upon to provide complete control of pests on the main crop (Daane & Costello 1998a).

The most promising option for utilising the particular predatory nature of spiders for the biological control of pests is to increase their density in crops as close to the pest density as possible (Sunderland & Samu 2000). Smith *et al.* (1996) suggested that a high density of spiders in the ground cover layer often indicates that they are important predators in the orchard canopy. Ground covers, like field margins, also serve an important role as overwintering sites for various natural enemies, ensuring the survival of the species until the next season when the agroecosystem can be recolonised (Dennis & Fry 1992; Dennis *et al.* 1994; Thomas & Marshall 1999).

Spiders are often the most abundant predators in various orchard ecosystems (*e.g.* Carroll 1980; Liao *et al.* 1984; Nyffeler & Benz 1987; Knight *et al.* 1997; Costello & Daane 1999), forming an essential part of the natural enemy complex. They can play an important role in the natural suppression of pest organisms, both on the main crop and in ground covers. Spiders have additional attributes to pest mortality not often encountered in other natural enemy groups, such as parasitoids, *e.g.* wasteful killing (unpalatable prey that are killed without feeding taking place), disturbance effects and the mortality of non-consumed pests in webs (see Mansour *et al.* 1981; Riechert 1999; Sunderland 1999). Additionally, the different lifestyles or guilds of spiders ensures that a particular prey species may be captured by numerous different methods (Marc & Canard 1997) and in various strata of the agroecosystem, a characteristic of ecosystem functioning known as resource-use complementarity (Wilby & Thomas 2002). All life stages of spiders are

predacious and can impact on pest populations. Many insect predators are only carnivorous in one life stage (*e.g.* larval lacewings), and with their restricted movement, are more strongly influenced by prey density, patch restriction and cannibalism (Kindlmann & Dixon 1999). Furthermore, spiders are able to balloon to more profitable feeding sites if prey density becomes too low.

This is the first published faunistic study on spiders in ground covers of orchard ecosystems in South Africa. The aim of this study was to determine the diversity and dominant species present, seasonal fluctuations of spider populations, the role of spiders as predators in this layer, and the role of ground cover selection in supporting arboreal populations. This may contribute to providing farmers with information on how best to adapt their management practices with regard to ground covers, in order to promote the abundance of spiders and other natural enemies, and to increase the impact on pest organisms in pistachio orchards. Basic faunistic surveys are essential for determining dominant species in agroecosystems for further focused study, as these species are likely to have the greatest impact on pest populations by virtue of their abundance in the agroecosystems, and may also serve as bioindicators of pesticide residue effects in the ground covers of the crop.

3.3 MATERIALS AND METHODS

3.3.1 Study area and period

The study took place in pistachio orchards on two farms in the Prieska district in the Northern Cape Province, South Africa. Sampling was done in two orchards at the Green Valley Nuts Estate (GVN, 22°56'41"S, 29°35'11"E), and an orchard at the farm Remhoogte (REM, 23°00'06"S, 29°31'55"E). The natural vegetation in the area is classified as Orange River Nama Karoo (Hoffman 1996). Orchard parameters and ground cover composition of the three sampling sites is given in Table 1. The spiders inhabiting ground covers in pistachio orchards were studied from July 2001 to July 2002, but no sampling was undertaken during the winter month of August 2001, and the autumn months of May and June 2002. This gave a total of ten samples per orchard. The ground covers were mowed in each orchard during September, December and March. Ground

cover growth is most vigorous from early spring (September) to late autumn (May), and during this period the ground covers were usually able to recover within a few weeks following mowing.

TABLE 1: Ground cover parameters in three pistachio orchards in the Prieska district, Northern Cape Province, at the start of the survey in July 2001.

PARAMETER	GVN 1	GVN 19	REM
Orchard age	8 years	5 years	9 years
Orchard size	16 ha	16 ha	1.5 ha
Ground cover characteristics	Mixed herbs, weeds and few grasses	Alternate rows of weeds and grasses	Mixed herbs and grasses, few weeds
Vegetation density	Moderately dense	Low	Dense
Dominant vegetation	Weeds	Equal distribution	Herbs

3.3.2 Sampling methods

Spiders were collected in each of the three orchards using a sweep net with a diameter of 40 cm. Two hundred sweeps, in an arc 1.0-1.5m wide, were taken in each orchard per month. Two transects each of one hundred sweeps, comprising four 25 sweep subsamples each, were walked in each orchard sampled, so that sampling would be random and reflect more accurately the composition of the orchard. All material was sorted by hand on site and preserved in 70% ethanol before proceeding with the next subsample. All spiders were subsequently sorted quantitatively and qualitatively, and identified, in the laboratory.

3.3.3 Statistical analysis

Total spider numbers in the three orchards were subjected to a Chi-square test with Yate's correction, at a significance level of 95%, in order to determine whether ground cover structure and density have an effect on total spider abundance.

The qualitative Sørensen's Quotient of similarity was used to compare the similarity of the spider faunas of the three pistachio orchards. The formula used in this index is $QS=2j/(a+b)$, where a and b are the number of species captured at the two sites, and j the number of species common to both samples (Gajdoš & Toft 2000). A higher value (closer to 1) indicates that the faunas at the two sites are more similar, while a value closer to 0 indicates a more unique fauna in the two habitats.

Spiders were separated into guilds based on their foraging strategies. Wandering spiders were divided into plant wanderers (PW) and ground wanderers (GW). Web-building spiders were separated into orb-web builders (OWB), hackle-web builders (HWB), gum-foot web builders (GWB), and sheet-web builders (SWB).

3.4 RESULTS

3.4.1 Numbers, diversity and guilds

A total of 1760 spiders representing 55 species were collected in the three pistachio orchards in the ten months sampled (Appendix 1). Total spider abundance was highest in GVN 1 ($n=631$), followed by REM ($n=580$) and GVN 19 ($n=549$). Total spider abundance (Appendix 1) was significantly higher ($P=0.0184$, $\chi^2=5.56$, $P<0.05$) in GVN 1 than in GVN 19, but numbers were not significant between GVN 1 and REM and also not significant between REM and GVN 19. This would suggest that dense ground cover growth and orchard age (time since orchard establishment) might, on occasion, have an influence on spider abundance. Two species, the lynx spider *Peucetia viridis* (Blackwall) and jumping spider *Heliophanus pistaciae* Wesolowska, dominated the spider fauna. They accounted for 29.3% and 23.4% of the total spiders collected, respectively (Appendix 1). The only other species accounting for more than 5% of the total were the crab spider *Thomisus stenningi* Pocock (6.5%) and the jumping spider *Phlegma* sp. (5.8%).

Species diversity was highest in GVN 1 (40 species), followed by GVN 19 (36 species) and REM (35 species). Sørensen's Quotient values (Table 2) were highest (0.789) for the GVN 19-REM combination. This indicated that the two orchards with the most contrasting vegetation densities and compositions had the most similar fauna. One

could deduce that ground cover composition has a minimal influence on the diversity of spiders. When similarity was compared at the guild level a similar pattern emerged (Table 2). Sørensen's Quotient values were only slightly higher for the plant-wandering guild in the GVN 1-GVN 19 combination (0.824) than for the GVN 19-REM combination (0.778). Ground wanderers and the various guilds of web-dwellers also displayed the most similar diversity between the orchards GVN 19 and REM. The reasons for this pattern are unknown, since the plant compositions of the two orchards are markedly different. Perhaps the presence of grasses in both orchards, while being scarce in GVN 1, could account for the greater similarity between GVN 19 and REM.

TABLE 2: Sørensen's Quotient values for spider populations and guilds collected in three pistachio orchards in the Prieska district, Northern Cape Province. Guild abbreviations: PW- plant wanderers; GW- ground wanderers; OWB- orb-web builders; HWB- hackle-web builders; GWB- gum-foot web builders; SWB- sheet-web builders.

	GVN 1-GVN 19	GVN 19-REM	GVN 1-REM
Total population	0.684	0.789	0.667
PW	0.824	0.778	0.632
GW	0.421	0.667	0.556
OWB	0.667	0.667	0.667
HWB	1.000	1.000	1.000
GWB	0.444	0.857	0.500
SWB	0.750	0.750	0.750

Fifteen of the sixteen species that represented more than 1% or more of the total fauna were found in all three orchards. It is possible that the presence or absence of scarce species may have a strong influence on the similarity index values. Such species may occur in an orchard, but were not necessarily collected in this survey. Consequently, longer surveys may provide a more accurate indication of the relationships between the spider faunas of different orchards.

Plant wanderers dominated the spider fauna in terms of diversity and abundance (Figure 1), comprising 76.7% of the spiders and 38.2% of the species present. Although

ground wanderers were very diverse (29.1% of all the species), they only formed a comparatively small part of the total numbers collected (8.9 %). Apart from the sheet-weavers, which comprised 7.1 % of the total (9.1% of the species), most of the remaining guilds only formed a minor part of the spider population, although they may have been considerably diverse. Such groups include hackle-web builders (3.0%, and 1.8% of the species), orb-weavers (2.7%, and 9.1% of the species), and gum-foot web-builders (1.6%, and 12.7% of the species).

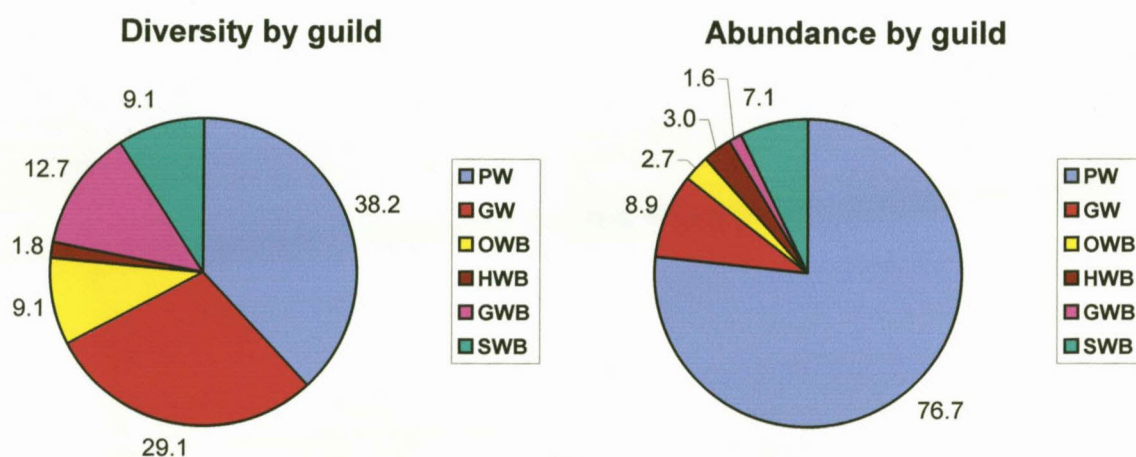


FIGURE 1: Guild composition of spider populations in ground covers of pistachio orchards in the Northern Cape, with reference to percentage diversity and abundance. Guild abbreviations are as follows: PW- plant wanderers; GW- ground wanderers; OWB- orb-web builders; HWB- hackle-web builders; GWB- gum-foot web builders; SWB- sheet-web builders.

3.4.2 Seasonal abundance patterns

The seasonal fluctuation of spider populations in the three orchards followed a variable pattern (Figure 2). Numbers were low in the winter, with a slight increase (GVN 19 and REM) and a sharp increase (GVN 1) in abundance in spring. This is a consequence of recovery of the ground cover growth, and accompanying response from

insect and spider populations. Numbers in all orchards peaked in summer (December–February), before decreasing dramatically in March (probably due to increased mechanical activity of ground cover cutting and pistachio nut harvesting). Numbers recovered somewhat in April before decreasing to a low in July.

Seasonal abundance patterns of the two dominant species (Figure 3) followed a similar pattern to that of the total spider catch, described above. This could be expected, as the two species together comprise approximately 55% of the spiders collected in the ground covers. However, there was a noticeable difference in the population structure of the two species. Almost all *P. viridis* collected were immatures, while the *H. pistaciae* population only comprised approximately 65% immatures. *Heliophanus pistaciae* also displayed more steady patterns of increase or decrease through the course of the season than *P. viridis*, which had sharper fluctuations in abundance (Figure 3).

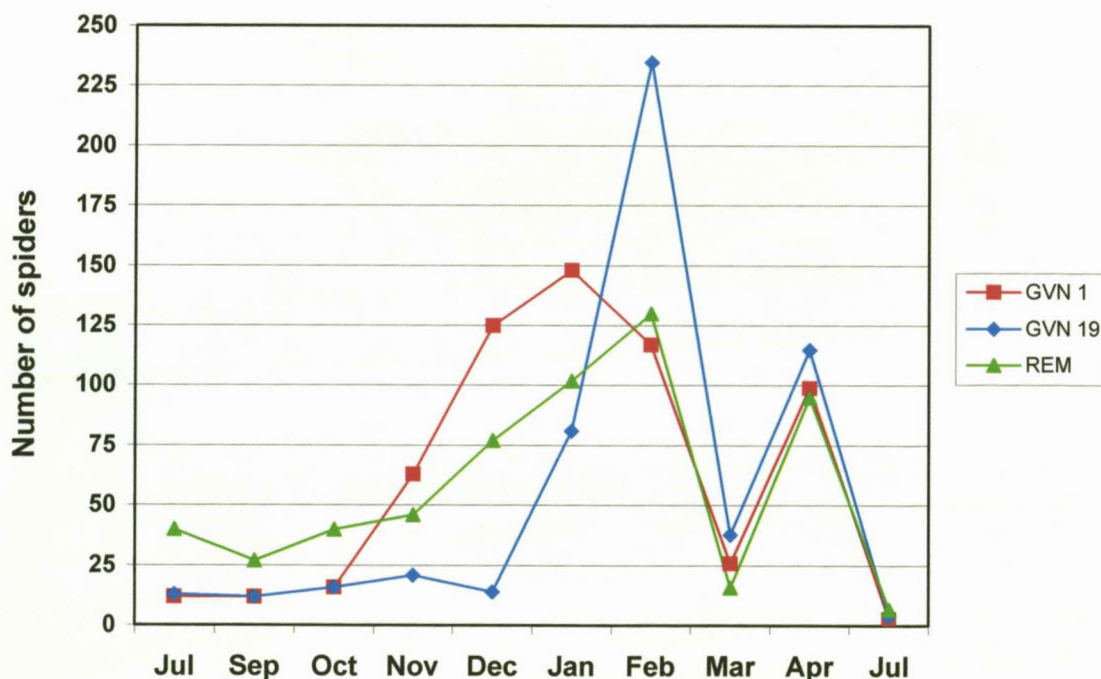


FIGURE 2: Seasonal fluctuations of spider populations in ground covers in three pistachio orchards in the Northern Cape Province over a period of one year.

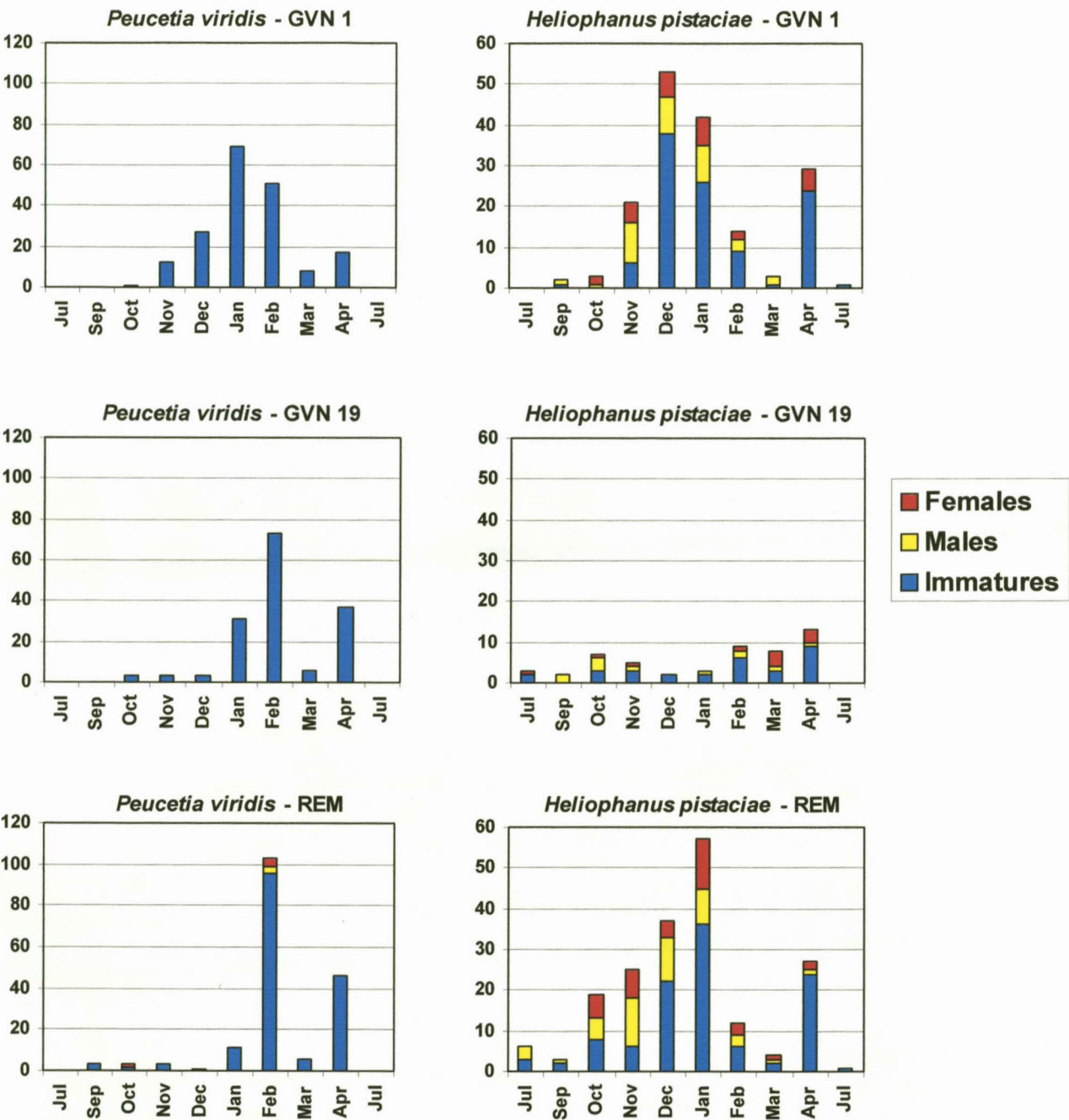


FIGURE 3: Seasonal fluctuations of *Peucetia viridis* and *Heliophanus pistaciae* in ground covers of three pistachio orchards in the Northern Cape Province over a period of a year.

5.4.3 Influence of vegetation structure

The percentage representation of the most common species varied between orchards (Figure 4), indicating some degree of preference by individual species for different vegetation structures. *Peucetia viridis* was similarly abundant in the three orchards and seemed to concentrate on any available vegetation, particularly herbs and weeds. The jumping spiders *H. pistaciae* and *Phlegra* sp. showed distinct preferences for particular plant compositions and densities. The former species prefers dense and moderately dense plantings where movement between plant foliage is easier, as in the predominantly mixed planting orchards (GVN 1 & REM). The latter is largely surface active, but occasionally wanders onto plants, and was more abundant in the orchards with at least some space between plants (GVN 1 and GVN 19), but was much less abundant in the dense vegetation at REM. Since these three species were among the most commonly found, providing ground covers of similar composition to GVN 1 may yield the greatest benefits for increasing populations of these species.

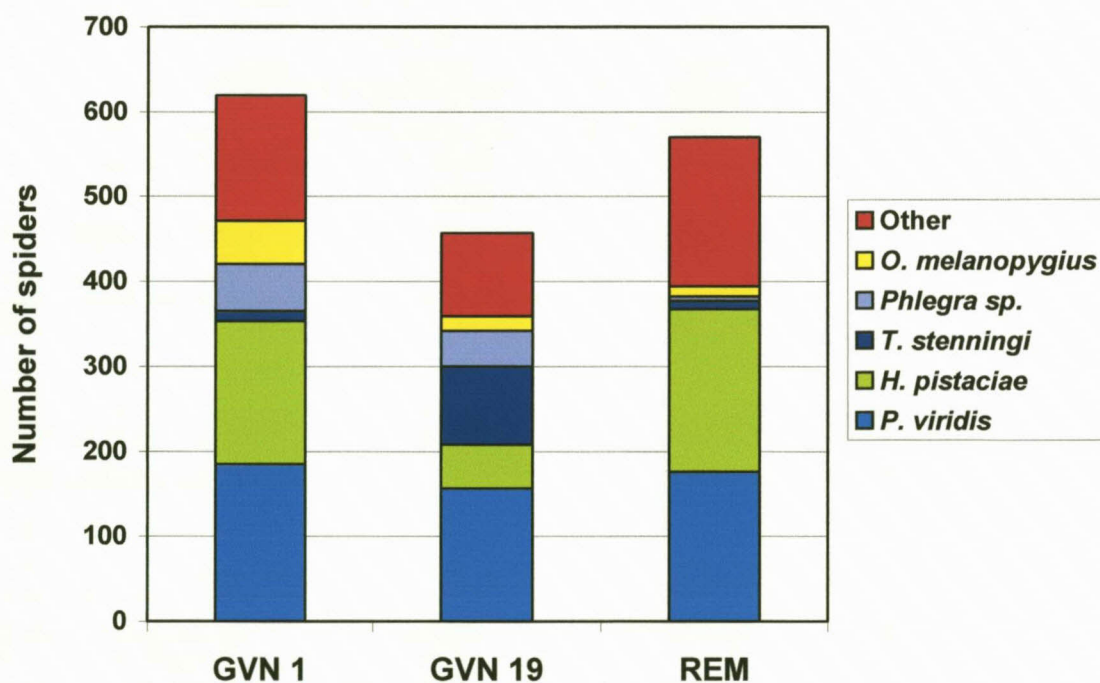


FIGURE 4: Relative abundance of five numerically dominant spider species in the ground cover layer of three pistachio orchards in the Northern Cape Province.

Thomisus stenningi and other crab spiders were most abundant in GVN 19, which could be attributed to the presence of alternate rows of grasses and weeds. This mixed vegetation complex provides a greater variety of niches to be occupied by this group. Included are typical grass-dwelling species (*Thomisus* spp., *Misumenops rubrodecoratus* Millot and *Heriaeus* sp.), as well as flower-dwelling species (primarily *Thomisus* spp.).

The dominant web-building spider in the ground covers, *Ostearius melanopygius* (O. P.-Cambridge), while not strongly dominant (4.6% of the total), was notably highest in GVN 1. This may be due to one or both of two factors: the vegetation structure, comprising a strong presence of herbs and short weeds, which may assist in providing suitable web sites close to the ground at the base of vegetation, or possibly due to the strong colonisation ability of this species from wheat and maize fields adjacent to this orchard.

3.4.4 Predation events

Although spiders were found preying on nine orders of insect prey, namely Collembola, Orthoptera, Thysanoptera, Hemiptera, Homoptera, Coleoptera, Diptera, Lepidoptera and Hymenoptera, only data on the seven taxa most frequently observed in the chelicerae of spiders are presented here (Table 3).

Spiders were found to prey on a variety of minor pests, as well as on certain taxa of beneficials. At least six spider species were each observed preying on minor pest thrips (Thysanoptera: Phlaeothripidae), leafhoppers (Homoptera: Cicadellidae), aphids (Homoptera: Aphididae) and fleahoppers (Hemiptera: Lygaeidae: *Nysius natalensis* Evans). Additionally, spiders were also observed preying on leaf beetles and flies on odd occasions. The most frequently attacked natural enemies were parasitoids (Hymenoptera: Chalcidoidea). On two occasions, spiders (*H. pistaciae* and *Philodromus* sp.) were also seen feeding on the small ladybird species *Scymnus levaillanti* Mulsant (Coleoptera: Coccinellidae). Since most predation events observed were on pest species, the impact of spiders on other natural enemies may be minimal.

TABLE 3: Most frequently encountered field observations of predation events involving spiders inhabiting ground covers in pistachio orchards in the Northern Cape Province.

SPIDER SPECIES	INSECT PREY						
	Thysanoptera: Phlaeothripidae	Hemiptera: Lygaeidae	Homoptera: Aphididae	Homoptera: Cicadellidae	Coleoptera: Chrysomelidae	Diptera: Ephydroidea	Hymenoptera: Chalcidoidea
<i>Archaeodictyna</i> sp.	X		X	X			
<i>Cheiracanthium furculatum</i>	X	X	X	X	X	X	
<i>Heliophanus pistaciae</i>	X	X	X	X		X	X
<i>Neoscona subfusca</i>	X		X	X			X
<i>Peucetia viridis</i>	X	X	X				
<i>Pardosa crassipalpis</i>		X	X		X		
<i>Philodromus</i> spp.	X	X	X	X			X
<i>Phlegra</i> sp.	X	X	X	X	X	X	X
<i>Thomisus</i> spp.	X	X	X	X			X

3.5 DISCUSSION

3.5.1 Influence of ground cover structure

Particular species were found to be most abundant in orchards with weedy and herb vegetation types, while other groups preferred predominantly grassy vegetation. The density of the vegetation growth also appeared to influence the relative abundance of certain species. Manipulation of the ground covers should be an important consideration to increase numbers and diversity of spiders and other natural enemies in orchards.

The nature of the ground covers and the plant density affects spider phenology differently. A more complex habitat provides a greater diversity of structures for web-building spiders to construct webs (Wyss *et al.* 1995). This is reflected in the greater abundance and diversity of spiders in GVN 1, an orchard dominated by weedy and herbal growth, which creates the most complex habitat structure. This, in turn, may be related to more luscious vegetation, which supports a greater diversity of herbivorous and saprophagous insects. Flowering plants attract large numbers of insects that provide a variety of prey for spiders, increasing their rates of survival (Costello & Daane 1998b).

3.5.2 Faunal relationships between strata

There is conflicting evidence as to the relationship between the faunas of ground covers and tree canopies. Spider species composition may differ considerably between the ground covers and the canopy in orchards (Samu *et al.* 1997; Costello & Daane 1998b), or there may be a large degree of overlap (Bogya *et al.* 1999, 2000; Pekár 1999; Rieux *et al.* 1999; Miliczky *et al.* 2000). The present study found that 87.3% of the species occurring in the ground covers also occurred in the tree crowns, and that *H. pistaciae* was very common in both strata. The former authors also suggested that the presence or absence of ground covers does not significantly increase the abundance or species richness of spiders arboreally. Considering the degree of species overlap found in this study, it appears that the opposite is true for pistachio (and possibly also other orchard crops) in South Africa, and that ground covers may play an important role in supplementing the arboreal spider fauna, assisting in the recovery of arboreal populations after chemical applications have reduced numbers (Rieux *et al.* 1999; Bogya *et al.* 2000).

Heliophanus pistaciae populations in ground covers reach a peak in December-January, and arboreal populations increase greatly in December, reaching a peak in March and April. This could suggest a large-scale vertical migration of this species to the tree crowns at the start of summer. Since *H. pistaciae* is strongly dominant in the pistachio tree canopies, where pest control efforts need to be concentrated, providing ground covers that enhance the abundance of this species at this level will increase arboreal populations. It will also enable these spiders to recolonise the canopies at a faster rate following disturbance events, such as chemical applications and harvesting, which will optimise their effect on arboreal pest populations.

Five scenarios can be deduced regarding the distinction between the ground cover and arboreal spider faunas of pistachio orchards. 1) Distinct dominance in the ground covers, while being scarce in the tree layer, as in the case of *P. viridis*; 2) Scarcity in the ground covers but common in the treetops, e.g. *Cheiracanthium furculatum* Karsch; 3) A distinct overlap between the populations arboreally and in the ground cover layer, as for *Heliophanus pistaciae*, which is one of the dominant species in both layers; 4) Scarcity in both the ground cover or tree layer, e.g. *Rothus vittatus* Simon; 5) Species scarce in either the ground cover or tree layer, and absent in the other layer, e.g. *Argiope australis* (Walckenaer) and *Pelecopsis janus* Jocqué, respectively.

3.5.3 Predatory effects

All of the minor pests included in Table 3 were encountered in most pistachio trees sampled, and have the potential to reproduce rapidly, creating an opportunity for severe damage to be effected on pistachio trees. These minor pests could develop to key pest status if insufficient measures are taken for their control. It is therefore essential to create an environment where spiders and other natural enemies can thrive in all strata of orchards, from the ground to the tree canopy, thereby maximising their effects on pests.

The thrips, aphids and leafhoppers can cause extensive leaf damage (abrasion and folding) (personal observation), reducing the photosynthetic capability of the plants, and consequently, nutrient conversion and growth. *Nysius natalensis* is a vector of fungal diseases to pistachio nuts (Swart 2002), which may result in significant loss in yields. While it is not especially abundant in the tree canopies, it is very common in ground

covers of most orchards, particularly when weedy plants such as *Conyza bonariensis* (L.) (Asteraceae) are present. As part of a greater natural enemy complex in the ground cover layer, spiders may play an important role in the suppression of these pests in this stratum.

Benefits that spider communities have as a predatory complex are the diverse lifestyles of individual species, utilisation of a greater number of niches (resulting in a greater pest control effect in various strata), and an ability to consume all life stages of a pest (Nyffeler *et al.* 1994; Marc & Canard 1997; Sunderland 1999). Structurally complex ground cover regimes, which have a variety of strata, will provide refuge for different species of predators, thereby minimising the role of intraguild predation (predation of one predator species on another) and maximising the predation impact on commonly utilised herbivorous prey species (Finke & Denno 2002).

This would imply that pest control effects at the ground cover level would be maximised in orchards with a complex structure, *i.e.* a mixture of herbs, weeds and grasses, such as GVN 1 and REM. This is reflected in the significantly greater abundance of spiders here, compared to GVN 19. Weedy strips sown in apple orchards were found to increase the arboreal density of web-building spiders, resulting in a significant reduction of aphid numbers through capture of alates (Wyss *et al.* 1995).

However, this may cause a secondary problem. A greater diversity of plant species at the ground cover level could support a greater diversity of herbivorous insects, increasing the risk of non-pest herbivores reaching pest status on the main crop at a later stage. This situation would need to be more closely scrutinised in a study comparing minor pest populations in the pistachio tree canopy in orchards with different ground cover structures.

3.5.4 Orchard management

Numerous methods of habitat manipulation can be used to increase the abundance of natural enemies in agroecosystems (Symondson *et al.* 2002). Halaj *et al.* (2000) used straw mulches in arable land to greatly increase the production of egg sacs and total spider numbers. Implementing such a strategy in more than 1000 hectares of pistachio orchards would be too expensive and impractical. However, cutting of the ground covers may provide ample debris to serve as refugia and safehavens for egg sac production on

the ground level, but whether this would impact positively on the arboreal spider populations is yet to be determined.

Cutting of the covers is likely to affect populations of various groups differently. Howell & Pienkowski (1971), working on the effect of cutting in alfalfa, found that numbers of orb-web builders (Tetragnathidae) and nocturnal species of wolf spider (Lycosidae) showed no difference following cutting. Populations of diurnal wandering spiders (Salticidae, Thomisidae) decreased, and sheet-weavers (Linyphiidae) increased following cutting. However, in the present study the entire spider population showed a dramatic decrease following ground cover mowing in March, but spiders managed to recover in the following month. Horton (1999) found that spider and parasitoid populations were increased arboreally in pear trees by decreasing mowing frequency, but this also resulted in an increase in arboreal spider mite populations. It is consequently necessary to give careful attention to the mowing frequency and timing of cutting to restrict negative effects on spiders and avoid pest proliferation.

It is also important to consider the importance of an effective management strategy (presently in place at GVN) for the ground covers, by keeping a clean space beneath trees, which is free of any ground cover vegetation. Encroachment of understory vegetation may reduce yield and growth vigour of the trees (Brown *et al.* 1997b; Costello & Daane 1997).

3.5.5 Concluding comments

The present study showed spiders to be a diverse and abundant arthropod group in the ground cover layer of pistachio orchards. Dominant species showed differing responses to vegetation type, although a preference for weedy and herbal vegetation seems apparent. However, since spider abundance and dominance in ground covers may vary from year to year (Pekár 1999), a lengthier survey may have shown variation in these respects.

Spiders may already play a role in controlling pests in the ground covers before these pests move to the tree canopy and cause damage. Therefore, spider populations should be enhanced by proper management practices at all levels of the orchard ecosystem to maximise their natural pest control effects.

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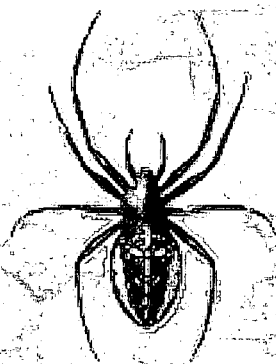
APPENDIX 1: Species diversity and abundance of spiders collected from ground covers in three pistachio orchards from July 2001-July 2002 († indicates a new species, ‡ indicates a possible new species, and ? indicates a dubious identification).

FAMILY/SPECIES	GUILD	GVN 1	GVN 19	REM	TOTAL	% OF TOTAL
ARANEIDAE						
<i>Argiope australis</i> (Walckenaer, 1805)	OWB		1		1	0.06
<i>Neoscona blondeli</i> (Simon, 1885)	OWB	10	6	10	26	1.47
<i>Neoscona subfusca</i> (C. L. Koch, 1837)	OWB	6	8	4	18	1.02
<i>Prasonica</i> sp.	OWB			2	2	0.11
CORINNIDAE						
<i>Austrachelas</i> sp.	GW	1			1	0.06
<i>Castianeira fulvipes</i> Simon, 1896	GW	2			2	0.11
<i>Castianeira</i> sp. 2	GW		3		3	0.17
<i>Trachelas pusillus</i> Lessert, 1923	PW	1		1	2	0.11
DICTYNIDAE						
<i>Archaeodictyna</i> sp.	HWB	12	19	21	52	2.95
GNAPHOSIDAE						
<i>Aneplasa nigra</i> Tucker, 1923	GW	3	2	1	6	0.34
<i>Camillina cordifera</i> (Tullgren, 1910)	GW		4		4	0.23
<i>Echemus</i> sp.	GW	1			1	0.06
<i>Micaria</i> sp.	GW	2			2	0.11
<i>Pterotricha auris</i> (Tucker, 1923)	GW	2			2	0.11
<i>Setaphis subtilis</i> (Simon, 1897)	GW		1		1	0.06
LINYPHIIDAE						
<i>Eperigone fradeorum</i> (Berland, 1932)	SWB	2	7		9	0.51
<i>Meioneta habra</i> Locket, 1968	SWB	1	1	1	3	0.17
<i>Meioneta</i> sp.†	SWB		1	4	5	0.28
<i>Microlinyphia sterilis</i> (Pavesi, 1883)	SWB	5		23	28	1.59
<i>Ostearius melanopygius</i> (O. P.-Cambridge, 1879)	SWB	51	17	12	80	4.55
LYCOSIDAE						
<i>Pardosa crassipalpis</i> Purcell, 1903	GW	2	6	12	20	1.14
Lycosinae sp.	GW			5	5	0.28
MITURGIDAE						
<i>Cheiracanthium furculatum</i> Karsch, 1879	PW	6	2	12	20	1.14
OXYOPIDAE						
<i>Peucetia viridis</i> (Blackwall, 1858)	PW	185	156	176	517	29.34
<i>Oxyopes bothai</i> Lessert, 1915?	PW	8	18	1	27	1.53
<i>Oxyopes hoggi</i> Lessert, 1915	PW	1	1		2	0.11
PHILODROMIDAE						
<i>Hirriusa arenacea</i> (Lawrence, 1927)	GW	1			1	0.06
<i>Philodromus</i> sp.	PW	3	17	1	21	1.19
<i>Suemus</i> sp. ‡	GW	6	19	32	57	3.24
<i>Thanatus</i> sp.	GW		1	6	7	0.40

APPENDIX 1- continued.

FAMILY/SPECIES	GUILD	GVN 1	GVN 19	REM	TOTAL	% OF TOTAL
PISAURIDAE						
<i>Rothus vittatus</i> Simon, 1898	PW			17	17	0.97
SALTICIDAE						
<i>Heliophanus charlesi</i> Wesolowska, 2003†	PW	7	6	2	15	0.85
<i>Heliophanus pistaciae</i> Wesolowska, 2003†	PW	168	52	191	411	23.35
<i>Natta horizontalis</i> Karsch, 1879	GW		1	1	2	0.11
<i>Pellenes</i> sp.	GW	1	1	1	3	0.17
<i>Phlegra</i> sp.	GW	55	42	5	102	5.80
<i>Pseudicius</i> sp.	PW			1	1	0.06
<i>Thyene aperta</i> (Peckham & Peckham, 1903)	PW			1	1	0.06
<i>Thyene inflata</i> (Gerstaecker, 1873)	PW	4	2	1	7	1.40
THERIDIIDAE						
<i>Enoplognatha</i> sp.	GWB	1			1	0.06
<i>Euryopis</i> sp.	GWB	1	2	1	4	0.23
<i>Latrodectus geometricus</i> C. L. Koch, 1841	GWB		5	1	6	0.34
<i>Latrodectus indistinctus</i> O. P.-Cambridge, 1904	GWB	5			5	0.28
<i>Theridion</i> sp. 1	GWB	2	1	5	8	0.46
<i>Theridion</i> sp. 2	GWB		3		3	0.17
<i>Tidarren</i> sp.	GWB	1			1	0.06
THOMISIDAE						
<i>Diaea puncta</i> Karsch, 1884	PW		1	1	2	0.11
<i>Heriaeus</i> sp.‡	PW	9	23	2	34	1.93
<i>Misumenops rubrodecoratus</i> Millot, 1941	PW	47	12	15	74	4.21
<i>Monaeses austrinus</i> Simon, 1910	PW	3	8		11	0.63
<i>Runcinia depressa</i> Simon, 1906	PW	1			1	0.06
<i>Thomisus machadoi</i> Comellini, 1959	PW	1	8	1	10	0.57
<i>Thomisus stenningi</i> Pocock, 1900	PW	12	92	10	114	6.48
<i>Xysticus</i> sp.	GW	1			1	0.06
ULOBORIDAE						
<i>Uloborus plumipes</i> Lucas, 1846?	OWB	1			1	0.06
Σ		631	549	580	1760	~100.00
TOTAL SPECIES		40	36	35	55	-
SPECIES RICHNESS		0.727	0.655	0.636	-	-

CHAPTER 4



**Surface-active spiders (Araneae)
in pistachio orchards and
surrounding grassland in South
Africa: diversity and patterns of
distribution**

4.1 ABSTRACT

Epigeic spider (Araneae) populations were studied in two pistachio orchards at Green Valley Nuts (GVN) and one orchard at Remhoogte (REM) and a stand of natural, undisturbed grassland (veld) at GVN in the Prieska district of the Northern Cape Province, South Africa. The study was conducted from August 2001 to July 2002 using ten pitfall traps per site (all sites) and 15 minutes of active searching (orchards only). A total of 2804 spiders were collected by pitfall trapping, representing 25 families and 80 species. The veld comprised the greatest abundance and diversity of spiders ($n=1112$, 56 spp.), followed by REM ($n=704$, 35 spp.), GVN 1 ($n=560$, 26 spp.) and GVN 19 ($n=428$, 25 spp.). During active searching 645 spiders were collected, representing 16 families and 63 species. Numbers and diversity were highest in GVN 1 ($n=262$, 46 spp.), followed by REM ($n=219$, 32 spp.) and GVN 19 ($n=164$, 31 spp.). Four families dominated the epigeic fauna collected by both sampling methods (Gnaphosidae, Linyphiidae, Lycosidae and Salticidae), but their abundance varied considerably between techniques. The dominant species also varied between the orchards (*Ostearius melanopygius* (O. P.-Cambridge)) and veld (*Asemesthes lineatus* Purcell). Populations at all sites peaked early in spring (October), as determined in pitfalls. Strong evidence is provided that orchard establishment and associated disturbances have a negative effect on individual epigeic spider species, as well as the abundance and diversity of spider communities. Recovery of diversity to pre-establishment levels may take decades. Factors influencing this, as well as the downfalls of trapping methods used in this study, are discussed.

4.2 INTRODUCTION

The knowledge of the epigeic spider fauna in southern African agroecosystems is sparse, with surveys only conducted in strawberries and cotton (Dippenaar-Schoeman 1976, 1979; Dippenaar-Schoeman *et al.* 1999). Little is known about their effect on the ground fauna, including pests, except for a study in strawberry fields, where the effect of the spider population on red spider mites was evaluated (Dippenaar-Schoeman 1976). Their role as predators on the ground surface elsewhere in the world is well documented,

particularly due to their high abundance. Numerous studies have implicated spiders as essential components of the predatory guild in field crops. Examples include wheat (Honěk 1988; Harwood *et al.* 2001), soya beans (Pfannenstiel & Yeargan 2002), cotton (Van den Berg A. M. & Dippenaar-Schoeman 1991; Dean *et al.* 1982; Breene *et al.* 1993), rice (Oraze & Grigarick 1989; Visarto *et al.* 2001) and maize (Honěk & Martinková 1991; Lang *et al.* 1999). Very little is known of the role that epigeic spiders play in the control of arboreal pests in orchards, even though it has been shown that indirect disturbance effects of spiders on Lepidoptera larvae in apple trees results in them falling from trees (Mansour *et al.* 1981). Spiders on the soil surface and in ground covers can then feed on them.

The disturbance effects of agricultural practices in annual cropping systems have been well studied. Factors influencing spider abundance and diversity in such temporary systems include several management practices such as ploughing, harvesting, chemical applications and management intensity, among others (Nyffeler *et al.* 1994; Stark *et al.* 1995; Perfecto *et al.* 1997; Thomas & Jepson 1997; Topping & Lövei 1997; Downie *et al.* 1999; Samu *et al.* 1999). In apple orchards, the abundance of epigeic spiders may be considerably influenced by management practices (Miliczky *et al.* 2000), or shows little difference between treatments (Bogya & Markó 1999). More specifically, herbicide applications may affect the seasonal fluctuations of epigeic spiders, while density of ground covers may affect spider abundance (Pekár 1999).

This study had three main aims. Firstly, to determine and compare the diversity of epigeic spiders in pistachio orchards and an undisturbed grassland ecosystem. Secondly, to establish whether orchard establishment and associated disturbance effects have an influence on the abundance and diversity of spiders in orchards when compared to undisturbed grassland, which, in this context, represents a virgin, pristine habitat. Lastly, to provide baseline information necessary to conduct further studies on the predation potential of selected spider species at the ground level on potentially pestivorous arthropods of pistachio nuts.

4.3 MATERIALS & METHODS

4.3.1 Study area and period

The study was carried out at the Green Valley Nuts estate (GVN, 22°56'41"S, 29°35'11"E) and at the farm Remhoogte (REM, 23°00'06"S, 29°31'55"E), both situated in the Prieska district in the Northern Cape Province, South Africa. Ground-living spiders were collected using pitfall traps, which were set out in three orchards: GVN 1, GVN 19 and at REM. The ground cover composition in the three orchards can be summarised as follows: GVN 1 contained a mixture of herbs and weeds, with few grasses; GVN 19 contained alternate rows of weeds and grasses, and REM had mixed herbs and grasses, with few weeds. In addition, traps were set out in a stand of natural grassland (hereafter referred to as "veld"), located 400m from the nearest developed pistachio orchard. The vegetation at this site is classified as Orange River Nama Karoo (Hoffman 1996).

The climate in the Prieska district is semi-arid, with very hot summers (occasionally exceeding 40°C), very cold winters (night temperatures often falling below -5°C) and low annual rainfall, averaging between 200 and 300mm. Epigeic spiders were collected from August 2001 to July 2002 at each of the four localities. Traps were checked monthly with the exception of the winter months (June-September), during which they were emptied every second month.

4.3.2 Sampling methods

The sampling method employed was identical for each of the four sites: ten pitfalls (diameter of 8cm) were set out flush with the soil surface (Figure 1) in a 5x2 grid, with 5 m separating each trap. Using pitfalls with a moderate diameter could give the best reflection of spider faunas, as smaller traps are usually most effective to characterize the dominant epigeic taxa, while large traps help to detect rare species (Work *et al.* 2002).



FIGURE 1: A pitfall trap set out in the ground covers of a pistachio orchard.

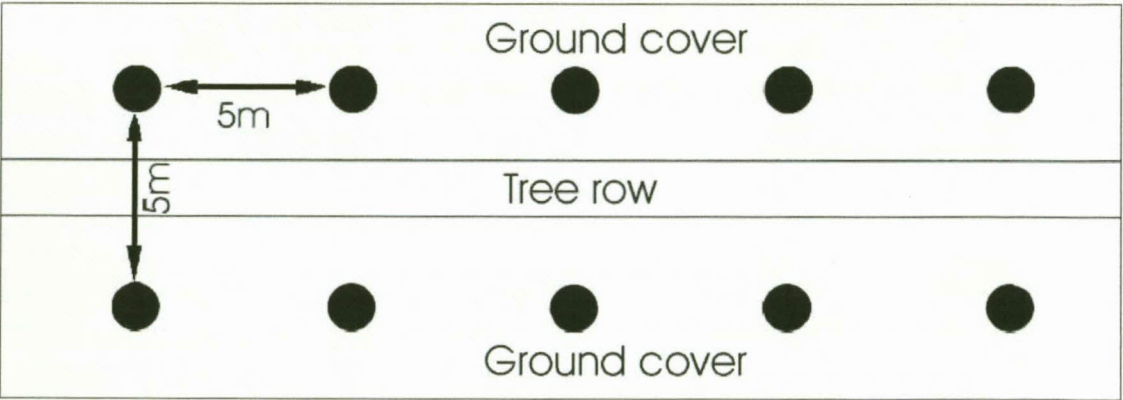


FIGURE 2: Pitfall trapping setup used to sample epigeic spiders in pistachio orchards in the Prieska district, Northern Cape Province.

In the pistachio orchards traps were set out between the rows of pistachio trees in the ground cover strips (Figure 2), and in the veld at a random site with uniform vegetation composition. Ethanediol was used as a preservative in the traps. Material was collected from the traps with a sieve, placed in separate bottles for each trap, and preserved in 70% ethanol.

The number of trap-days per site was very similar, which made the data more strongly comparative: GVN (3700 trap-days), GVN 19 (3710 trap-days), REM (3690 trap-days), and veld (3700 trap-days). The use of pitfall traps has its limitations in providing absolute estimates of abundance, as the capture efficiency varies considerably between species (Holland *et al.* 1999), and some taxa may be overestimated, while others may be underestimated (Lang 2000).

In light of the discretions of pitfall trapping mentioned above, additional collecting was done in the three pistachio orchards (but not in the veld) by actively searching at the base of ground cover vegetation in random sites for precisely 15 minutes and collecting all spiders observed. All spiders seen on the soil surface were captured by hand in a glass vial and immediately transferred to a bottle with 70% ethanol, irrespective of the life stage of the captured individual. In the event of two spiders being encountered within a short space of time, then the first spider that was observed would be pursued and captured first, to reduce bias for certain taxa. The collected spiders were pooled together as a monthly sample for an orchard. Collecting was done each month that the pitfall traps were serviced. For analysis of seasonal fluctuations of spider populations, the seasons are defined as follows: spring extends from September to November, summer is from December to the end of February, autumn from March to May, and winter from June to the end of August.

4.3.3 Statistical analysis

An analysis was done using a Chi-square test with Yate's correction at $P < 0.001$ to compare total spider abundance and species, using paired combinations of the three orchards and the veld, in order to determine sites with significantly higher spider numbers and diversity. This could indicate a relationship between habitat age and spider abundance and diversity. These determinations would then indicate whether spider

populations recover in a short or long period following the disturbance effects of orchard establishment.

Species richness was used to compare the species composition in each pistachio orchard relative to the natural veld stand. Richness was calculated as the number of species collected at a site divided by the total number of species collected by that method. This analysis was done for both sampling methods used.

The qualitative Sørensen's Quotient of similarity, $QS=2j/(a+b)$, where a and b are the number of species in the two habitats, and j is the number of species common to both samples, was used to determine the similarity of the spider faunas in the three pistachio orchards and veld (Gajdoš & Toft 2000). A high value (closer to 1) indicates a more similar fauna in habitat a compared to habitat b , while a lower value (closer to 0) indicates a more unique fauna. This analysis was only conducted on the pitfall trapping data, as no searching was conducted in the veld.

A linear regression analysis was performed on the diversity in the orchards, with orchard age as the second parameter used for the calculation. Using the equation derived from the analysis, it would be possible to project the time necessary for spider diversity to recover and reach levels comparable to undisturbed veld in the area. The intercept was not forced through the point (0;0), as it is unlikely that all spiders will die during the process of orchard establishment, and there should always be a residual diversity present. Additionally, spiders disperse by ballooning, and consequently, certain spider species will colonise newly established orchards within the first weeks following establishment, and add to the diversity of the habitat.

4.4 RESULTS

4.4.1 *Diversity and abundance*

The three predatory taxa most commonly collected in the pitfall traps were ants, spiders and carabid beetles, respectively. In total, 2804 spiders representing 25 families and 80 species were collected at the four sites over the twelve-month period from pitfall traps. Abundance and diversity by pitfall trapping was highest in the veld, with 1112 spiders representing 56 species collected (Appendix 1). The second most abundant and

diverse site was the orchard REM (n=704, 35 species), followed by GVN 1 (n=560, 26 species) and GVN 19 (n=428, 25 species). The most abundant families collected (pooled data of all four sites) were the Gnaphosidae (33.8%), Linyphiidae (20.9%), Lycosidae (13.6%) and Salticidae (13.3%).

Population composition of pitfall-collected specimens pooled over the entire study period can be summarised as follows (% of immatures, males and females): GVN 1 (27.1%, 48.0%, 24.8%), GVN 19 (24.8%, 47.7%, 27.6%), REM (33.1%, 30.8%, 35.2%), and veld (36.2%, 48.8%, 14.4%). The proportion of males was remarkably similar between the two orchards at GVN and the veld, where they comprised nearly half of the spiders. REM had a similar proportional composition of immatures, males and females.

The dominant spider species differed between the orchards and the veld. The cosmopolitan sheet-weaver *Ostearius melanopygius* (O. P.-Cambridge) was dominant in all three orchards, comprising 28.6% in GVN 1, 25.2% in GVN 19 and 34.1% at REM. However, this species was much less common in the veld, where it only comprised 4.4% of the fauna. It would therefore seem that certain species display a high affinity and adaptability to disturbed agricultural habitats. The exact opposite could be demonstrated by the dominant veld species, the ground spider *Asemesthes lineatus* Purcell, which comprised 29.1% (n=321) of the fauna here, but was nearly absent in the orchards (Appendix 1). This species is probably severely affected by the various disturbances occurring in the orchards, or may not be able to survive in disturbed areas.

In total, 645 spiders (63 species) were collected by active searching (Appendix 2). The highest number and diversity collected was in GVN 1 (n=262, 46 species), followed by REM (n=219, 32 species) and GVN 19 (n=164, 31 species). Since active searching is considerably more subjective than pitfall trapping, one cannot read too much into the diversity of spiders sampled in this manner in the three orchards. In terms of dominance, the same four families that were most common in the pitfalls were also most prevalent in the searching, although the relative abundance varied from that of the pitfall traps. Most commonly found were the Linyphiidae (28.4%), Lycosidae (18.3%), Gnaphosidae (15.9%) and Salticidae (15.4%). The reasons for this variation are possibly the different levels of mobility of certain taxa, which makes them more or less susceptible to pitfall trapping, and the absence of searching in the grassland, where Gnaphosidae were more

strongly dominant than in orchards, accounting for their higher representation in pitfalls there.

The variable vegetation growth and density in the three orchards, which created niches differing in their suitability as refugia for the ground-dwelling spider fauna, may also have contributed to the different results obtained by the two methods. In comparisons of the diversity collected by the two methods (105 species in total), 36.2% of the species were collected using both methods, 40.0% exclusively by pitfall trapping and 23.8% by searching only.

4.4.2 Seasonal fluctuations

Seasonal abundance of the spider populations at the four sites followed relatively similar patterns (Figure 3). Adults formed the bulk of the populations at all sites during most months of the year. At all sites there was an early season build-up, with a peak in spring (October), which was due to a high proportion of active adults, particularly males seeking mates. There was a decrease at the end of spring (November), possibly as a result of decreased adult activity and increased ant activity, particularly in the orchards. Secondary, smaller peaks occurred in summer (December to February). The veld spider population had a small, tertiary peak in February, while the populations of GVN 1 and REM had tertiary peaks late in autumn (May). Generally, populations remained low in winter, due to extremely cold temperatures, which reduced spider activity.

Active searching data were not used for determining seasonal fluctuations, as they would provide inaccurate results. This is firstly because site selection was random and certain sites may have higher abundance than others, due to the patchy distribution of spider populations in the different orchards. Secondly, the variable influence vegetation composition has on collecting success, due to the variable suitability of certain plant patches as refugia and foraging sites for different spider species, may also unintentionally have selected for certain taxa over others.

Numerically dominant species in the orchards and veld showed variable seasonal abundance patterns (Figure 4). The abundance of *O. melanopygius* was much greater in the orchards and indicated a clear seasonal pattern. This species was common during the winter and early spring months, but numbers remained low in summer. In the veld,

numbers were consistently low throughout the year, without a clearly distinguishable seasonal pattern. *Aneplasa nigra* Tucker peaked in October in both habitats, comprising a large proportion of adults (more than 50% in the orchards, approximately 50% in the veld). During the rest of the season, numbers in the orchards remained low. No individuals were captured in the veld during the other months, despite more than 60 individuals being captured during October.

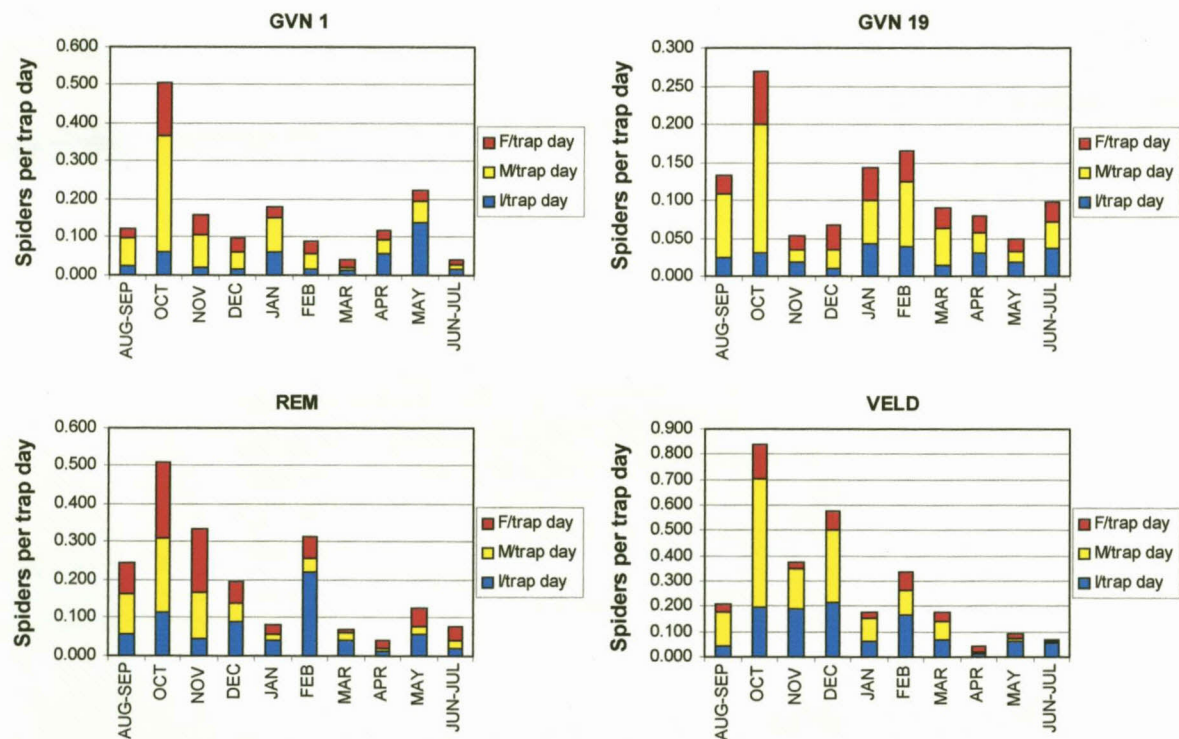
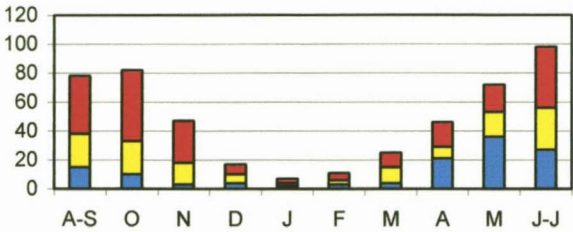
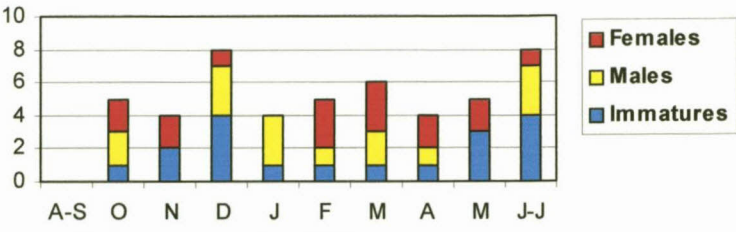


FIGURE 3: Seasonal fluctuations of epigeic spider populations in three pistachio orchards and a stand of veld in the Prieska district, Northern Cape Province. Abbreviations are as follows: I- immatures, M- males, F- females.

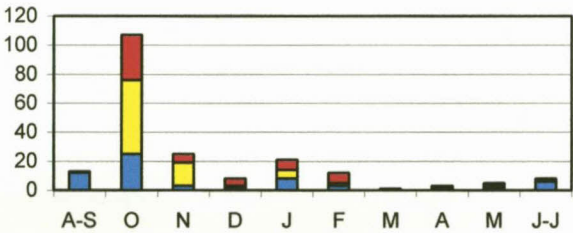
Ostearius melanopygius (O)



Ostearius melanopygius (V)



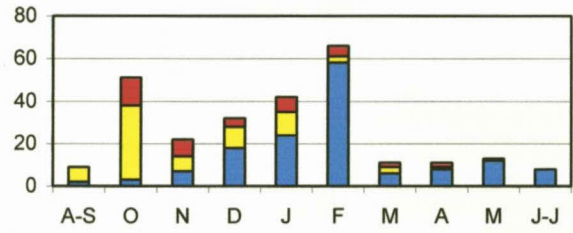
Aneplasa nigra (O)



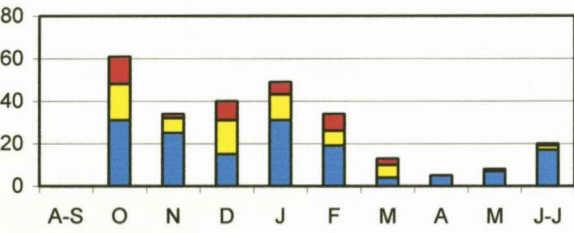
Aneplasa nigra (V)



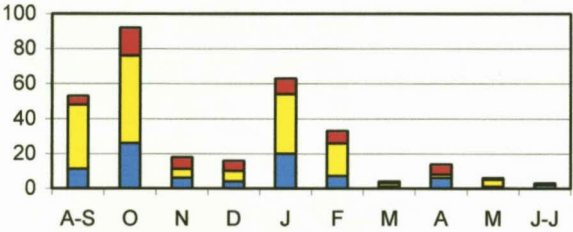
Pardosa crassipalpis (O)



Asemesthes lineatus (V)



Phlegra sp. (O)



Hirriusa arenacea (O)

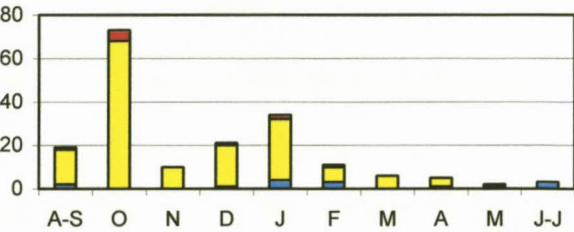


FIGURE 4: Seasonal fluctuations of numerically dominant spider species collected by pitfall trapping in pistachio orchards (O) and veld (V) in the Prieska district, Northern Cape Province.

In orchards, numbers of *Pardosa crassipalpis* Purcell reached a primary peak in October, decreased sharply in November, followed by a steady increase to a larger, secondary peak in February. Thereafter, numbers remained low through winter. In spring, most spiders collected were adults, but following that, immatures formed the bulk of the population, due to hatching of eggs produced by spring-active adults. Numbers of *Phlegra* sp. in the orchards showed two peaks, in October and January, but numbers were comparatively low through the rest of the season. Adults consistently formed the bulk of the populations.

The numerically dominant veld species, *A. lineatus*, reached its greatest abundance in October, but numbers remained high at more than 30 per month up until February (Figure 4). During this period a secondary peak was reached in January. Immatures consistently comprised 40% or more of the population. Numbers decreased in March and remained low through winter. Most of the *Hirriusa arenacea* (Lawrence) collected were males (Figure 4). This species also had a prominent peak in October, followed by a dramatic drop in numbers in November and an increase to a small, secondary peak in January, after which numbers decreased to a low during the winter months.

4.4.3 Statistical analysis

There appears to be a distinct hierarchy related to total spider abundance at the four sites. The veld had significantly higher spider numbers than all three of the orchards, REM had significantly higher numbers than the two orchards at GVN, and GVN 1 had significantly higher numbers than GVN 19 (all χ^2 , $P < 0.001$). This would indicate a distinct relationship between orchard age and total spider abundance. The veld represents the optimal age of a habitat in this region, with each orchard having greater spider abundance with increased age. The significantly higher numbers of spiders in the veld also supports the suggestion that the disturbance effects associated with orchard establishment, management and activity, have a significant negative influence on the survival of certain species of spiders.

Species richness collected by pitfall trapping was considerably greater in the veld (0.700) than in any of the orchards. This could be attributed to the high number of unique

species collected in the veld (Table 1). Among the orchards, REM had the highest species richness. The active searching data indicated GVN 1 to have higher species richness (0.730) than REM (0.508) and GVN 19 (0.492). The most likely factor influencing this is the more heterogeneous ground cover vegetation at GVN 1, which is likely to support a greater diversity of species.

Although comparisons of species richness at the four sites were not significant (χ^2 test, Yate's correction), definite trends have emerged, with the undisturbed veld having the highest richness of all sites, followed by the older orchards.

Sørensen's Quotient values for combinations of the four sites showed the faunas of GVN 1 and GVN 19 to be most similar (Table 2). REM has a less similar fauna to these orchards, and the lowest similarity to the veld, reflecting on the geographical isolation of this orchard from the GVN estate. The veld was most dissimilar to the orchards, indicating that a unique fauna is found at this site.

The linear regression analysis of the relationship between orchard age and diversity by pitfall trapping (Figure 5) provided the equation $y=2x+12$. This projection was based on the assumption that an increasing number of species from surrounding habitats may establish populations in the orchards in the years following establishment. Since 57 species were collected in the veld, it could be projected that at least 22.5 years may pass before spider diversity in the orchards could reach the levels found in veld, if ever. However, this period may be extended because of the increased disturbance in mature orchards by increased chemical applications, ground cover mowing, and harvesting, which may directly affect the establishment of epigeic species. Some species would never establish because of inadequate environmental requirements in the orchards.

TABLE 1: Species diversity and richness of ground-dwelling spiders captured by two methods in three pistachio orchards and veld in the Prieska district, Northern Cape Province.

	PITFALLS			ACTIVE SEARCHING			POOLED SPECIES (2 METHODS)
	SPECIES PER SITE	SPECIES RICHNESS	UNIQUE SPECIES OF SITE	SPECIES PER SITE	SPECIES RICHNESS	UNIQUE SPECIES OF SITE	
GVN 1	26	0.325	3	46	0.730	17	57
GVN 19	25	0.313	0	31	0.492	7	48
REM	35	0.438	10	32	0.508	5	50
VELD	56	0.700	29	-	-	-	56
TOTAL SPECIES PER METHOD	80	-	-	62	-	-	105
UNIQUE SPECIES PER METHOD	42	-	-	25	-	-	-

TABLE 2: Sørensen's Quotient values for combinations of spider diversity collected by pitfall trapping in three pistachio orchards and veld in the Prieska district, Northern Cape Province.

ORCHARDS	GVN 1	GVN 19	REM	VELD
GVN 1	-	0.745	0.426	0.390
GVN 19			0.533	0.444
REM				0.374

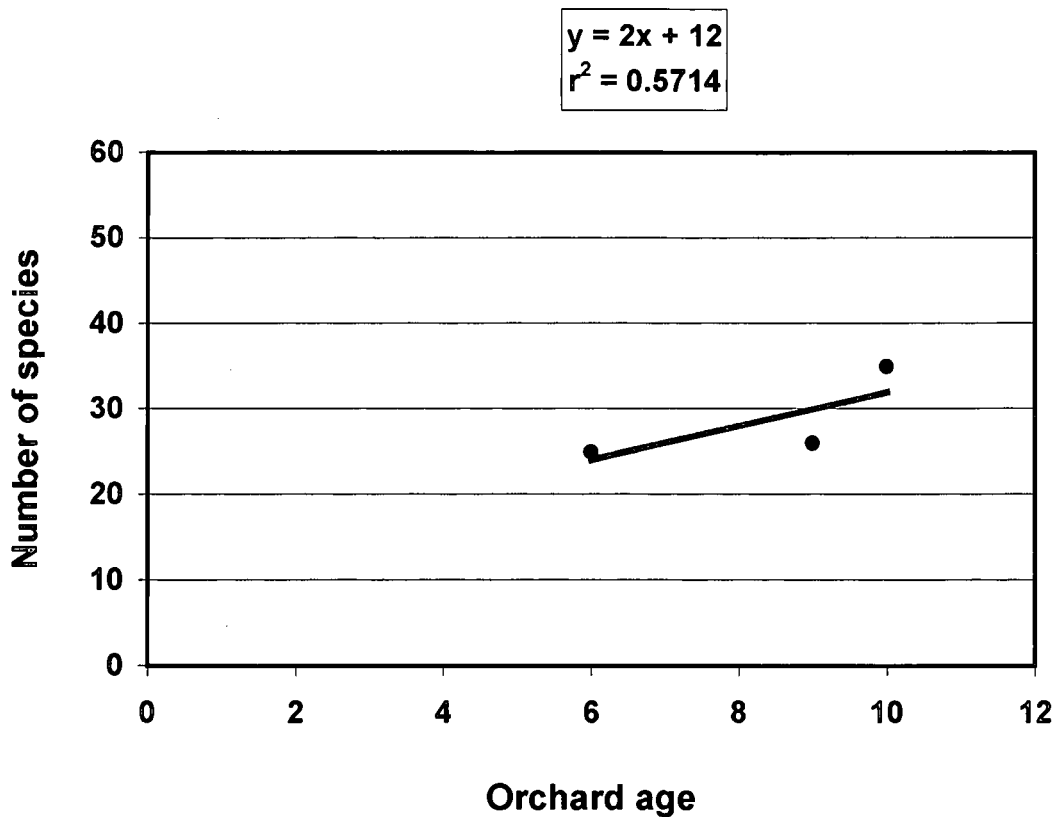


FIGURE 5: Linear regression analysis of the relationship between orchard age and species diversity as determined by pitfall trapping. The intercept was not forced through (0;0).

4.5 DISCUSSION

4.5.1 Faunal characteristics

This study uncovered a high diversity of ground-living spiders for an arid region (*i.e.* 104 species, 29 families), which is comparable to studies conducted in other arid and semi-arid regions of southern Africa. Lotz *et al.* (1991) collected 31 families in grassland in the central Free State, Haddad & Dippenaar-Schoeman (2002) found 21 families, representing 82 species, in abandoned mounds of the termite *Trinervitermes trindervoides* (Sjöstedt) (Isoptera: Termitidae) in the central Free State, and Russell-

Smith (2002) recorded 34 families and 151 species in the Etosha National Park in Namibia. The high diversity recorded here could be attributed to the variation in the ground vegetation at the various sites, which creates numerous sites of suitability for different species, ultimately increasing overall species diversity.

The species assemblages were found to be remarkably different between sites, particularly between the orchards and the veld. Three main factors are likely to have an influence, namely agricultural disturbance, vegetation composition and habitat fragmentation. This supports the findings of Topping & Lövei (1997), who found the species compositions of disturbed agricultural areas (field crops in New Zealand) and surrounding natural habitats to be considerably different, with very little overlap. Habitat complexity has been found to influence the diversity and abundance of spiders in natural ecosystems (Whitmore *et al.* 2002).

Gibb & Hochuli (2002) found spider species assemblages to vary considerably between small and large habitat fragments, suggesting that higher trophic levels (*e.g.* predators, such as spiders) are more susceptible to habitat fragmentation. The veld site forms part of the extensive natural habitat of the geographical region, and is more likely to remain ecologically stable compared to the orchards. This would sustain individual spider species and overall species diversity. The spiders in the smaller fragment of REM should be more susceptible to disturbance, but were more diverse than the two orchards at GVN, which form part of a larger habitat fragment. This could be due to REM being an older, more dynamic orchard, which borders with natural habitat on two sides and with field crops on the two other sides. It may consequently be subjected to immigration effects to a larger degree than the other orchards, accounting for greater diversity.

The orchards had a much larger amount of leaf litter and plant debris (from ground cover mowing) on the soil surface compared to the veld. Spiders may be dominant predators in orchard leaf litter communities (Halaj *et al.* 1998). Since the presence of leaf litter and plant debris often increases spider populations (Afun *et al.* 1999), one would have expected the epigeic spider numbers to be greater in the orchards than what they were found to be.

REM had a significantly higher diversity, number of unique species and abundance of spiders compared to GVN 1 and GVN 19 (Appendix 1). This could be

attributed to a combination of four factors: 1) The physical isolation of this orchard, separate from the Green Valley Nuts estate; 2) The smaller size of the orchard, which allows more rapid colonization by spiders from surrounding natural habitats; 3) REM is an older orchard, which has allowed more time for spider populations to recover following the disturbance effects of orchard establishment; 4) The unique characteristics of the ground covers and other vegetation surrounding the orchard, allows greater habitat complexity.

Ground spiders (Gnaphosidae) were found to be the most abundant taxon at the family level, which follows a similar pattern to studies conducted in other arid and semi-arid areas of southern Africa (Russell-Smith 1981, 2002; Lotz *et al.* 1991; Van den Berg, A. & Dippenaar-Schoeman 1991; Haddad & Dippenaar-Schoeman 2002). Van den Berg, A. & Dippenaar-Schoeman (1991) also found *A. lineatus* to be the dominant species in an area with high numbers of *Hodotermes mossambicus* (Hagen) termites. The frequent collection of *Trinervitermes trinervoides* (Sjöstedt) termites in pitfalls in the veld site would suggest that these spiders might aggregate in areas of high prey (termite) availability.

The dominant species in orchards and the veld were markedly different, with the sheet-weaver, *O. melanopygius*, most abundant on the ground surface of the orchards, and the ground spider, *A. lineatus*, most common in the veld. The former species probably has a high degree of adaptability to disturbed habitats and a high colonisation potential to dominate the orchard fauna so strongly. It furthermore meets the requirements for classification as an agrobiont species, *i.e.* species that reach high levels of dominance in agroecosystems (Samu & Szinetár 2002). The frequent cutting of vegetation in farming habitats depresses populations of linyphiid spiders (Thomas & Jepson 1997; Bell *et al.* 2002), so with fewer ground cover cuttings in orchards one could expect *O. melanopygius* populations to reach even greater levels of dominance. The prominence of linyphiids on the ground surface in orchards was also observed by Miliczky *et al.* (2000), where they comprised 53-90% of the epigeic fauna in apple orchards in the United States under different management intensities. Mansour *et al.* (1985) found the Linyphiidae to account for 19% of the epigeic fauna in avocado orchards in Israel.

Two additional species show potential for agrobiont status: the wolf spider, *P. crassipalpis*, accounted for 26.6% of the fauna at REM, but was considerably less abundant in the other orchards. The epigeic jumping spider, *Phlegma* sp., represented 26.6% in GVN 1 and 22.4% in GVN 19, but only 6.5% at REM. The differences in the abundance of these two species may be directly related to the density of the ground cover vegetation (see Chapter 3), which may restrict movement of *Phlegma* sp. (REM), while the high soil temperatures may be less suitable for foraging by *P. crassipalpis* in GVN 1 and 19. Vegetation density has previously been implicated as a factor influencing the activity of surface-dwelling spiders in agroecosystems (Honěk 1988; Honěk & Martinková 1991). The latter species is widely distributed throughout southern Africa and commonly found in agroecosystems such as cotton, maize, citrus in Southern Africa (Dippenaar-Schoeman pers. comm.), and could be regarded as an agrobiont species. It was the numerically dominant species in strawberries (Dippenaar-Schoeman 1979), and was found to prey on a variety of pest species (Dippenaar-Schoeman 1977).

4.5.2 Agricultural disturbance

According to Samu *et al.* (1999) many farming operations result in major habitat-scale disturbances to spider populations. Various activities such as harvesting, plowing, pesticide applications and deforestation are likely to affect micro-habitats in all systems, and are known to dramatically reduce natural enemy populations, including spiders (*e.g.* Nyffeler *et al.* 1994; Perfecto *et al.* 1997; Thomas & Jepson 1997; Topping & Lövei 1997). Arthropod species richness may also decline in disturbed systems (Downie *et al.* 1999; Kocher & Williams 2000; Kruess & Tschamtké 2002). Further to this, reducing the frequency of ground cover mowing has been shown to increase natural enemy populations arboreally (Horton 1999). Such actions may also reduce disturbance effects on epigeic spider populations, and may increase the species richness of the agricultural habitat (Downie *et al.* 1999). Although other studies have indicated that pesticide applications to the tree canopies have a minimal effect on the epigeic fauna of orchards (Bogya & Markó 1999; Pekár 1999; Miliczky *et al.* 2000), the almost bimonthly applications of herbicides (primarily Roundup™) for control of weeds in the tree rows

may have a greater effect on the epigeic spider populations in pistachio orchards than arboreal chemical applications.

The veld, with a lack of any disturbance effects, displayed a considerable advantage over the orchards in spider diversity and abundance. The veld site captured the greatest number of unique species (29 species) collected by pitfall trapping, whilst the orchards all contained markedly fewer unique species. This indicates the inability of many species to successfully colonise disturbed orchard habitats in the years following establishment, and demonstrates a limited adaptability of certain species to disturbed agricultural habitats. The low number of unique species in the two GVN orchards not only indicates relative homogeneity in their epigeic populations, but also points out that a high number of unique indicator species occur in the veld. Such species indicate the health or ecological integrity of the ecosystems they inhabit, demonstrating habitat degradation by decreases in numbers or by their absence. In this case the disturbance effects of orchard establishment may be the cause of their absence within orchards. It may be that vegetation density and soil structure are optimal in the veld for species such as *A. lineatus*, *Agelena gaerdesi* Roewer and the trapdoor spiders, or that their dispersal capabilities and orchard colonisation abilities are limited.

Recolonisation of disturbed systems by spiders seems to be an extensive process. Wilmers *et al.* (2002) suggested that colonisation processes of ecosystems are characterised by an increase in the number of species, after which diversity fluctuates around a certain level. It is quite possible that the orchards will never maintain a diversity that is comparable to veld, which would be a consequence of continued orchard disturbances, but that species that establish populations successfully will persist in the long-term. Rare species are most likely to form extinction components, as a scarcity of mating partners will hinder population growth and successful establishment.

4.5.3 Role in biological control

The epigeic spider fauna in pistachio orchards has an undetermined role in pest control at present. However, the results of studies in field crops suggest that spiders may play an important role as predators here, feeding on various arthropods, including pests of the crop plants. Mansour *et al.* (1981) and Losey & Denno (1998) found that the activity

of predators (spiders and ladybirds, respectively) on the crop plants elicited dropping behaviour of pests from the crop, which provides epigeal predators with food. Losey & Denno (1998) found that the combined predation rates of the predators on the plants (ladybirds) and ground (carabid beetle) were nearly double the sum of their respective individual predation rates. Similarly, arboreal predators in pistachio trees could disrupt pests, which could provide food for predators on the soil beneath the trees, including spiders. Ground-dwelling linyphiid spiders may relocate webs to sites of greater prey availability (Harwood *et al.* 2001), which will optimize the effects of epigeic species on potential pests.

Additionally, numerous common epigeic species (*e.g.* *O. melanopygius*, *Phlegra* sp. and *P. crassipalpis*) were frequently collected on ground cover plants (see Chapter 3). These species could then prey on pests in both strata, including potentially pestivorous herbivores in the pistachio canopy. Particular mention should be given to the false chinch bug *Nysius natalensis* Evans (Hemiptera: Lygaeidae), leaf beetles (Coleoptera: Chrysomelidae) and aphids (Homoptera: Aphididae), which utilize weeds as alternate host plants.

Pekár (1999) found a 20% overlap between the epigeic species and arboreal fauna, and suggested that epigeic populations may support the arboreal fauna. Of the 104 species collected from the soil surface here, exactly half were also collected in the tree canopies, presenting 59.8% of the arboreal species diversity. However, none of the “typical” ground-dwellers formed more than 2% of the total arboreal spiders collected. These results would therefore support those of Pekár (1999). One could deduce that epigeic species may play an additive role in pest suppression efforts in tree crowns by migrating vertically during the season, adding to the numbers of arboreal predators.

4.5.4 Disadvantages of pitfall traps as a collecting method

The cutting of ground covers often partially filled or covered the traps with grass and other debris, which could facilitate the escape of spiders from the traps. This probably resulted in an underestimation of the spider count in the orchards. The lack of covers for the traps (omitted to prevent damage during ground cover mowing) allowed rain to enter the traps on occasion. This dissolved the solvent and made the solution more

susceptible to evaporation. However, only during the extremely hot month of January did the solvent evaporate sufficiently in some traps to allow spiders to escape.

Activity of ants in orchards and the occasional disturbance of the soil around pitfalls by curious burrowing mammals sometimes also affected spider counts. The sand accumulating in the traps by ant foraging would absorb the preservative, while the mammalian burrowing around traps would effectively lift the trap rim relative to the surrounding soil surface, reducing the capture efficiency of the traps. Although ants may not reduce the survival of epigeic spiders, they do reduce densities (Eubanks *et al.* 2002).

The need for supplementary techniques in sampling showed that searching provided different numerical results (dominance and diversity), but that the dominant taxa collected by pitfalls also featured in the searching. Therefore, the latter technique could be recommended as a supplementary sampling method to pitfalls. The time spent searching could possibly be increased to half an hour. This would clarify abundance tendencies and acquire greater species diversity.

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APPENDIX 1: Species diversity and abundance of spiders collected from pitfall traps in three pistachio orchards and veld from July 2001-July 2002 († indicates a new species, ‡ indicates a possible new species, and ? indicates a dubious identification).

Family/species	GVN 1	GVN 19	REM	VELD	Total	% of total
AGELENIDAE						
<i>Agelena gaerdesi</i> Roewer, 1955				63	63	2.25
AMMOXENIDAE						
<i>Ammoxenus coccineus</i> Simon, 1893	2	14		46	62	2.21
<i>Rastellus deserticola</i> Haddad, in press†				10	10	0.36
ARANEIDAE						
<i>Neoscona subfusca</i> (C. L. Koch, 1837)				1	1	0.04
CAPONIIDAE						
<i>Caponia</i> sp.				1	1	0.04
CORINNIDAE						
<i>Cambalida</i> sp.†			1		1	0.04
<i>Castianeira fulvipes</i> Simon, 1896		3	2		5	0.18
<i>Castianeira</i> sp. 2	22	23	2	3	50	1.78
CTENIDAE						
<i>Ctenidae</i> sp. 1			1		1	0.04
CYRTAUCHENIIDAE						
<i>Ancylotrypa namaquensis</i> (Purcell, 1908)				8	8	0.29
<i>Ancylotrypa pusilla</i> Purcell, 1903				6	6	0.21
<i>Ancylotrypa</i> sp. 3‡			4	40	44	1.57
DICTYNIDAE						
<i>Archaeodictyna</i> sp.	1				1	0.04
GNAPHOSIDAE						
<i>Aneplasa nigra</i> Tucker, 1923	64	67	64	62	257	9.17
<i>Asemesthes lineatus</i> Purcell, 1908	1	1		321	323	11.51
<i>Asemesthes numisma</i> Tucker, 1923?				7	7	0.25
<i>Asemesthes purcelli</i> Tucker, 1923				6	6	0.21
<i>Asemesthes</i> sp. 4	1	1		9	11	0.39
<i>Camillina cordifera</i> (Tullgren, 1910)	6	18	16	6	46	1.64
<i>Camillina corrugata</i> (Purcell, 1907)	2				2	0.07
<i>Drassodes ereptor</i> Purcell, 1907		1	1		2	0.07
<i>Drassodes lophognathus</i> Purcell, 1907			19	6	25	0.89
<i>Drassodes sesquidentatus</i> Purcell, 1908				1	1	0.04
<i>Echemus</i> sp.				8	8	0.29
<i>Latonigera</i> sp.	10	2	4		16	0.57
<i>Megamyrmecon</i> sp.				1	1	0.04
<i>Micaria</i> sp.			1		1	0.04
<i>Poecilochroa</i> sp.				1	1	0.04
<i>Pterotricha auris</i> (Tucker, 1923)	6			2	8	0.29
<i>Setaphis bilinearis</i> Tucker, 1923	26	4		52	82	2.92
<i>Setaphis browni</i> (Tucker, 1923)				1	1	0.04
<i>Setaphis subtilis</i> (Simon, 1897)	1	8	3	1	13	0.47
<i>Trephopoda hanoveria</i> Tucker, 1923?	22	25		1	48	1.71

APPENDIX 1- continued.

Family/species	GVN 1	GVN 19	REM	VELD	Total	% of total
<i>Trichothyse</i> sp.				2	2	0.07
<i>Xerophaeus</i> sp.				3	3	0.11
<i>Zelotes oneili</i> (Purcell, 1907)	2	10	8	40	60	2.14
Gnaphosidae sp. imm.			1		1	0.04
Gnaphosinae sp. imm.	2				2	0.07
HERSILIIDAE						
<i>Hersiliola</i> sp.				2	2	0.07
IDIOPIDAE						
<i>Gorgyrella schreineri</i> Purcell, 1903				1	1	0.04
LINYPHIIDAE						
<i>Eperigone fradeorum</i> (Berland, 1932)	4		19		23	0.82
<i>Meioneta habra</i> Locket, 1968			2	2	4	0.14
<i>Metaleptyphantes familiaris</i> Jocqué, 1984			1		1	0.04
<i>Ostearius melanopygius</i> (O. P.-Cambridge, 1879)	160	108	240	49	557	19.86
<i>Pelecopsis janus</i> Jocqué, 1984				1	1	0.04
Linyphiidae sp.				1	1	0.04
LIOCRANIDAE						
<i>Rhaeboctesis trinotatus</i> Tucker, 1920		1		1	2	0.07
LYCOSIDAE						
<i>Evippa</i> sp. 1			1		1	0.04
<i>Evippa</i> sp. 2†				24	24	0.86
<i>Evippomma squamulatum</i> (Simon, 1898)				5	5	0.18
<i>Hippasa</i> sp.		1	2		3	0.11
<i>Lycosa</i> sp. <i>sensu lato</i>			10		10	0.36
<i>Pardosa crassipalpis</i> Purcell, 1903	53	22	187	15	279	9.95
<i>Pardosa foveolata</i> Purcell, 1903		1	4	2	7	0.25
<i>Trabea purcelli</i> Roewer, 1951				1	1	0.04
Lycosinae sp. 1		1	5	35	41	1.46
Lycosinae sp. 2			6		6	0.21
Lycosinae sp. 3				1	1	0.04
Lycosidae sp. 1			2		2	0.07
ORSOLOBIDAE						
<i>Afrilobus</i> sp.†				3	3	0.11
OXYOPIDAE						
<i>Oxyopes bothai</i> Lessert, 1915?				1	1	0.04
<i>Peucetia viridis</i> (Blackwall, 1858)	1				1	0.04
PALPIMANIDAE						
<i>Diaphorocellus biplagiata</i> (Simon, 1893)				2	2	0.07
PHILODROMIDAE						
<i>Hirriusa arenacea</i> (Lawrence, 1927)			22	197	219	7.81
<i>Philodromus</i> sp.			4	8	12	0.43
<i>Thanatus</i> sp.	2	2	2	8	14	0.50

APPENDIX 1- continued.

Family/species	GVN 1	GVN 19	REM	VELD	Total	% of total
PHOLCIDAE						
<i>Smeringopus</i> sp.	4	5			9	0.32
PRODIDOMIDAE						
<i>Theuma fusca</i> Purcell, 1907				4	4	0.14
SALTICIDAE						
<i>Heliophanus pistaciae</i> Wesolowska, 2003†	3		4		7	0.25
<i>Pellenes</i> sp.	12	11	14	30	67	2.39
<i>Phlegra</i> sp.	150	96	47	4	297	10.56
<i>Tusitala barbata</i> Peckham & Peckham, 1902			1		1	0.04
SEGESTRIIDAE						
<i>Ariadna</i> sp.				1	1	0.04
THERIDIIDAE						
<i>Latrodectus geometricus</i> C. L. Koch, 1841			3		3	0.11
<i>Latrodectus indistinctus</i> O. P.-Cambridge, 1904			1		1	0.04
<i>Theridion</i> sp. 1				2	2	0.07
<i>Theridion</i> sp. 2				1	1	0.04
THOMISIDAE						
<i>Xysticus</i> sp.	1	1			2	0.07
ZODARIIDAE						
<i>Diores triangulifer</i> Simon, 1910	2	2		1	5	0.18
<i>Ranops</i> sp.†				2	2	0.07
Σ	560	428	704	1112	2804	~100.00
TOTAL SPECIES	26	25	35	57	80	-
SPECIES RICHNESS	0.325	0.313	0.438	0.712	-	-

APPENDIX 2: Species diversity and abundance of spiders collected by active searching in ground covers in three pistachio orchards from July 2001-July 2002 († indicates a new species, ‡ indicates a possible new species, and ? indicates a dubious identification).

Family/species	GVN 1	GVN 19	REM	Total	% of total
AMAUROBIIDAE					
Macrobuninae sp.			8	8	1.24
ARANEIDAE					
<i>Neoscona blondeli</i> (Simon, 1885)		1		1	0.16
<i>Neoscona subfusca</i> (C. L. Koch, 1837)		1	1	2	0.31
CAPONIIDAE					
<i>Caponia</i> sp.	1			1	0.16
CORINNIDAE					
<i>Cambalida</i> sp.†	2		4	6	0.93
<i>Castianeira fulvipes</i> Simon, 1896		4	6	10	1.55
<i>Castianeira</i> sp. 2	3	8	1	12	1.86
<i>Castianeira</i> sp. 3	1		1	2	0.31
<i>Castianeira</i> sp. 4	1			1	0.16
<i>Cetonana</i> sp.	5		1	6	0.93
<i>Trachelas pusillus</i> Lessert, 1923	5		4	9	1.40
DICTYNIDAE					
<i>Archaeodictyna</i> sp.		3	1	4	0.62
GNAPHOSIDAE					
<i>Aneplasa nigra</i> Tucker, 1923	1	5		6	0.93
<i>Camillina cordifera</i> (Tullgren, 1910)	21	6	12	39	6.05
<i>Camillina corrugata</i> (Purcell, 1907)	1			1	0.16
<i>Drassodes ereptor</i> Purcell, 1907	8			8	1.24
<i>Drassodes</i> sp.‡	1			1	0.16
<i>Echemus</i> sp.	1			1	0.16
<i>Micaria</i> sp.		1		1	0.16
<i>Pterotricha auris</i> (Tucker, 1923)	17	15		32	4.97
<i>Pterotricha varius</i> (Tucker, 1923)	1	1		2	0.32
<i>Setaphis bilinearis</i> Tucker, 1923	1			1	0.16
<i>Setaphis browni</i> (Tucker, 1923)	1			1	0.16
<i>Trachyzelotes</i> sp.			1	1	0.16
<i>Trephopoda hanoveria</i> Tucker, 1923?		2		2	0.31
<i>Xerophaeus vickermani</i> Tucker, 1923	1	2	1	4	0.62
<i>Xerophaeus</i> sp. 2	1	1	1	3	0.47
<i>Xerophaeus</i> sp. 3	2		2	4	0.62
<i>Zelotes oneili</i> (Purcell, 1907)	1			1	0.16
Gnaphosinae sp.	1			1	0.16
LINYPHIIDAE					
<i>Eperigone fradeorum</i> (Berland, 1932)	1	1	3	5	0.78
<i>Meioneta habra</i> Locket, 1968		7		7	1.09
<i>Meioneta</i> sp. 2†		1		1	0.16
<i>Meioneta</i> sp. 3	1	1		2	0.31
<i>Microlinyphia sterilis</i> (Pavesi, 1883)	1	1		2	0.31
<i>Ostearius melanopygius</i> (O. P.-Cambridge, 1879)	76	29	62	167	25.89
Linyphiidae sp.	1			1	0.16

APPENDIX 2- continued.

Family/species	GVN 1	GVN 19	REM	Total	% of total
LYCOSIDAE					
<i>Evippa</i> sp. 1	1		1	2	0.31
<i>Hippasa</i> sp.	1		1	2	0.31
<i>Lycosa</i> sp. <i>sensu latu</i>	1			1	0.16
<i>Pardosa crassipalpis</i> Purcell, 1903	38	28	34	100	15.50
<i>Pardosa foveolata</i> Purcell, 1903			2	2	0.31
<i>Trabea purcelli</i> Roewer, 1951	1			1	0.16
Lycosinae sp. 1	1		7	8	1.24
Lycosinae sp. 2	2			2	0.31
MITURGIDAE					
<i>Cheiracanthium furculatum</i> Karsch, 1879	3	1		4	0.62
OXYOPIDAE					
<i>Peucetia viridis</i> (Blackwall, 1858)	1	9	13	23	3.57
PHILODROMIDAE					
<i>Hirriusa arenacea</i> (Lawrence, 1927)		1	3	4	0.62
<i>Philodromus</i> sp.		5	1	6	0.93
<i>Thanatus</i> sp.	1		13	14	2.17
PISAUROIDAE					
<i>Rothus vittatus</i> Simon, 1898	9		1	10	1.55
SALTICIDAE					
<i>Heliophanus charlesi</i> Wesolowska, 2003†	2	1		3	0.47
<i>Heliophanus pistaciae</i> Wesolowska, 2003†	9	5	17	31	4.81
<i>Myrmarachne</i> sp.		1		1	0.16
<i>Natta horizontalis</i> Karsch, 1879	10	1	3	14	2.17
<i>Phlegma</i> sp.	20	20	10	50	7.75
THERIDIIDAE					
<i>Enoplognatha</i> sp.			2	2	0.31
<i>Euryopsis</i> sp.	2	1	1	4	0.62
<i>Latrodectus indistinctus</i> O. P.-Cambridge, 1904			1	1	0.16
<i>Tidarren</i> sp.	1			1	0.16
THOMISIDAE					
<i>Heriaeus</i> sp.‡	1			1	0.16
<i>Thomisus kalaharinus</i> Lawrence, 1936		1		1	0.16
ULOBORIDAE					
<i>Uloborus plumipes</i> Lucas, 1846?	1			1	0.16
Σ	262	164	219	645	~100.00
TOTAL SPECIES	46	31	32	63	-
SPECIES RICHNESS	0.730	0.492	0.508	-	-

CHAPTER 5



**Aspects of the biology of
Heliophanus pistaciae, an
agrobiont jumping spider in
pistachio orchards in South
Africa (Araneae: Salticidae)**

5.1 ABSTRACT

As part of a greater arthropod survey on pistachio orchards in South Africa, some aspects of the biology of a numerically dominant jumping spider was studied from January 2001 to December 2002 in two orchards at Green Valley Nuts (GVN 1 & 19) and a third orchard at Remhoogte (REM). During this period, *Heliophanus pistaciae* Wesolowska was collected in tree canopies by insecticide fogging, in ground covers by sweep net, and on the ground surface by pitfall trapping. Laboratory observations were undertaken to determine aspects of the feeding and reproductive behaviour. This species dominated the arboreal spider fauna in all three orchards sampled, comprising a mean of 53.8%, while in the ground covers it was the second most abundant, comprising a mean of 23.4% of the total. Only seven *H. pistaciae* specimens were collected by pitfall trapping. Arboreally, numbers of *H. pistaciae* peaked between December and March, depending on the year, orchard and climatic conditions. Populations in the ground covers generally peaked in December or January. Prey capture, intra- and inter-sex rivalries, courtship and mating were all observed and described. Egg production in the field was greatest in early summer, but declined during autumn, winter and spring. A mean of 12.6 eggs are produced per egg sac (n=88). Two parasites were also associated with *H. pistaciae*: the egg parasite *Odontacolus* sp. (Hymenoptera: Scelionidae) infested 5.7% of egg sacs collected in the field; 3.3% of the females collected were parasitised by an undetermined polysphictine ichneumonid wasp. No males or immatures were parasitised. Knowledge of the biology of this spider may create a better understanding of its role in pest control.

5.2 INTRODUCTION

The jumping spiders (Araneae: Salticidae) are one of the best-studied families in Africa with regards to the biology of individual species (Dippenaar-Schoeman & Jocqué 1997). Most species are diurnal wandering polyphagous predators that use their exceptionally good eyesight to locate and capture prey (Jackson & Pollard 1996). Salticids display diverse predatory strategies, with araneophagy (Jackson 2002),

myrmecophagy (e.g. Curtis 1988; Jackson & Willey 1994; Jackson & Pollard 1996; Wesolowska & Salm 2002), and termitophagy (Wesolowska & Cumming 1999, 2002; Wesolowska & Haddad 2002) being encountered in representatives of numerous African genera. Recently, Wesolowska & Jackson (2003) described a new species of *Evarcha* Simon from Kenya that preys primarily on blood-fed mosquito females ($\pm 70\%$ of their diet), which provides another example of prey specialisation.

Jumping spiders are among the most abundant and diverse spider groups in various African biomes (Cumming & Wesolowska 2000; Wesolowska & Russell-Smith 2000; Rollard & Wesolowska 2002; Whitmore *et al.* 2002). Even though arid and semi-arid areas are regarded as harsh environments, salticids seem to be able to maintain a high diversity, which is even comparable to that of tropical areas (Griffin & Dippenaar-Schoeman 1991; Russell-Smith 2002). This indicates that each biome has species specifically adapted to survive under the climatic and environmental constraints of the habitats in which they occur. However, they may be considerably less abundant in arid than in tropical environments (e.g. Lotz *et al.* 1991; Haddad & Dippenaar-Schoeman 2002).

The numerous surveys carried out thus far in South African agroecosystems have shown salticids to be of variable abundance. In field crops they were common on crop foliage (Van den Berg & Dippenaar-Schoeman 1991), but were less abundant on the ground surface and in low-growing foliage (Dippenaar-Schoeman 1979; Dippenaar-Schoeman *et al.* 1999). In orchard systems salticids tend to be more common (Van den Berg *et al.* 1992; Dippenaar-Schoeman *et al.* 2001a), and may not only represent a strongly dominant component of the spider fauna, but also of the predator community as a whole.

Despite their prominence in orchard systems, little is known about the biology of South African salticids in such crops. Only Dippenaar-Schoeman *et al.* (2001b) provided information on the abundance and seasonal fluctuations of four salticid species commonly found in macadamia orchards in the Mpumalanga Lowveld. Despite *Heliophanus* C. L. Koch being one of the most speciose jumping spider genera in Africa, with more than 90 species described thus far (Wesolowska 1986; Wesolowska 2003), very little is known about their biology except for a single termitophagous species

(Wesolowska & Haddad 2002). This chapter aims to report on some aspects of the biology of *Heliophanus pistaciae*, an agrobiont spider in pistachio orchards in the Northern Cape Province, South Africa, which was recently described by Wesolowska (2003). In addition to being the most abundant spider in pistachio orchards in the present study, this species was also common on foliage in fig, walnut and pecan nut orchards at the same locality (personal observation). Agrobiont species are defined as species that reach a high degree of dominance in agroecosystems (Samu & Szinetár 2002).

5.3 MATERIALS & METHODS

5.3.1 Study area and period

Spiders were collected from two pistachio orchards at the Green Valley Nuts Estate (GVN, 22°56'41"S, 29°35'11"E) and a separate orchard at the farm Remhoogte (REM, 23°00'06"S, 29°31'55"E) in the Prieska district in the Northern Cape Province, South Africa. The study lasted two years, from January 2001 to December 2002. No sampling was done during the winter months of June and August (with the exception of pitfalls), as arthropod numbers in the trees and ground covers were extremely low at this time. The three pistachio orchards were of variable size and age, *i.e.* GVN 1 (16 ha, 8 years old at the start of the study), GVN 19 (16 ha, 5 years old) and REM (1.5 ha, 9 years old). The ground cover compositions of the three orchards can be briefly described as follows. Ground cover growth was moderately dense in GVN 1, and comprised a mixture of herbs, weeds and few grasses. In GVN 19, ground covers were relatively sparse, and comprised alternating rows of weeds and grasses. The ground cover density was highest in REM, and the vegetation was composed of mixed herbs and grasses, with sporadic weed growth.

5.3.2 Sampling methods

5.3.2.1 Fogging

Over a period of two years spiders were collected from pistachio trees during the last fortnight of each month by spreading 36m² of white sheeting below a tree, and

spraying the foliage and bark with the insecticide dichlorvos at 15ml/10l. After waiting five minutes, the main branches of the trees were vigorously shaken to dislodge any spiders that had not yet fallen onto the sheets. All spiders were then collected from the sheets and preserved in 70% ethanol. Following collecting, all spiders residing under bark, in dry leaves in the tree canopy and other prone objects (e.g. tree-supporting plastic tape) were also caught. All egg sacs of *H. pistaciae* that were collected during 2002 from such sites were preserved in 70% ethanol. Ten trees were sampled per month in each of the three orchards, giving a total of 200 trees sampled per site during the two-year study period.

5.3.2.2 Sweep netting

Spiders were collected from ground covers using a sweep net with a diameter of 40cm. Two-hundred sweeps were taken in each of the three orchards per sample date and material collected was preserved in 70% ethanol. Spiders were sampled from July 2001 to July 2002, with the exception of the colder months of August 2001, and May and June 2002 (a total of 10 samples per orchard), when ground covers had been cut and arthropod numbers were very low. In total, 2000 sweeps were sampled per site during the study period.

5.3.2.3 Pitfalls

Ten pitfalls (diameter of 8cm) were set out flush with the ground surface in the ground cover vegetation in each of the three orchards. Traps were arranged in two rows of five each (i.e. 10 traps per site), with traps separated by a distance of five metres. The traps were monitored from August 2001 for a period of twelve months using ethanediol as a preservative. Traps were emptied monthly during spring, summer and autumn, but only every second month during winter. Approximately 3700 trap-days were sampled per site during the study period.

5.3.3 Prey capture, reproductive behaviour and mating

The interactions between male and female *H. pistaciae* were studied in the laboratory in small petri dishes (diameter of 60mm, height of 20mm), which were

supplied with a piece of filter paper (diameter 55mm), which was moistened daily. Food was introduced through an access tube in the lid of the dish. Two females and one male were introduced into each microcosm, and the interactions between the spiders were observed in eight microcosms over a 7-day period. In two separate dishes, two males were kept and observations on their interactions were noted for 2 days. During this time, three *Drosophila melanogaster* Meigen (Diptera: Drosophilidae) flies were introduced into the microcosm each day as food. All inter- and intrasexual behaviour patterns and interactions, as well as prey capture sequence, were noted.

5.3.4 Parasites

All preserved spiders and egg sacs collected in the pistachio orchards were carefully studied in the laboratory for any signs of ectoparasites and egg parasites using a dissection microscope. Live spiders captured in the field were maintained in the laboratory in an attempt to rear the parasites to adulthood for identification. Material was prepared for scanning electron microscopy (SEM) using standard techniques. All material was dehydrated using a series of increasing ethanol concentrations, after which it was critical point dried in an argon chamber. Material was pasted on stubs before being coated three times with gold in a sputter coater. Specimens were studied in a JEOL WinSEM at 10kV, and photos taken on parasitised spiders and eggs.

5.3.5 Diet

Observations of *H. pistaciae* feeding in the field (in pistachio trees and during sweep netting) were noted. The type of arthropod preyed upon was noted, and the insect was preserved in 70% ethanol, and identified to family level in the laboratory. While spiders were maintained in the laboratory prior to behavioural observations and feeding tests, they were provided with a variety of arthropods collected by sweep netting in an undisturbed stand of grassland near Bloemfontein in the Free State Province. All items preyed on were noted and identified to family level.

5.4 RESULTS

5.4.1 Abundance of *H. pistaciae*

Heliophanus pistaciae was numerically dominant in the pistachio orchards, being the most abundant spider species in all three orchards. In total, 3452 of the 5797 spiders collected in the pistachio orchards were salticids, representing 60.0% of the spider fauna. Of these, 3118 were *H. pistaciae*, representing 53.8% of the total spider fauna and 90.3% of the jumping spiders. The only other salticid that was noticeably abundant was *Thyene inflata* (Gerstaecker, 1873), which accounted for 3.8% of the total spiders (n=220) and 6.4% of the salticids. Dominance of *H. pistaciae* in the three orchards varied from approximately 60% in GVN 1 to 46.7% in REM (Table 1).

TABLE 1: Relative abundance of *Heliophanus pistaciae* in the three strata of pistachio orchards in the Prieska district, Northern Cape Province.

		GVN 1	GVN 19	REM	TOTAL
Arboreally	n	1230	860	1028	3118
	% of total	59.97	55.48	46.68	53.79
Ground covers	n	168	52	191	411
	% of total	26.62	9.47	32.93	23.35
Ground surface	n	3	0	4	7
	% of total	0.54	0	0.57	0.25

In the ground covers *H. pistaciae* was the second most common spider, its numbers being exceeded only by that of the lynx spider, *Peucetia viridis* (Blackwall) (Oxyopidae). The latter species accounted for an average of 29.3% of the spider fauna, while *H. pistaciae* comprised 23.4% of the total. However, the numbers of *H. pistaciae* varied greatly between orchards. Numbers were lowest in orchards with a low density of ground cover growth (GVN 19, 9.5% of the total), and much higher in GVN 1 (26.6%) and REM (32.9%), which are orchards with denser vegetation growth at the ground level (Table 1).

Only three spiders of the 560 spiders collected in GVN 1 and four of the 704 spiders collected in REM by pitfall trapping were *H. pistaciae*, with no individuals collected in GVN 19 (Table 1). This species is therefore extremely scarce on the ground surface, and the few specimens collected here probably fell from the ground cover foliage into the traps, possibly after being disturbed in the vegetation. The three sampling methods revealed that *H. pistaciae* actively forages on plant foliage, and avoids the soil surface. This differs from a *Pellenes* sp. and a *Phlegma* sp., which were jumping spiders commonly occurring on the ground surface.

An interesting observation was the relative scarcity of two congeneric species compared to *H. pistaciae*. *Heliophanus trepidus* Simon represented <0.2% of the arboreal fauna and was absent in the ground covers, while *H. charlesi* Wesolowska comprised 0.4% of the arboreal fauna and 0.9% of the ground cover fauna. This would indicate that *H. pistaciae* is much more adaptable to the pistachio orchard ecosystem, with its various disturbance effects.

5.4.2 Seasonal population fluctuations

5.4.2.1 Arboreal spiders

Numbers of *H. pistaciae* in the tree canopies of the three orchards increased slowly during spring 2001 (September-November), with a sharp increase during December and January with the emergence of the first generation of spiderlings from spring egg sacs (Figure 1). Although no data were available for September-December 2000, it appears that during the first season of study the populations peaked in February (REM) and March 2001 (GVN 1 and GVN 19), but in the second season numbers peaked earlier, in December and January. Numbers decreased from March and April towards the winter months, when populations remained low. Spiders collected during winter were found overwintering in dead leaves or beneath bark, and comprised similar numbers of immatures, males and females. The abundance of *H. pistaciae* in the second spring season sampled (September-December 2002) was unusually low compared to the corresponding months of the previous season. The particular reasons for this pattern are not clear.

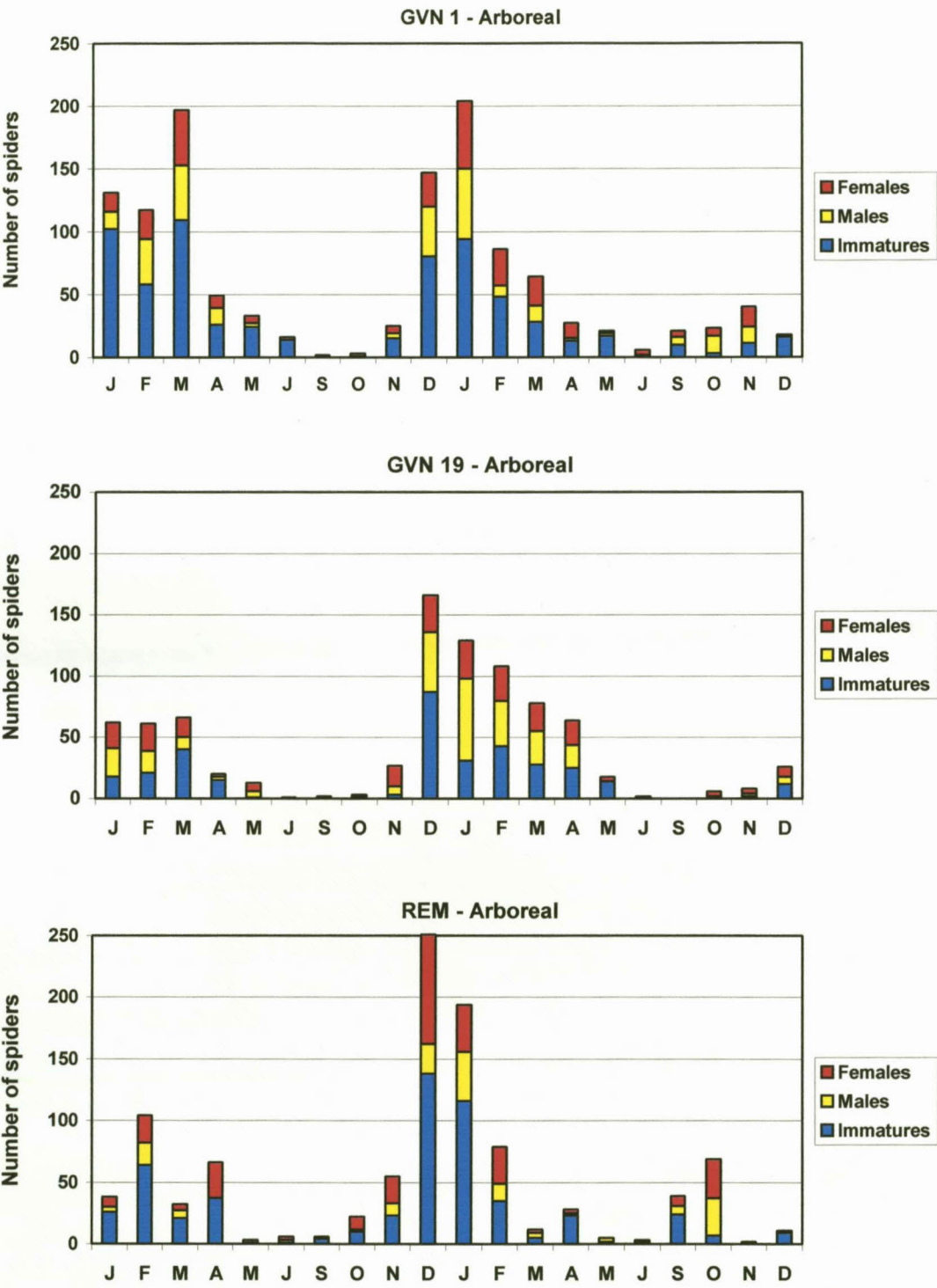


FIGURE 1: Seasonal fluctuations of arboreal *Heliophanus pistaciae* populations in three pistachio orchards over a period of two years (January 2001-December 2002).

It appears as if applications of endosulphan (in December 2001) had a minimal impact on *H. pistaciae* populations, with a maximum decrease of $\pm 20\%$ in the month following application (in REM). Similarly, parathion sprayed in April 2002 didn't seem to have a strong negative effect on populations of *H. pistaciae* during the following month.

5.4.2.2 Ground cover spiders

Although only one season's sampling was done, population fluctuations in the ground covers seemed to follow a similar pattern to the arboreal fauna (Figure 2). Numbers of *H. pistaciae* peaked in December and January, with a steady decrease during summer and autumn. An interesting pattern emerged when comparing the seasonal fluctuations of *H. pistaciae* in the pistachio trees and the underlying ground covers.

When numbers of spiders decreased in the ground covers during summer (January-February) there was an increase in the abundance of spiders arboreally, which would support the suggestion of a vertical migration from the ground covers to the tree crowns during this period. This may increase the impact of this species on potentially pestivorous herbivores during the important stage of nut kernel formation.

5.4.3 *Prey capture, reproductive behaviour and mating*

5.4.3.1 Feeding behaviour

Prey movement is noticed by *H. pistaciae* from as far away as 4-5cm, depending on the size of the prey. The spider makes a short running burst of 1-2 cm in the direction of the prey. Any movement of the prey attracts the spider's attention, and the spider turns to face the prey head on. The spider may approach cautiously in a stalking posture, or walks slowly towards the prey. Once within 1 to 1.5 cm of the prey, the spider runs rapidly forward towards the prey and lunges, using the front two pairs of legs to grasp the prey and sedate it. The spider holds the prey in the chelicerae following envenomation, and begins feeding once the insect has stopped moving.

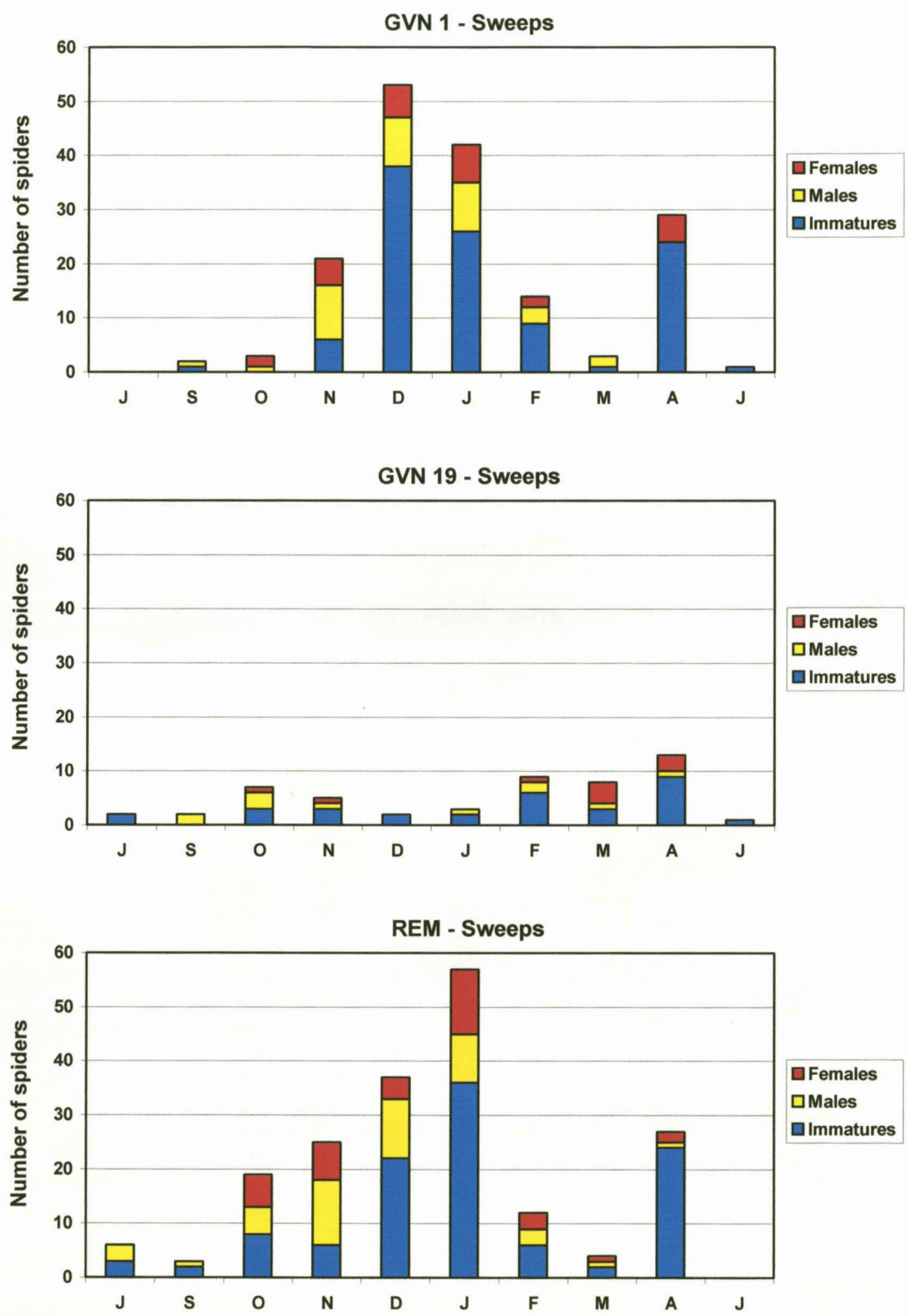


FIGURE 2: Seasonal fluctuation of *Heliophanus pistaciae* in the ground covers of three pistachio orchards during one season (July 2001-July 2002).

On numerous occasions in the laboratory, *H. pistaciae* was seen walking on draglines spun between the lids and bases of the petri dishes. More than ten observations of prey capture from the dragline were noted, with the spider leaping from the line, and either retreating back to the base of the line with its prey, or remaining on the base of the petri dish following prey sedation.

5.4.3.2 Male-male rivalries

When males encountered each other, they faced one another head-on, and ran rapidly sideways over a distance of <1cm, wiggling their pedipalps at the same time. Each spider would occasionally dart forward and then retreat. When spiders were within 1cm of each other the front legs would be raised, during intimidating darts and while standing still. This appears to be the most distinctive intimidatory behaviour sequence. The weakest male would usually be the one to retreat. The winner of such rivalries would simply hold his ground, and didn't follow the loser any further.

5.4.3.3 Female-female rivalries

When encountering one another, females would face each other. Occasionally their forelegs were raised, and one female would then charge the other, which would usually retreat and forage elsewhere.

5.4.3.4 Female intimidation on males

Apart from the responses of non-receptive females to males during courtship (described below), females would occasionally respond to males with intimidation. If a male wandered to within 1cm of a female, she would typically charge the male away, often using her forelegs to grab at his abdomen.

5.4.3.5 Courtship

When a male viewed a female within 4cm, he would move in her direction to attract her attention. Once a female had turned towards the male, he crouched with his body flat against the surface, and his front two pairs of legs and his pedipalps pointed to the front. He would then rise onto his tiptoes, and run from side-to-side in a zigzag

pattern, with his pedipalps pointing downwards. While doing so, he could cover 1.5cm to the side, while progressing forward slowly at $<0.5\text{cm}$ per run. While standing still between runs, the male moved his pedipalps back and forth along the body axis.

Non-receptive females would often dart forward at males, occasionally with their forelegs raised, before retreating. Occasionally, females that were apparently responsive would allow males to within 1cm from her, before charging and “snapping” at the male. Most males would respond to the darting of females by turning around and running a short distance before once again turning towards the female to assess her receptivity. Male retreats and turns lasted less than five seconds.

5.4.3.6 Mating

Two mating events were observed in the laboratory. The first lasted 27 minutes, before the second female in the microcosm disturbed the breeding pair, causing them to abandon the copulation. The second copulation lasted 1h 36min, without any disturbance from the other female in the microcosm.

If courtship was successful and the female was receptive, the male approached the female on his tiptoes with pedipalps raised, to within 0.3 to 0.5cm. The female flattened her body against the surface. The male approached, lifting his front legs, and tapped the female's cephalothorax, while the pedipalps were held wide apart, pointing towards the substrate. If the female showed no further aggression, the male would move around to her side, facing her body perpendicularly. Here he stood still for up to 5 minutes, until the female raised her abdomen towards him, indicating her receptivity for mating. The opposite side principle can be applied to this species, *i.e.* males approaching the female on her right side find the abdomen raised to the right, and copulate with the embolus of the left pedipalp entering the right-hand copulatory opening of the female. The male then reached across the cephalothorax and forced his embolus into her epigyne. During the copulation the male's body position was between 90° and 150° to that of the female. He maintained this position until the end of the copulation, using his legs to grasp the opposite side of her cephalothorax.

The pair remained very still during the copulation. Both spiders (but mainly the male) would gently rock their bodies up and down at a low frequency throughout the

copulation. Males also moved their abdomens up and down, with these wiggles varying in frequency from 1 sec to more than a minute. The male rarely moved his body from side-to-side, but this movement was noted on more than 10 occasions.

On one occasion a male was found in a cocoon together with a sub-adult female in the field. It is likely that the males remain with sub-adult females in the retreats until they moult to the adult stage, in order to gain first access to virgin females and mate with them.

5.4.4 Egg production

Searching for egg sacs yielded 88 sacs in the three orchards over a year of sampling (*i.e.* 10 months). This would imply that, on average, an egg sac is found in one in three trees sampled. However, a clear pattern of production emerged (Table 2). Egg sac production was highest early in summer, with 35 sacs produced in January, 22 in February and 19 in March. After this, production decreased sharply, with very few sacs found during the autumn, winter and spring months. It must be noted that the low egg sac production in spring is probably related to the low number of *H. pistaciae* from September to December 2002 (Figure 1). The number of eggs per sac varied greatly in all months, with a range of 6 to 20 (mean of 12.6).

TABLE 2: Egg sac production of *Heliophanus pistaciae* collected from pistachio orchards in the Northern Cape over a period of a year.

	EGG SACS	MEAN EGGS/SAC	STANDARD	RANGE
	<i>n</i>		DEVIATION	
January	35	12.46	1.77	[8;16]
February	22	12.41	2.77	[8;20]
March	19	13.68	3.20	[6;19]
April	7	11.71	3.15	[6;15]
May	1	9.00	0	0
July	0	0	0	0
September	1	7.00	0	0
October	1	17.00	0	0
November	2	11.50	3.54	[9;14]
December	0	0	0	0

Almost all egg sacs were found guarded by the females that produced them. The eggs were covered in a cocoon of thick, soft silk and comprised a dorsal and ventral disk. This cocoon was enclosed with the female in a retreat of less dense silk, typical of the rest cocoons constructed when the spiders are not foraging. Eggs produced in the laboratory took approximately three weeks to hatch (n=4 sacs).

5.4.5 Parasites

An egg parasite *Odontacolus* sp. (Hymenoptera: Scelionidae) (Gerhardt Prinsloo, personal communication) was collected from *H. pistaciae* egg sacs (Figure 3). Five of the 88 egg sacs collected (5.7%) were infected by this egg parasite (Table 3). Usually, three or four parasites were found in a single egg, raising the possibilities of multiple ovipositions or perhaps polyembryony. Infected egg sacs often contained adult parasites either emerging from the egg or moving actively inside the egg sac. At least one egg sac from each orchard was parasitised, indicating a broader distribution of the parasite within the greater pistachio orchard ecosystem.

TABLE 3: Prevalence of the egg parasite *Odontacalus* sp. in the eggs of *Heliophanus pistaciae*. Numbers in parenthesis represent the number of eggs parasitised during each life stage.

DATE	NUMBER OF EGGS	INFESTED EGGS	LARVAE	PUPAE	ADULTS	RANGE	MEAN PARASITES PER EGG
31/01	8	8	-	16 (6)	7 (2)	[1;5]	2.88
27/02	9	5	11 (3)	7 (2)	-	[3;5]	3.60
27/02	10	2	8 (2)	-	-	[4]	4.00
27/02	18	16	51 (15)	-	1 (1)	[1;5]	3.25
26/03	4	4	-	12 (4)	-	[3]	3.00

Ectoparasitic ichneumonid wasp larvae were only collected from the abdomens of female *H. pistaciae* (Figure 4). Only 28 females were found hosting developing larvae, representing 3.3% of the females collected in tree canopies. This indicates a low

infestation rate. No males or juvenile spiders were infected. Additionally, more than 50 *H. pistaciae* retreats under bark and in dry leaves contained hymenopteran cocoons (length: 4-5mm long), which probably belong to this particular parasite. This would suggest that the host becomes paralysed or inactive during the final stages of the parasite larval development prior to pupation, reflecting a parasite-induced change in phenology.

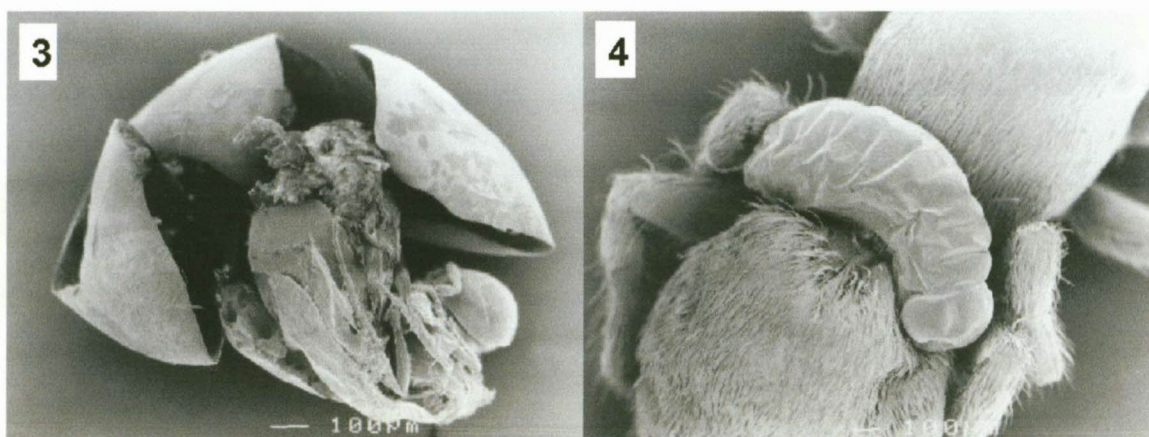


FIGURE 3-4: 3. An adult *Odontocalus* sp. emerging from a *H. pistaciae* egg; 4. An ectoparasitic polysphictine larvae developing on a female *H. pistaciae* abdomen.

Attempts to rear these parasites from four live adult females were not successful, and the identification of the species is presently not known, although it probably belongs to the tribe Polysphictini (Ian Gauld, personal communication). Interestingly, the level of infestation by these ichneumonid larvae seems to follow the seasonal abundance of female *H. pistaciae* (Figure 5). The apparent aversion for males and juvenile spiders may suggest the presence of a chemical (possibly a mating pheromone) released by the female spider to which the female wasp is attracted.

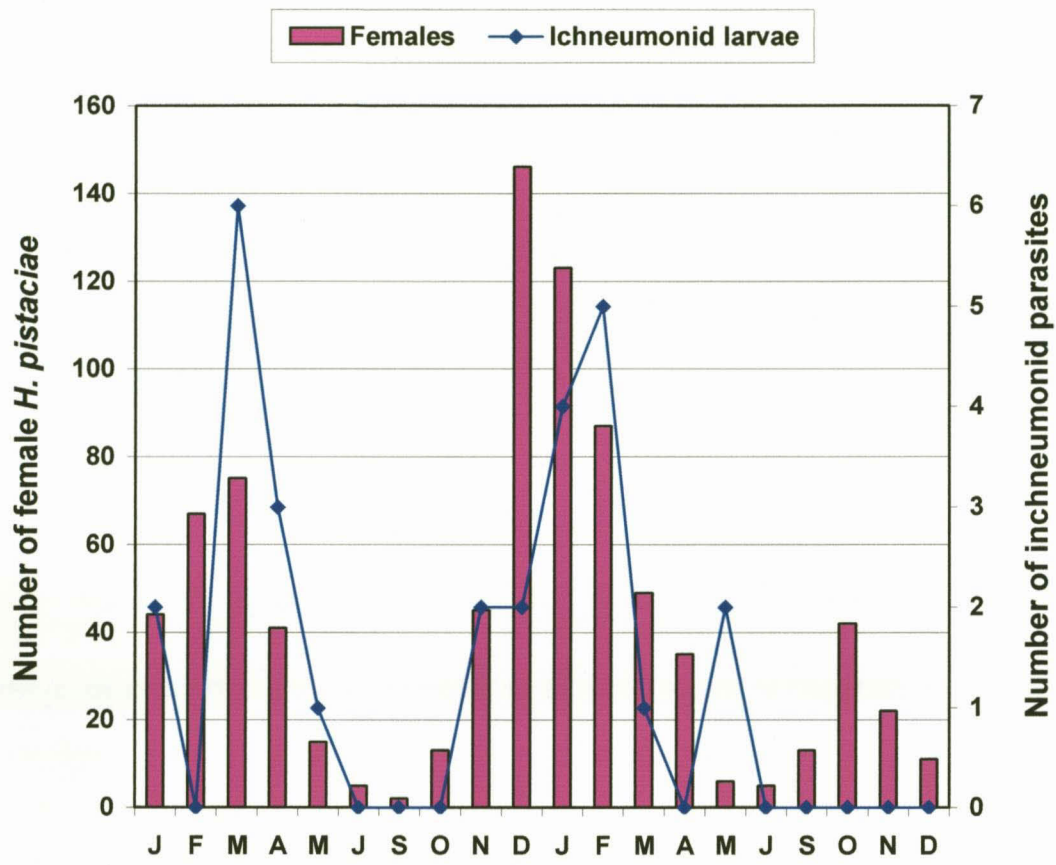


FIGURE 5: Abundance of female *H. pistaciae* and their ectoparasitic ichneumonid larvae over the course of two seasons.

5.4.6 Diet

The diet of *H. pistaciae* was found to be typical of a generalist predator (Table 4). These spiders were seen preying on arthropods of seven orders and 11 families in the field. Laboratory specimens fed on insects from six orders and 11 families collected from grassland. This includes eight herbivorous taxa, four saprophages, one predator and one parasitoid taxon.

TABLE 4: Predation events involving *Heliophanus pistaciae* in the field and laboratory.

PREY TAXON	ARBOREAL	SWEEPS	LABORATORY
Hemiptera: Lygaeidae	X	X	X
Homoptera: Aphididae	X	X	X
Homoptera: Cicadellidae	X	X	X
Homoptera: Delphacidae			X
Thysanoptera: Phlaeothripidae	X	X	X
Coleoptera: Coccinellidae	X		
Coleoptera: Chrysomelidae	X		X
Diptera: Cecidomyiidae	X		
Diptera: Dolichopodidae			X
Diptera: Drosophilidae			X
Diptera: Ephydriidae		X	X
Diptera: Muscidae	X		X
Hymenoptera: Chalcidoidea	X		X
Acari: Tetranychidae	X		

5.5 DISCUSSION

5.5.1 Role of biology in pest control

Understanding the biology of a predator is a key element in determining the effect that a particular species may have on herbivorous pests. As such, this study provided information on some aspects of the biology of the dominant spider species in pistachio orchards at Prieska. However, it is not only essential to consider the biology of the predator, but also of prey species that need to be controlled (Liao *et al.* 1984). With the information acquired on *H. pistaciae* it would seem that the greatest impact by this species on pests would be during the summer months, when arboreal populations reach their peak abundance.

Many of the *H. pistaciae* collected during the winter months were found in dead leaves or under bark, niches which serve as overwintering sites for salticids (Putman 1967). Specimens were also found throughout the year resting in abandoned bird nests in the tree canopy. These individuals are probably responsible for the production of the first generation of egg sacs, which, together with spiders ballooning from surrounding habitats, accounts for the increase in arboreal populations during spring. Second instar spiderlings that were artificially removed from their egg sacs were occasionally found to move to the extremities of foliage and attempt to balloon. This would indicate that

ballooning is an important dispersal mechanism of this species, and may account for the large-scale increases in orchard populations in late spring. Retaining dead leaves in trees could be a valuable tool in enhancing the reproduction of the species and building populations early in the season. Epigeic and ground cover populations may benefit from feeding on detritivorous Collembola and Diptera that inhabit weed residues and leaf litter. This may build *H. pistaciae* populations early in the season, increasing numbers that can impact pests later in the season (Sunderland *et al.* 1986).

The apparently low reproductive output of jumping spiders (*e.g.* Bartos 2002; Wesolowska & Haddad 2002), including *H. pistaciae*, makes the dominance of pistachio spider communities by *H. pistaciae* even more remarkable. This could be attributed to the production of egg sacs in protected sites (under bark, in crevices and in dry leaves), the structure of the egg sac, and protection of the eggs by the female (see also Austin 1985; Taylor 1997; Rossa-Feres *et al.* 2000; Bartos 2002; Wesolowska & Haddad 2002), which may reduce egg predation and parasitism. The somewhat cryptic colouration of females and juveniles, which enables them to blend in well with pistachio bark, may also contribute to decreased mortality of *H. pistaciae* by parasites and predators.

Considering the high abundance of *H. pistaciae* in the tree canopies and ground covers, and their potential as biological control agents, further efforts should be made to assess the direct effects of endosulphan and parathion, as well as other chemicals that may be sprayed in the pistachio orchards, on *H. pistaciae* and other spiders. This idea is supported by the results of a study on the effects of four pesticides on spiders (*i.e.* tallux, malathion, monocrotophos and endosulphan), which found that endosulphan had relatively the lowest toxicity on the jumping spider *Marpissa calcutaensis* (Tikader), but that mortality of this species was still very high when exposed to this insecticide (Sekar & Shunmugavelu 1992).

5.5.2 Role of *H. pistaciae* as a polyphagous predator

It has been suggested that spiders as single species are unable to control a specific pest species in agroecosystems, and rather that they have a greater impact on pests as part of the natural enemy complex than as single-species components (Riechert & Lockley 1984). This is largely due to their diverse lifestyles, which complement one another in

restricting the amount of enemy-free space available to pests (Sunderland 1999). However, when such a large degree of dominance is found by a single species of spider, what effects could then be achieved? It has been shown that *H. pistaciae* is a polyphage, as are many other species of jumping spiders (Dondale 1956; Jackson & Pollard 1996). Consequently, their predatory impact may not be determinate in bringing about the demise of a particular pest species, but rather, that this predator may cause a loss in numbers of a variety of pests, which together with other natural enemies (including other spider species) could have a significant impact. There are cases where salticid spiders have been shown to be major mortality agents of hemipteran pests (Dean *et al.* 1987; Breene *et al.* 1989). This would suggest that *H. pistaciae* might have a positive effect in diminishing populations of the false chinch bug, *Nysius natalensis* Evans (Hemiptera: Lygaeidae), which is a minor pest in the pistachio trees (Swart 2002). *Heliophanus pistaciae* preyed on this minor pest in the ground covers, and in field and laboratory feeding trials. However, in spite of the above-mentioned *H. pistaciae* population structure, web-building spiders may still have greater economic benefits than jumping spiders in the control of hemipteran pests (see Sterling *et al.* 1992).

Since *H. pistaciae* is a reasonably small spider species, it is unlikely to prey on herbivores much larger than itself. Therefore, its prey range is limited to minor pests such as *N. natalensis*, aphids (Aphididae), thrips (Phlaeothripidae), leaf beetles (Chrysomelidae) and mites (Acari: Tetranychidae), as well as other arthropods within a size range less than 6mm, such as flies, small ladybirds and parasitic wasps. Spiders have also been known to prey on the eggs of pests (Nyffeler *et al.* 1990; Pfannenstiel & Yeargan 2002), and in this way, *H. pistaciae* could impact on larger pests such as stinkbugs (Pentatomidae), which are some of the key pests on pistachio in the world (Michailides 1989) and on other nuts in South Africa (Joubert & Neethling 1994; Van den Berg *et al.* 1999).

A further question raised is what effect patchiness has on the success of *H. pistaciae* as a predator? Spiders have previously been shown to be important aphidophages in nut orchards (Liao *et al.* 1984; Bumroongsook *et al.* 1992). During this survey, an unidentified species of aphid was found to aggregate occasionally on the growth tips of young pistachio stems, where it would feed on young developing leaves.

As many as 40 aphids were found on a single leaf cluster. On one occasion a *H. pistaciae* female was recorded with a distended abdomen feeding on alate and nymphal aphids in such an aggregation. Spiders may aggregate at sites containing increasing aphid populations (Bumroongsook *et al.* 1992), and consequently the majority of aphids in such an aggregation could be devoured if a single spider discovered them. It is also possible that *H. pistaciae* may also disturb aggregations of aphids, causing them to fall to the ground (see Mansour *et al.* 1981), where they may die of starvation, or be consumed by epigeic predators. In this way, *H. pistaciae* may also contribute to mortality of this pest. Bilde & Toft (2001) showed that aphid prey reduces the fecundity and growth of their predators, but this is not likely to influence *H. pistaciae* as it encounters a broad prey spectrum in pistachio orchards.

5.5.3 Parasitism effects

The two parasites collected in this study are from the order Hymenoptera, which are well known as spider mortality agents. Some small wasp species of the families Encyrtidae, Eulophidae, Eupelmidae, Ichneumonidae and Pteromalidae are parasitic on spider eggs (Edgar 1971; Muma & Stone 1971; Kusigemati 1985; Barron 1987; Wheeler & McCaffrey 1989; Flórez-Daza & Campos-Moreno 1999; Haddad & Dippenaar-Schoeman 2001).

Members of the family Scelionidae have been previously implicated as spider egg parasites. According to Eason *et al.* (1967) scelionid females exhibit well-developed host-finding behaviour and use chemotactic stimuli to find their spider hosts. Scelionids oviposit through the silk egg sac into the eggs beneath, but cannot oviposit into eggs at the centre of the egg mass due to limitations on the length of the parasite's ovipositor (Eason *et al.* 1967; Austin 1984). Therefore the eggs in the middle of the sac are protected from parasitism, which may also be the case for *Odontacolus* sp. parasitising *H. pistaciae* eggs. This may explain the presence of unparasitised eggs amongst parasitised eggs in three of the five egg sacs collected here (Table 3). Austin (1984) also determined that superparasitism in *Ceratobaeus* spp. was uncommon, and that multiple ovipositions were accidental and ultimately resulted in cannibalism by the larvae until only one remained in the egg. In *Odontacolus* sp. the situation seems to be very different, with

most eggs having at least three developing larvae, suggesting either intentional superparasitism (without cannibalism) or polyembryony. Guarisco (1999) found the scelionid *Idris saitidis* Howard to be an exclusive egg parasite of the jumping spider *Phidippus clarus* (Keyserling), and suggested a high level of host specificity in this group. Similarly, *Odontacolus* sp. was only raised from *H. pistaciae* eggs, and wasn't reared from any egg sacs of *Cheiracanthium furculatum* Karsch (Miturgidae) or *Theridion* sp. (Theridiidae).

The family Ichneumonidae is parasitic on a wide variety of arthropods (Gauld *et al.* 2002), including spiders. Eggs are deposited on the outside of the spider hosts' abdomen, and the larva develops externally (Eberhard 2001). It is likely that the female *H. pistaciae* host dies before the larva pupates, and that parasitised females do not reproduce.

While it is difficult to make any projections as to the possible negative effects of the egg- and ectoparasites of *H. pistaciae* on future generations, one must assume the possibility that populations may be severely damaged by a sharp increase in parasitism levels. While the present levels of egg parasitism by *Odontacolus* sp. are quite low, it is possible that infestation levels may change from season to season (Edgar 1971; Wheeler & McCaffrey 1989), which could see a much greater impact on the reproductive success of *H. pistaciae* in coming years.

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CHAPTER 6



**An assessment of the biological
control potential of *Heliophanus
pistaciae* (Araneae: Salticidae)
on *Nysius natalensis*
(Hemiptera: Lygaeidae), a pest
of pistachio nuts**

6.1 ABSTRACT

The predation potential of *Heliophanus pistaciae* Wesolowska (Araneae: Salticidae) on one of the minor pests of pistachio nuts, *Nysius natalensis* Evans (Hemiptera: Lygaeidae), and vinegar flies, *Drosophila melanogaster* Meigen (Diptera: Drosophilidae), was assessed in laboratory and field trials. Laboratory tests were conducted using petri dish microcosms, and field trials using cotton mesh bags placed over pistachio nuts clusters. In feeding tests, female and male *H. pistaciae* consumed significantly more *D. melanogaster* than *N. natalensis* in the first and second days of the experiments (unpaired t-test with Welch's correction). Consumption of *N. natalensis* by both sexes increased significantly during the second day of the experiments. Feeding by females on *D. melanogaster* increased insignificantly during the second day, while feeding by males decreased insignificantly. There was no significant intersex difference in the number of *N. natalensis* killed, but females consumed significantly more *D. melanogaster* than males. During both time periods, both male and female *H. pistaciae* consumed significantly more *D. melanogaster* than *N. natalensis*. Prey preference tests found female *H. pistaciae* to prefer *D. melanogaster* (91%) to *N. natalensis* (9%). Initially, all females tested fed only on *D. melanogaster*, but the proportion of *N. natalensis* killed increased as the trials progressed. Different capture rates may be related to prey size and/or palatability. Field trials found female *H. pistaciae* (n=8) to kill a mean of 1.38 *N. natalensis* in a 24-hour period. The experiments indicate that *H. pistaciae* may have a limited role as a biological control agent of *N. natalensis*, but a combination of predation and effective orchard management should be able to suppress *N. natalensis* populations below damaging levels in pistachio canopies.

6.2 INTRODUCTION

Spiders form an important part of the natural enemy complex in orchard ecosystems, fulfilling a role as generalist predators (Specht & Dondale 1960; Carroll 1980; Liao *et al.* 1984; Knight *et al.* 1997; Amalin *et al.* 2001). While single species are unlikely to control pests alone, the complex of spiders can have a significant impact on

herbivores (Riechert & Lawrence 1997), largely as a result of the diverse lifestyles and habits of individual species. This reduces competition between spiders for individual prey species in the niches occupied by different guilds (Marc & Canard 1997) and, consequently, the amount of enemy-free space available to pests. Together with other predators and parasitoids, spiders form part of a natural enemy complex with the potential to keep pests below damaging levels on the crop (Sunderland 1999). The functional and numerical responses exhibited by some spider species indicate that they may contribute to the regulation of pest populations in agroecosystems (Marc *et al.* 1999). Field trials have shown that individual spider species may be important biocontrol agents in certain orchard crops (*e.g.* Mansour *et al.* 1985; Mansour & Whitcomb 1986; Bumroongsook *et al.* 1992).

A variety of predatory habits are encountered among jumping spiders (Salticidae). Most species are generalist hunting predators, feeding on a variety of prey, mostly insects (Jackson & Pollard 1996). Some species have evolved to become specialist araneophages (*e.g.* Jackson 2002), often specialising on specific taxa of spiders, such as orb-weavers. Some generalists have also been observed to feed on spider eggs (Jackson & Willey 1994). Unique examples of termitophagous specialists (Wesolowska & Cumming 1999, 2002; Wesolowska & Haddad 2002), and a mosquito-preying specialist (Wesolowska & Jackson 2003) have recently been recorded from Africa.

Jumping spiders are often very abundant in orchards (Van den Berg *et al.* 1992; Dippenaar-Schoeman *et al.* 2001) and, consequently, one would expect them to play an important role as natural enemies of certain pests. In orchard systems the impact of salticids on pests has not been sufficiently studied, although there are numerous examples that suggest they might be important generalist predators of several orchard pests. Marc & Canard (1997) found jumping spiders preying on leafhoppers and aphids in apple orchards. Miliczky & Calkins (2002), reporting on spiders as predators of leafroller larvae in apple orchards, found that two salticid species killed more than 40% of larvae that they were exposed to, with three other salticid species causing lesser degrees of mortality. Bumroongsook *et al.* (1992) found salticids to cause moderate mortality (compared to other spiders) of the blackmargined aphid, a pecan nut pest, in laboratory and field feeding tests. Jumping spiders also contribute to the mortality of citrus psylla in

South African citrus orchards (Van den Berg *et al.* 1992), where they are numerically dominant predators.

This study aimed to determine the role of a very common jumping spider found in pistachio orchards in South Africa, *Heliophanus pistaciae* Wesolowska (Araneae: Salticidae), in the control of the false cinch bug *Nysius natalensis* Evans (Hemiptera: Lygaeidae) on pistachio nuts. This pest is known to cause significant crop loss directly by its' feeding on nuts and also indirectly by consequent fungal transmission and lesion formation on nuts (Swart 2002). The positive role spiders exert in controlling another hemipteran pest, the cotton fleahopper (Miridae), on cotton and woolly croton (Dean *et al.* 1987; Breene *et al.* 1988, 1989, 1990; Sterling *et al.* 1992), suggests that *H. pistaciae* and other spiders may be important predators of *N. natalensis*, especially if their high abundance in the pistachio tree canopies is considered. Feeding tests were conducted under laboratory and field conditions to determine feeding rates of *H. pistaciae* on *N. natalensis*.

6.3. MATERIALS & METHODS

6.3.1 *Laboratory experiments*

6.3.1.1 Experimental setup

The feeding experiments were conducted under laboratory conditions, with temperatures fluctuating between 22°C and 25°C. Petri dishes with a diameter of 60mm and height of 20mm were used, with a disc of filter paper (diameter 55mm) on the bottom. The filter paper was moistened once daily to ensure that moisture was constantly available to organisms. A 8mm piece of rubber tubing was inserted and glued to the lid of the petri dish, through which prey could be introduced into the microcosm. While experiments were underway the access tube remained sealed with a cotton wad. Spiders used in the experiments were starved for three days prior to the start to ensure that they were hungry and likely to feed.

Two prey species were tested in the laboratory. *Nysius natalensis* specimens were captured from a wild host plant, the weed *Conyza bonariensis* (L.) (Asteraceae), using a

sweep net with a diameter of 40cm. Winged vinegar flies *Drosophila melanogaster* Meigen (Diptera: Drosophilidae) were maintained in the laboratory on a culture medium of rotting banana pulp, and served as alternate prey. This species is regarded as an intermediate quality prey of high palatability for spiders (Toft 1999).

6.3.1.2 Experiment 1: Predation rates with limited prey availability

Since prey availability in the field never remains constant and may be depleted by predation or prey dispersal and escape, an attempt was made to determine feeding rates of *H. pistaciae* with restricted prey availability. A fixed number of ten prey items were introduced into the microcosm with a single *H. pistaciae* at the start of a 48-hour study. After 24 hours the number of prey consumed was observed, and new prey were introduced to replace the dead ones. After 48 hours the number of prey consumed was again counted. This would indicate whether *H. pistaciae* grew accustomed to the larger prey (*N. natalensis*) and if feeding rates were higher on the second day of exposure, and if predation rates were relatively constant on the smaller, palatable prey (*D. melanogaster*).

A set of control experiments were run concurrently with the trials to assess whether prey mortality was natural or due to predation. This test was carried out on an equal number of male and female *H. pistaciae*, with twenty of each sex tested against the two prey species, *N. natalensis* and *D. melanogaster*. Ten controls of each prey species were monitored over the 48-hour period. Therefore, a total of 100 tests were carried out in this experiment.

6.3.1.3 Experiment 2: Prey choice experiments

The same microcosms used in the first experiment were used here. Experiments were carried out in the laboratory, starting at 07:00. One specimen each of *N. natalensis* and *D. melanogaster* were introduced into a microcosm containing a female *H. pistaciae*. The first prey item to be captured was recorded. A replacement was then added for each prey item killed. This process was repeated until five prey items had been captured, at which time the experiment was terminated. The time taken for the spiders to complete

feeding on their five prey items was also determined. In total, twenty female *H. pistaciae* were tested.

6.3.2 Field experiment

6.3.2.1 Experiment 3: Field predation on *N. natalensis*

A preliminary field trial was conducted in pistachio orchards at the Green Valley Nuts Estate (22°56'41"S, 29°35'11"E) in the Prieska district, Northern Cape Province, South Africa, to determine whether *H. pistaciae* preys on *N. natalensis* in pistachio trees. Experiments were carried out in a single orchard (GVN 1), on mature trees of the cultivar Sirora, during February 2003.

Fine cotton mesh bags were placed over a nut cluster, after which a single female *H. pistaciae* and five *N. natalensis* were introduced. The bags were sealed with elastic bands to prevent the arthropods from escaping. Eight trials were conducted for 24 hours each, and two controls (no *H. pistaciae* present) were also run concurrently. Mortality of *N. natalensis* in each of the 10 mesh bags was assessed once 24 hours had passed.

6.3.3 Statistics

Mean and standard deviation (SD) of prey consumption on *N. natalensis* and *D. melanogaster* were calculated after 24 hours and from 24-48 hours. Using this information, predation rates were compared using combinations of various factors, including time, prey species and spider sex. These combinations were compared with an unpaired t-test with Welch's correction, calculated using the statistics program GraphPad InStat version 3.05.

Increases or decreases in capture rates of individual *H. pistaciae* were also analysed to determine tendencies in capture and satiation. If an individual captured the same number of prey, this was regarded as no change. A difference of 1 or 2 prey was regarded as a small change (increase or decrease), a difference of 3 or 4 prey as a moderate change, and a difference of 5 or more prey as a large change.

6.4 RESULTS

6.4.1 Experiment 1: Predation rates with limited prey availability

Of the twenty females tested against *N. natalensis*, only five ate during the first 24 hours, which increased to 16 during the second day. Four individuals never preyed on *N. natalensis* on either day. Only two male *H. pistaciae* killed *N. natalensis* on the first day, which increased to 15 during the second day. Five individuals never killed bugs on either day. All of the *H. pistaciae* of both sexes tested against *D. melanogaster* ate flies during both days of the study, with the exception of one female that may have been satiated after eating eight flies in the first 24 hours, and never fed during the second day.

Predation rates on *N. natalensis* increased dramatically during the second day of the study (Table 1). Females preyed on 2.20 ± 1.77 (mean \pm SD) bugs on the second day compared to 0.25 ± 0.44 during the first 24 hours. Similarly, males increased their feeding rates from 0.10 ± 0.31 in the first 24 hours to 1.85 ± 1.66 during the second day. Increases in consumption for both sexes were very significant (Table 2). None of the *N. natalensis* in the control experiments died, indicating that all mortality in the trials was due to predation. The mean consumption of *N. natalensis* between sexes was not significantly different on either of the two days (Table 2).

TABLE 1: Predation rates of *Heliophanus pistaciae* on *Nysius natalensis* and *Drosophila melanogaster* in the laboratory after two consecutive 24-hour periods.

TEST	TIME	n	RANGE	PREY MORTALITY (MEAN \pm SD)
♀ <i>H. pistaciae</i> + <i>N. natalensis</i>	0-24 hrs	20	[0;1]	0.25 ± 0.44
	24-48 hrs	20	[0;6]	2.20 ± 1.77
♂ <i>H. pistaciae</i> + <i>N. natalensis</i>	0-24 hrs	20	[0;1]	0.10 ± 0.31
	24-48 hrs	20	[0;5]	1.85 ± 1.66
Control (<i>N. natalensis</i> alone)	0-24 hrs	10	0	0
	24-48 hrs	10	0	0
♀ <i>H. pistaciae</i> + <i>D. melanogaster</i>	0-24 hrs	20	[1;10]	5.80 ± 2.76
	24-48 hrs	20	[0;10]	6.00 ± 3.23
♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>	0-24 hrs	20	[1;10]	4.25 ± 2.47
	24-48 hrs	20	[1;10]	3.35 ± 2.56
Control (<i>D. melanogaster</i> alone)	0-24 hrs	10	[0;1]	0.2 ± 0
	24-48 hrs	10	[0;2]	0.4 ± 0

Trials using *D. melanogaster* as a prey item showed that female *H. pistaciae* increased their feeding from 5.80 ± 2.76 during the first 24 hours to 6.00 ± 3.23 during the second day of the tests (Table 1), but this increase was not significant (Table 2). Feeding by males decreased from 4.25 ± 2.47 after 24 hours to 3.35 ± 2.56 during the second day of the study. This decrease in feeding rates was also insignificant. A very small proportion of flies in the control experiments died after 24 hours (mean=0.2) and 48 hours (mean=0.4), suggesting that almost all *D. melanogaster* mortality could be attributed to predation by the spiders.

During the first 24 hours of the trials, females consumed only slightly significantly more *D. melanogaster* than males, but the difference during the second day was very significant (Table 2). This would indicate that males become satiated more quickly than females, and decrease their feeding rates in the second day, while females continue to utilise the abundant food source, possibly to be able to provide nutrition for egg production. Predation on *N. natalensis* was found to be significantly lower than for *D. melanogaster* for both female and male spiders during both days of the trials (Table 2). This would suggest that numerous factors might be responsible for the different predation rates on the two prey species, including prey palatability, activity, and prey size relative to that of the spider.

Analysis of consumption rates of the individual spiders found that, to varying degrees, the majority of spiders increased predation on *N. natalensis* during the second day (Table 3). In most cases, the spiders only demonstrated a slight increase in predation rates (nine females [45%] and ten males [50%]). Five females (25%) and three males (15%) demonstrated moderate increases in consumption rates during the second day of the study. Five females (25%) and five males showed no change in feeding rates. This group was composed of individuals that didn't feed on *N. natalensis* at all during the trial, with the exception of one female that preyed on one *N. natalensis* during each of the days. No spiders of either sex were found to decrease their feeding rates on this prey species.

TABLE 2: Results of unpaired t-test with Welch's correction on combinations of feeding rates of male and female *Heliophanus pistaciae* on *Nysius natalensis* and *Drosophila melanogaster* in the laboratory. Significance levels: n.s.=not significant, * = slightly significant, ** = moderately significant, and *** = very significant.

TEST	TIME	df	P	t	SIGNIFICANCE
♀ <i>H. pistaciae</i> + <i>N. natalensis</i>	24 hrs vs 48 hrs	21	<0.0001	4.791	***
♀ <i>H. pistaciae</i> + <i>D. melanogaster</i>	24 hrs vs 48 hrs	37	0.8340	0.211	n.s.
♂ <i>H. pistaciae</i> + <i>N. natalensis</i>	24 hrs vs 48 hrs	20	0.0002	4.627	***
♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>	24 hrs vs 48 hrs	37	0.2650	1.132	n.s.
♀ vs ♂ <i>H. pistaciae</i> + <i>N. natalensis</i>	0-24 hrs	33	0.2233	1.241	n.s.
♀ vs ♂ <i>H. pistaciae</i> + <i>N. natalensis</i>	24-48 hrs	37	0.5226	0.645	n.s.
♀ vs ♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>	0-24 hrs	37	0.0683	1.878	*
♀ vs ♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>	24-48 hrs	36	0.0067	2.876	***
♀ <i>H. pistaciae</i> + <i>N. natalensis</i> vs ♀ <i>H. pistaciae</i> + <i>D. melanogaster</i>	0-24 hrs	19	<0.0001	9.227	***
♀ <i>H. pistaciae</i> + <i>N. natalensis</i> vs ♀ <i>H. pistaciae</i> + <i>D. melanogaster</i>	24-48 hrs	29	<0.0001	4.619	***
♂ <i>H. pistaciae</i> + <i>N. natalensis</i> vs ♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>	0-24 hrs	19	<0.0001	7.462	***
♂ <i>H. pistaciae</i> + <i>N. natalensis</i> vs ♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>	24-48 hrs	32	0.0354	2.197	**

TABLE 3: Changes in prey capture rates of *Heliophanus pistaciae* on two prey species, *Nysius natalensis* and *Drosophila melanogaster*. Categories for capture rate changes are explained in the Materials and Methods section.

CHANGE IN FEEDING RATES	♀ <i>H. pistaciae</i> + <i>N. natalensis</i>	♂ <i>H. pistaciae</i> + <i>N. natalensis</i>	♀ <i>H. pistaciae</i> + <i>D. melanogaster</i>	♂ <i>H. pistaciae</i> + <i>D. melanogaster</i>
Total number of tests	20	20	20	20
Decreased by >5	0	0	3	3
Decreased by 3-4	0	0	2	2
Decreased by 1-2	0	0	1	6
No change	5	5	3	2
Increased by 1-2	9	10	7	4
Increased by 3-4	5	3	2	2
Increased by >5	1	2	2	1

Females feeding on *D. melanogaster* showed no change (n=3, 15%), a slight increase (n=7, 35%) or larger degrees of increase (n=4, 20%) in the second day (Table 3). Six females (30%) demonstrated a decrease in consumption rates on *D. melanogaster*. This indicates that the majority of females were not satiated, and continued to utilise the abundant food source, possibly for nutrient acquisition for egg production. Seven males (35%) increased their feeding in the second day, another two (10%) had no change in feeding rates, while eleven (55%) decreased their consumption rates, to varying degrees. This would indicate that the males, which are smaller than females, are satiated more rapidly. This may be because males have a shorter lifespan than females, and spend more time actively searching for mates than they do feeding.

6.4.2 Experiment 2: Prey choice experiments

Of the twenty female spiders tested, only seven fed on *N. natalensis*. Five of these fed on a single *N. natalensis*, and two individuals fed on two. Only 9% of the available prey (n=100) attacked and killed were *N. natalensis* (Figure 1), which indicates a high preference for the palatable prey item, *D. melanogaster*. All of the first prey items captured by the spiders were *D. melanogaster*, with an increasing number of *N. natalensis* captured as the trial progressed (Figure 1). The female that consumed its five prey most rapidly completed feeding after 2h 15mins, and the female that took the longest to complete feeding took 37 hours.

6.4.3 Experiment 3: Field predation on *N. natalensis*

Six of the eight female *H. pistaciae* tested in the field trials had preyed on *N. natalensis* after 24 hours. An average of 1.38 ± 1.06 *N. natalensis* were consumed per spider (range: [0;3]). None of the *N. natalensis* in the controls died, and consequently all mortality could be attributed to predation by *H. pistaciae*. Additional tests should be conducted to clarify predation levels and examine seasonal fluctuations in predation rates on different prey, including *N. natalensis*.

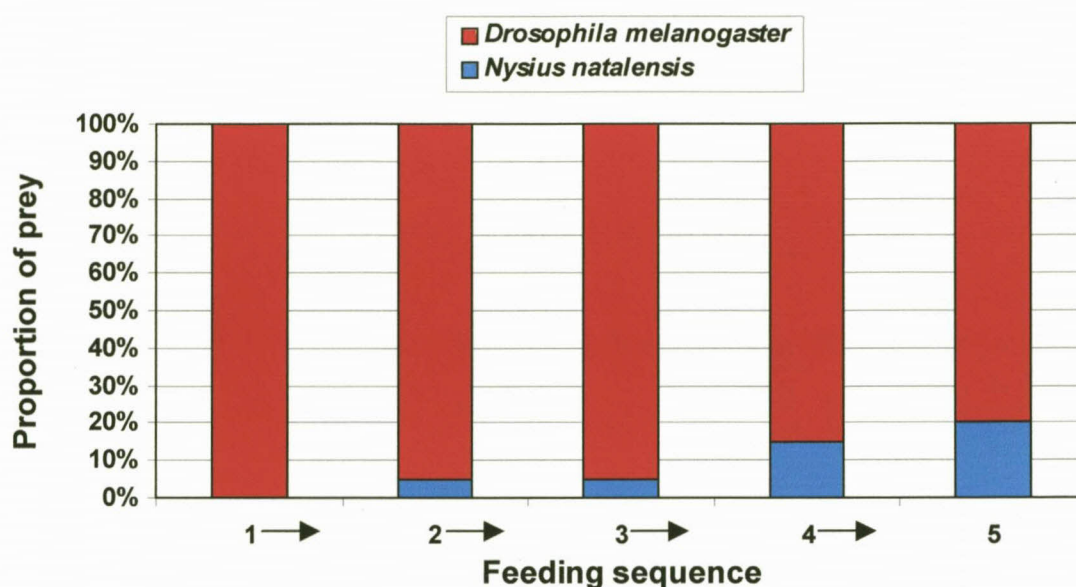


FIGURE 1: Proportion of capture by *Heliophanus pistaciae* of two prey species in prey preference trials.

6.5 DISCUSSION

6.5.1 *Factors influencing predation rates*

The markedly lower predation rates of *H. pistaciae* on *N. natalensis* compared to *D. melanogaster* can be attributed to several factors. Firstly, *N. natalensis* has a similar body length to *H. pistaciae*, with some specimens being larger than male spiders, while *D. melanogaster* is approximately half the body length of *H. pistaciae*. Hunting spiders usually capture prey smaller than themselves (Nentwig 1987), and salticids typically feed on prey that is, on average, 90% of their body length, although they may capture prey up to 150% of their body size (Nentwig & Wissel 1986). *Heliophanus pistaciae* may thus be more likely to prey on *D. melanogaster* than on *N. natalensis* when a choice is available, and may avoid the larger prey when they have no choice. The spiders feeding on flies will also remain hungry for a longer period when feeding on smaller prey, and will consume more prey before they are satiated.

Secondly, the flies were much more active in the petri dishes than the bugs. This would have dramatically increased the likelihood of *H. pistaciae* encountering their prey, and of consequent prey capture. Visually dependent hunting spiders are largely dependent on prey movement for location of food (Persons & Uetz 1996), and this may contribute to higher capture rates of *D. melanogaster*. Hunger state increases the importance of visual and vibratory cues to hunting lycosid spiders (Persons 1999), which may also be true for salticid spiders.

Thirdly, *D. melanogaster* is generally regarded as a palatable prey item for most spiders, which is often used to compare predation rates on non-palatable prey such as aphids and bugs (Bilde & Toft 1997, 2001; Toft & Wise 1999a). Spiders feeding on *D. melanogaster* may consume considerably larger quantities than of unpalatable prey, which they may develop an aversion for (Toft & Wise 1999b). This preference is reflected in the very high predation on *D. melanogaster* in the prey preference tests, as well as the significantly higher feeding rates on *D. melanogaster* in Experiment 1. The preference experiment indicates that the spiders first need to become accustomed to *N. natalensis*, and overcome any initial aversions developed to this prey as a consequence of the release of repellent defensive chemicals.

The predatory effect of *H. pistaciae* on *N. natalensis* in the laboratory may be that of superfluous killing, since no *H. pistaciae* were actually observed feeding on this prey species. It may be possible that the confined space of the experimental microcosm affected this, as spiders that were disturbed during feeding may have dropped their prey and moved elsewhere. According to Riechert (1999), superfluous killing entails field capture rates that significantly exceed the rates of consumption under high prey densities, and includes partial consumption of multiple preys and the killing of prey items that are never fed on. This aspect of spider predation is an added benefit to pest control, as the spider doesn't feed on certain prey items and could therefore remain hungry (Sunderland 1999), which may result in the deaths of a greater number of pests before the spider is satiated. Since *H. pistaciae* killed *N. natalensis* in the field trials, and was also observed preying on this pest in pistachio trees and orchard ground covers (see Chapters 2 & 3), it must be assumed that this species forms part of the spider's prey spectrum in the field.

6.5.2 Impact on *N. natalensis*

In the scenario of pest control based on one or two spider species, it is much better to select species undergoing the later stages of development at the beginning of the pests' damaging period, since these stages consume greater numbers of prey (Marc *et al.* 1999). As *H. pistaciae* adults are present throughout the year, and typically comprise between 30-50% of the arboreal population, they could consume larger numbers of prey compared to immatures. However, the number of arboreal *H. pistaciae* only increases dramatically during late spring and early summer (December and January), which implies that their greatest impact on *N. natalensis* would be from the middle of the season, at which time nuts are already developing. This may restrict the nut damage induced by *N. natalensis* during the crucial period of kernel formation. This is supported by the field trials results, which found that *H. pistaciae* feeds on *N. natalensis* in the pistachio trees.

However, *N. natalensis* populations do not presently reach high levels in pistachio trees (Swart 2002), so the likelihood of encounter in the tree canopy and subsequent predation by *H. pistaciae* on multiple *N. natalensis* is unlikely. In the orchard ground covers, numbers of *N. natalensis* may reach very high densities (Swart 2002), and here *H. pistaciae* may kill multiple adults and nymphs. Since *H. pistaciae* is a generalist predator, it is unlikely that it will concentrate its feeding on *N. natalensis* when a wide prey selection is available, but in this way it may impact a greater variety of pests, including aphids (Homoptera: Aphididae), thrips (Thysanoptera: Phlaeothripidae) and *N. natalensis*, and in so doing, aid other natural enemies in their control.

Numerous studies on the cotton fleahopper (Hemiptera: Miridae) showed salticids to be important predators of this hemipteran pest. Dean *et al.* (1987) and Breene *et al.* (1988, 1989, 1990) found *Phiddipus audax* (Hentz) and other salticids to readily capture fleahopper adults. Breene *et al.* (1989) suggested that jumping spiders might possess the highest efficiency as predators of fleahopper nymphs. However, Sterling *et al.* (1992) demonstrated salticids to be of relatively low economic value in the control of fleahoppers compared to other spider groups. Considering the strong numerical dominance of *H. pistaciae* in the pistachio canopy, where they comprise more than 50% of the spider fauna, they are likely to have some value in reducing damage caused by *N. natalensis*.

Female spiders are usually known to feed and consume more prey than their male conspecifics (Walker & Rypstra 2001, 2002). This can be explained by the nutritional requirements of females for egg production and the longer lifespan of females, for which they need more food for energetic requirements. Success in prey capture may increase with increased age and experience in the period following emergence from egg sacs in certain hunting spiders (*e.g.* Morse 2000), implying that spiders will have an increasing impact on pests as they mature. It is probable that the prey consumed by different life stages of spiders will vary according to the prey and sizes of spiders. It could be suggested that *H. pistaciae* immatures concentrate feeding on mites, thrips and small flies, while adults prey on larger prey, including flies, leaf beetles (Coleoptera: Chrysomelidae), aphids and *N. natalensis*.

A positive correlation exists between spider numbers and numbers of potential prey (Nentwig 1982; Riechert & Lockley 1984; Bumroongsook *et al.* 1992), and is regarded as the numerical response to prey densities. The feeding capacity of certain spiders on unpalatable prey is limited (Bilde & Toft 1997), and single-prey diets of unpalatable prey may significantly reduce reproductive outputs (Toft 1995; Bilde & Toft 2001). The consumption of a mixed prey spectrum may decrease their impact on *N. natalensis*, but will reap reproductive rewards that will increase *H. pistaciae* populations, and possibly, their impact on other pests.

6.5.3. Role of orchard management

Proper orchard management practices will play an important role in the control of *N. natalensis*, and prevent populations reaching damaging levels. Two possible strategies could be employed to decrease *N. natalensis* numbers. Control of its wild host weed, *C. bonariensis*, by using herbicides in the ground cover layer could limit *N. natalensis* population increases early in the season. Alternately, patches of the weed may be sown to serve as a trap crop to lure *N. natalensis* away from pistachio trees. Pesticides applied to such patches of the weed at the peak of *N. natalensis* occurrence could dramatically reduce *N. natalensis* populations to levels below the economic threshold. Either strategy could prove useful in reducing arboreal numbers of *N. natalensis*, and in so doing, render predation by *H. pistaciae* more efficient at low pest densities.

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CHAPTER 7



**Summary and future focus for
spider research in pistachio
orchards in South Africa**

The present study, conducted on the farms Green Valley Nuts (GVN) and Remhoogte (REM) in the Prieska district, Northern Cape Province, South Africa, from January 2001 to December 2002, was the first intensive survey of spiders conducted on pistachio nuts anywhere in the world. This study was rather unique compared to other orchard crops, in that the pistachio orchards are located in an arid area, while most other orchard crops are grown in areas with higher rainfall and more favourable climatic conditions. It confirmed what multitudes of other surveys in orchard crops have demonstrated, *i.e.* that spiders are an abundant and highly diverse group of generalist predators in orchard ecosystems. The three orchards in which sampling was undertaken differed with regard to their age and size: GVN 1 was 8 years old and 16 ha in size at the start of the study, GVN 19 was 5 years old and 16 ha in size, and REM was 9 years old and 1.5 ha in size. A total of 143 species, representing 31 families, were collected in surveys of the arboreal, ground cover and epigeic faunas. Their numerical abundance in pistachio orchards suggests that they may play an important role as predators of pests.

In the tree canopies, 5803 spiders were collected from 200 trees sampled in each orchard over a two-year period, representing 87 species of 18 families. Numbers and diversity were highest in REM ($n=2202$, 70 spp.), followed by GVN 1 ($n=2051$, 64 spp.) and GVN 19 ($n=1550$, 47 spp.). Orchard age was found to have a significant effect on spider abundance and diversity. Their numbers were surprisingly high compared to other predators, with as many as 85 individuals collected by fogging in a single tree. Monthly spider abundances usually exceeded recorded numbers of other prominent natural enemy groups, including predatory beetles (Coleoptera: Coccinellidae and Staphylinidae), lacewings (Neuroptera: Chrysopidae and Hemerobiidae) and parasitic wasps (Hymenoptera: Braconidae, Chalcidoidea, Ichneumonidae, among others). Additionally, spiders were collected in the pistachio canopies throughout the year, while most other natural enemy groups were restricted to the spring and summer seasons. Arboreal spider populations reach their peak abundance in late spring and summer, and consequently, their greatest impact on pests may be during the important period when the nut kernels are developing. Three numerically dominant spider species, the jumping spider *Heliophanus pistaciae* Wesolowska (Salticidae, 53.8%), sac spider *Cheiracanthium furculatum* Karsch (Miturgidae, 12.8%), and orb-weavers *Neoscona subfusca* (C. L.

Koch) (Araneidae, 6.4%), were found to prey on numerous minor pests, including false chinch bugs (Hemiptera: Lygaeidae), aphids (Homoptera: Aphididae), leafhoppers (Homoptera: Cicadellidae), thrips (Thysanoptera: Phlaeothripidae), leaf beetles (Coleoptera: Chrysomelidae), and phytophagous mites (Acari: Tetranychidae). This would indicate that spiders might contribute to the natural regulation of populations of these pests. However, they also preyed on two key groups of natural enemies (ladybird beetles [Coccinellidae] and parasitoids [Chalcidoidea]). Since these two natural enemy groups are both abundant and diverse, and observations of predation on these taxa by spiders were less common compared to pest predation, one can assume that spiders have a minimal effect on their populations.

In the ground covers, 55 spider species representing 14 families were collected in a yearlong study (10 samples of 200 sweeps per orchard). Numbers and diversity were highest in GVN 1 (n=631, 40 spp.), followed by REM (n=580, 35 spp.) and GVN 19 (n=549, 36 spp.). Spider abundance was affected by the vegetative composition of the ground covers, but the influence on spider diversity was less pronounced. Numbers of parasitoids and ladybirds occasionally exceeded spider numbers, and their abundance appears to be affected by ground covers too. These insects displayed an apparent preference for weedy plants, which may accommodate suitable hosts and prey, respectively. The ground cover spider fauna was dominated by two species, the green lynx spider *Peucetia viridis* (Blackwall) (Oxyopidae, 29.3%), and *H. pistaciae* (23.4%). Populations in all three orchards peaked in summer (January-February), and were dramatically affected by ground cover mowing and nut harvesting in March. Nine species of spiders observed in the field (*P. viridis*, *H. pistaciae*, *C. furculatum*, *N. subfusca*, *Archaeodictyna* sp. [Dictynidae], *Pardosa crassipalpis* Purcell [Lycosidae], *Philodromus* spp. [Philodromidae], *Phlegma* sp. [Salticidae] and *Thomisus* spp. [Thomisidae]) were found to prey on nine orders of insect prey, including five minor pest taxa (the aforementioned taxa, except mites). This could be a positive indication that spiders may play a role in suppressing populations of these pests in the ground covers, where they feed on alternate host plants. The dispersal of these pests to the tree canopies under favourable environmental conditions or under high levels of competition may threaten the health and production of the pistachio trees. Consequently, predation by spiders in ground

covers may play a role in keeping population numbers of these pests in check before they can damage the crop.

On the ground level, spider populations in three orchards were compared with a stand of undisturbed, natural grassland (veld). Using pitfall traps and active searching as the collecting methods, a total of 105 species representing 29 families were sampled. The study indicated that the disturbance effects associated with orchard management have a strongly negative effect on the diversity and abundance of epigeic spiders in pistachio orchards. In veld, 1112 spiders representing 57 species were collected by pitfall trapping, while significantly fewer spiders and species were collected in REM (n=704, 35 spp.), GVN 1 (n=560, 26 spp.) and GVN 1 (n=428, 25 spp.). The dominant species in two habitats was also different, reflecting the differential adaptability of spider species to agricultural disturbance. The veld population was dominated by the ground spider, *Asemesthes lineatus* Purcell (Gnaphosidae, 29.1%), a species that was extremely scarce in the orchards, while the orchard fauna was dominated by the sheet-web builder, *Ostearius melanopygius* (O. P.-Cambridge) (Linyphiidae, mean=29.3%), which only represented 4.4% of the veld fauna. In the pistachio orchards, number of ants exceeded those of spiders, but this is to be expected, as highly mobile ant workers are likely to form a large proportion of arthropods captured in pitfalls. A total of 645 spiders were collected in the three orchards by active searching, representing 63 species, 25 of which were uniquely collected by this method. Numbers and diversity were highest in GVN 1 (n=262, 47 spp.), second highest in REM (n=219, 32 spp.), and lowest in GVN 19 (n=164, 31 spp.). These differences could be attributed to the heterogeneity of the ground cover vegetation in GVN 1 (providing a greater variety of niches), as well as the patchy distribution of spider populations among different vegetation types. Epigeic spiders may play a role in pest control by feeding on pests that are disturbed in the pistachio canopy and ground covers, and fall to the ground, where they may be captured and consumed by epigeic predators.

In comparisons of the fauna of the three strata, 87.3% of the ground cover species and 49.5% of the epigeic species were also found to occur in the tree canopy. However, none of the "typical" ground-dwelling species collected in the survey of epigeic spiders represented more than 2% of the arboreal fauna. The degree of overlap in the species

composition of the ground covers and tree canopies, as well as the numerical abundance of *H. pistaciae* in both strata, indicates that ground covers, and to a lesser degree, the epigeic fauna, play an important role in supplementing the arboreal fauna. These two strata can consequently serve as sources from which the tree canopy can be recolonised following pesticide applications, as well as to increase arboreal numbers and diversity, enhancing the impact of spiders on pest organisms.

Numerous agrobiont species, which can be defined as predatory species reaching high levels of dominance in agroecosystems, were identified. Most notable was *H. pistaciae*, which comprised an average of 53.8% of the arboreal fauna and 23.4% of the ground cover fauna. Interestingly, the species was described from specimens collected in this study, which is unusual, considering the high numbers collected here. *Peucetia viridis* was common in the ground covers (29.3%), but was rather scarce in the tree canopies. *Pardosa crassipalpis* has also been commonly found in other crops in South Africa, and qualifies as an agrobiont. Two other ground-dwelling species, *O. melanopygius* and *Phlegma* sp., were sufficiently abundant in at least one orchard to warrant future consideration for agrobiont status. This would be subject to studies of the epigeic fauna in other agroecosystems to determine whether their abundance is widespread.

Additional studies were conducted on *H. pistaciae* to determine aspects of the biology of this species. This species was targeted for specific study in regard to its high numerical abundance in two of the three orchard strata; the seasonal abundance, reproductive biology, prey spectrum, and parasitism effects were studied. The seasonal fluctuations of the arboreal and ground cover spider populations, as a whole, were probably affected by the numerical dominance of *H. pistaciae*, whose populations peaked in late spring and summer in the tree canopies, and early summer in the ground covers of the three orchards. Six minor pests (listed above) form part of the prey spectrum of *H. pistaciae* in the field. Two parasitic organisms, the egg parasite *Odontacolus* sp. (Hymenoptera: Scelionidae), and an unidentified ectoparasitic polysphictine wasp (Hymenoptera: Ichneumonidae) parasitising female *H. pistaciae*, were found associated with this species. The seasonal abundance and distribution of *H. pistaciae* in pistachio, as

well as field observations on their prey spectrum, would suggest that this species might have a role to play in the control of various minor pests.

As such, the predation potential of *H. pistaciae* on *Nysius natalensis* Evans (Hemiptera: Lygaeidae), a minor pest of pistachio nuts, was studied under laboratory and field conditions. Although consumption of *N. natalensis* was significantly lower for both sexes than on vinegar flies, *Drosophila melanogaster* Meigen (Diptera: Drosophilidae), *H. pistaciae* females also preyed on *N. natalensis* in the field (mean = 1.38 per day), and consequently, there are indications that *H. pistaciae* may play a role in the control of this pest in pistachio tree canopies. Generally, females preyed on significantly greater numbers of both prey, which may be indicative of the nutritional requirements of females for reproduction, the fact that males may spend more time searching for mates than they do feeding, as well as the smaller size of the males, and consequently, the relatively larger size of the prey species, which may influence capture success.

Numerous possibilities exist for the further study of spiders in pistachio and other orchards in the Prieska district. Firstly, more intensive sampling should be conducted on figs, walnuts, pecan nuts and olives to determine the species composition of these orchards, and determine whether *H. pistaciae* is also abundant on these crops. Initial, non-quantitative random samplings on these crops indicated that *H. pistaciae* is also common here, but that the relative abundance varies between crops. *Cheiracanthium furculatum*, and orb-weavers of the genus *Neoscona* were also common on these crops. Only after surveys have been done can their role in the control of pests on these crops be quantified.

Further feeding tests should also be conducted to determine the role of *H. pistaciae* and other numerically abundant species in all three strata on pest organisms, perhaps using larger cages to reduce the effects of cage size on spider behaviour. No species other than *H. pistaciae* was studied with regard to control of *N. natalensis*. In view of the nut damage caused by this pest, assessments of the biocontrol potential of other species should be assessed in the near future. The role of spiders as predators of eggs and early instar nymphs of the stinkbug, *Atelocera raptoria* Germar (Pentatomidae), should also be assessed. The adults of this species are too large to be captured by almost all spider species present. This species is one of the major pests on pistachio, and

presently, little is known of their control by spiders. On six occasions, preying mantids (Mantidae) were found feeding on these stinkbugs, and investigations into enhancing this predator group should also be investigated, as they appear an important natural enemy of this pest. The possibility of utilising egg parasites of stinkbugs should also be considered.

Presently, little is known of the actual damage that these pests cause to pistachio nuts and foliage, and investigations to broaden the knowledge of pest phenology, damage (including economic threshold levels), and control should be conducted, so as to avoid indiscriminate use of pesticides, which may harm natural enemies. The role that spiders may play in the biological control of the aforementioned minor pests needs to be further investigated. This will provide information on the importance that they may play in the regulation of pest populations, as well as their relative importance as natural enemies compared to insect predators and parasitoids.

Presently, endosulphan is the only insecticide applied to the pistachio tree canopy at GVN and REM (for control of hemipteran pests and mites), although a variety of herbicides are applied for weed control in tree rows, and fungicides for various diseases in the trees. The impact of these pesticides on spider communities, as well as individual species of spiders and other natural enemies, needs to be assessed to determine impacts on natural enemies forming part of an orchard IPM system.

Albeit somewhat beyond the scope of the present study, nine new and six possibly new species of spiders were also discovered, and provided material for taxonomic studies from an area that had not been previously sampled in South Africa. An effort should be made to describe these new species, thereby increasing the knowledge of spider diversity in the Afrotropical region, but especially in African agroecosystems, which are both still grossly under-researched. This study has thereby highlighted the value that ecological surveys have in increasing the taxonomic knowledge of the fauna on this continent.