Arboreal spiders (Arachnida: Araneae) in pistachio orchards in South Africa

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As part of a biomonitoring programme on pistachio orchards in South Africa, spiders were collected from tree canopies in three orchards from January 2001 to December 2002, using an insecticide mistblower and dichlorvos as a knockdown agent. Sampling was conducted in two orchards (GVN 1 and GVN 19) on the Green Valley Nuts Estate, and one orchard (REM) on the farm Remhoogte. In total, 5843 spiders were collected, representing 18 families and 88 species. Numbers and diversity were highest in REM ($n = 2240$, 69 species.), followed by GVN 1 ($n = 2055$, 64 species) and GVN 19 ($n = 1548$, 47 species). Three species dominated the spider fauna: the jumping spider *Heliophanus pistachio* Wesołowska (53.4%), the sac spider *Cheiracanthium furculatum* Karsch (12.7%) and the orb-web spider *Neoscona subfusca* (C L Koch) (6.4%). There were significantly more spiders during 2001 and 2002 in the older orchards, GVN 1 and REM, than in the younger orchard, GVN 19. Differences in abundance between orchards differed between months, with no consistent pattern. Sørensen's quotient values indicated a greater similarity between the faunas of the two older orchards than between the older orchards and the young orchard, indicating that orchard age has an effect on diversity. Spiders are abundant generalist predators in pistachio orchards, and probably play an important role in pest control.

Key words: abundance, age, Araneae, diversity, IPM, pistachio.

Pistachio, *Pistacea vera* L. (Anacardiaceae), is presently being established as a new crop in South Africa. The introduction of a new crop in a country foreign to its origin always carries the risk of unknown pest and pathological threats that may hinder the establishment of the crop and successful production. As part of a continued integrated pest management (IPM) programme on pistachio, a biomonitoring programme was initiated to determine the insect and arachnid fauna in these orchards, with the aim of identifying target pest species and the natural enemies that may play a role in their control.

There is limited knowledge of the pest status and damage of many of the herbivores occurring in pistachio orchards in South Africa. The biomonitoring programme has to date identified several key and minor pests. Two key pests are the woolly chafer *Sparrmannia flava* Arrow (Coleoptera: Scarabaeidae: Melolonthinae), which causes extensive defoliation of trees, and the stinkbug *Atelocera raptoria* Germar (Hemiptera: Pentatomidae), which causes leaf damage to young trees and physical damage to nuts in older trees (Swart 2002; Louw & Fourie 2004). *A. raptoria* has already been implicated as a pest of macadamia nuts in the Mpumulanga Lowveld (Van den Berg et al. 1999).

Spiders form an important part of the predatory guild in many agroecosystems (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. 2001; Yee et al. 2001). Recently they have received an increased amount of attention regarding their role as predators in agroecosystems (reviewed in Nyffeler & Benz 1987). It has been shown that a single spider species is not capable of controlling a particular pest species, but rather that the spider community on a crop is collectively able to suppress a pest species below damaging levels (Riechert & Lawrence 1997). As both of the major pistachio pests are large (>15 mm in length), spiders may only play a limited role in their control. The impact of spiders is likely to be greater on minor pests, such as the false chinch bug, *Nysius natalensis* Evans (Hemiptera: Lygaeidae), which causes physical damage to pistachio nuts (Swart 2002).

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Table 1. Characteristics of three pistachio orchards surveyed at Green Valley Nuts Estate (GVN) and on 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, irrigated fields and pistachio orchards	Surrounded by other pistachio orchards orchards	Bordered by riverine bush, irrigated fields and disturbed grassland

A study on the predation of *N. natalensis* by an agrobiont jumping spider in pistachio, *Heliophanus pistaciae* Wesołowska (Salticidae), indicated that this pest species forms part of the spider's prey spectrum in the field (Haddad et al. 2004a).

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). Surveys of spiders in South Africa have recently received an increased amount of attention as the role of these organisms as predators in agroecosystems 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), macadamia (Dippenaar-Schoeman et al. 2001a), avocado (Dippenaar-Schoeman et al. 2005) and ground covers in pistachio orchards (Haddad et al. 2004b). Locally, the role of spiders as biocontrol agents of mites in strawberries and cotton (Dippenaar-Schoeman 1976; Van den Berg & Dippenaar-Schoeman 1991), of citrus pests (Van den Berg et al. 1987, 1992; Dippenaar-Schoeman 1998), and a minor pistachio pest (Haddad et al. 2004a) has been studied.

The present study considered the diversity and abundance of arboreal spiders in three pistachio orchards. It is the first survey of the arboreal spider fauna of pistachio orchards in the world, and forms part of the South African National Survey of Arachnida (SANSA) in agroecosystems.

Materials and methods

Study area

The study was carried out in two orchards (GVN 1 and GVN 19) on the Green Valley Nuts Estate (GVN; 22°56′41″S, 29°35′11″E), and a third orchard (REM) on the farm Remhoogte (23°00′06″S, 29°31′55″E) in the Prieska district, Northern Cape Province, South Africa. The farms fall within the semi-arid region of South Africa, with annual rainfall averaging between 200 and 300 mm. The natural vegetation in the region is classified as Orange River Nama Karoo (Hoffman 1996). Characteristics of each orchard, at the beginning of the study in January 2001, are summarised in Table 1.

All orchards were subject to applications of various chemicals as part of an IPM programme. Plant growth stimulants (Bladbuff™, Commodobuff™, Optibor™, Compliment™) were used for promotion of pistachio flowering, budding and nut growth. Pesticide treatments were identical in frequency and timing in all three orchards. Roundup™ was applied to weeds in the tree rows to prevent encroachment on the trees. The only insecticides applied were parathion in April and endosulphan in December, during both seasons, for the control of stinkbugs and other hemipterans. Benlate™ was applied as a fungicide to control infections by various fungal pathogens.

Sampling methods

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 in the trees during the cold winter months. Most arthropods found during winter were overwintering under bark or in dead leaves in the tree canopy.

Ten trees were randomly selected in each orchard on each sampling 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 (15 ml 10 l^{-1} water) was used as a knock-down 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 (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.

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 from each tree.

Owing to extremely windy conditions, which made fogging impossible, trees were sampled using a beating sheet (0.5 × 0.5 m) in REM during September 2001, and in GVN 19 and REM in December 2002. The branches in the lower half of two trees were beaten to account for the branches in a single tree. All spiders on the sheet were collected. Searching was carried out as described above.

Some species could only be identified to genus or subfamily level due to the unresolved taxonomy of certain families or the presence of immatures in the samples. Species represented by adults that could not be determined to species level due to inadequate descriptions are referred to by morphospecies number. Voucher specimens have been deposited in the National Collection of Arachnida (NCA), ARC-Plant Protection Research Institute, Pretoria, South Africa.

Statistical analysis

Data on monthly spider abundances were analysed with the linear mixed effects model (LME) and the generalised linear model (GLM) within R (R Development Core Team 2004). In LME, orchard type was a fixed factor and the month of sampling a random factor. The analysis was carried out separately for 2001 and 2002. As the data did not meet assumptions of normality and homoscedasticity they were log-transformed prior to analysis. This was followed by a comparison of abundances for particular months using GLM with Poisson error structure. Since the Poisson model showed overdispersion, the quasi-poisson family was used instead. Post hoc comparisons between orchards were done using *t*-tests (Crawley 2002).

Species richness was determined as the number of species in an orchard divided by the total species in all three orchards. 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 (Magurran 1988). A higher value (closer to 1) indicates greater similarity between the faunas at the two sites.

Results

Abundance

A total of 5843 spiders, represented by 18 families and 88 species, was collected in the three orchards during the course of this study (Table 2). This includes four new species, two described by Wesołowska (2003).

Total numbers of spiders were highest in REM (n = 2240), followed by GVN 1 (n = 2055) and GVN 19 (n = 1548). Only three species individually comprised more than 5% of the total spider fauna (Table 2), namely the jumping spider *Heliophanus pistaciae* (Salticidae, 53.4%), the sac spider *Cheiracanthium furculatum* Karsch (Miturgidae, 12.7%), and the orb-weaver *Neoscona subfusca* (C L Koch) (Araneidae, 6.4%). Family abundance showed a skewed dominance, with the Salticidae most common in all three orchards. In GVN 1 they comprised 65.9% of the total catch, in GVN 19, 61.2%, and in REM, 51.6%. Among the remaining families only the Miturgidae (9.9%, 16.0%, and 13.9% in GVN1, GVN 19 and REM, respectively), Araneidae (7.2%, 4.1%, 13.2%) and Theridiidae (4.4%, 7.9%, 4.2%,) represented, on average, more than 5% of the fauna (Table 2).

In 2001 (Fig. 1) there was a significant difference in the abundance of spiders between orchards (LME, F-test, $P = 0.0003$). There were, however, significantly more spiders throughout the season in GVN 1 and REM than in GVN 19 (t-tests, $P < 0.003$). Only in a few months were the differences between orchards significant (GLM, F-test, $P < 0.05$). The differences were not consistent throughout the season. In January, there were more spiders in GVN 1 and GVN 19 than in REM (GLM, $P = 0.046$). In February, no differences were found (GLM, $P = 0.18$). In March, there were significantly more spiders in GVN 1 and REM than in GVN 19 (GLM, $P = 0.044$). From April to Septem-

Table 2. Diversity and abundance of arboreal spiders collected in pistachio orchards from January 2001 to December 2002.

Family/species	GVN 1	GVN 19	REM	Total	% of total
ARANEIDAE					
Araneus sp.		1		1	0.02
Cyrtophora citricola (Forskål, 1775)			2	2	0.03
Hypsosinga sp.		1		1	0.02
Neoscona blondeli (Simon, 1885)	34	15	65	114	1.95
Neoscona moreli (Vinson, 1863) ?	1		1	2	0.03
Neoscona rapta (Thorell, 1899)	2			2	0.03
Neoscona subfusca (C L Koch, 1837)	105	46	225	376	6.44
Neoscona sp. 5	4			4	0.07
Pararaneus cyrtoscapus (Pocock, 1898)	1		4	5	0.09
CORINNIDAE					
Austrachelas sp. imm.	1			1	0.02
Cambalida coriacea Simon, 1909	2			2	0.03
Castianeira sp. 1		3	10	13	0.22
Castianeira sp. 2		2		2	0.03
Cetonana simoni (Lawrence, 1942)	2		1	3	0.05
Copa flavoplumosa Simon, 1885	3	1	19	23	0.39
Trachelas pusillus Lessert, 1923	2		2	4	0.07
DICTYNIDAE					
Archaeodictyna sp.	35	28	61	124	2.12
GNAPHOSIDAE					
Aneplasa nigra Tucker, 1923	6	5	5	16	0.27
Camillina cordifera (Tullgren, 1910)	1	1	2	4	0.07
Drassodes sesquidentatus Purcell, 1908	8	11	5	24	0.41
Echemus sp.		1	1	2	0.03
Latonigera sp.			10	10	0.17
Micaria sp.	1	2	3	6	0.10
Pterotricha auris (Tucker, 1923)	1		3	4	0.07
Setaphis subtilis (Simon, 1897)	1		1	2	0.03
Trichothyse sp.	1	2	1	4	0.07
Xerophaeus vickermani Tucker, 1923		2		2	0.03
Xerophaeus sp. 2	2	1	4	7	0.12
LINYPHIIDAE					
Eperigone fradeorum (Berland, 1932)	14	2	23	39	0.67
Erigone sp.		1	2	3	0.05
Meioneta habra Locket, 1968	8	3	8	19	0.33
Meioneta sp. 2 †	1	2	2	5	0.09
Meioneta sp. 3	1	2	2	5	0.09
Metaleptyphantes familiaris Jocqué, 1984	1			1	0.02
Microlinyphia sterilis (Pavesi, 1883)	1		3	4	0.07
Ostearius melanopygius (O P-Cambridge, 1879)	49	15	37	101	1.73
Pelecopsis janus Jocqué, 1984			1	1	0.02
Tybaertiella sp.	1			1	0.02
LYCOSIDAE					
Pardosa crassipalpis Purcell, 1903	10	7	7	24	0.41
MIMETIDAE					
Mimetus sp. ‡			1	1	0.02
MITURGIDAE					
Cheiracanthium furculatum Karsch, 1879	202	240	302	744	12.73
Cheiracanthium vansoni Lawrence, 1936	2	7	9	18	0.31

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Table 2 (*continued*)

Family/species	GVN 1	GVN 19	REM	Total	% of total
OXYOPIDAE					
Oxyopes bothai Lessert, 1915 ?	1	1	2	4	0.07
Oxyopes hoggi Lessert, 1915	1		1	2	0.03
Peucetia viridis (Blackwall, 1858)	20	7	27	54	0.92
PHILODROMIDAE					
Gephyrota sp. ‡			7	7	0.12
Hirriusa arenacea (Lawrence, 1927)			2	2	0.03
Philodromus browningi Lawrence, 1952	13	1	15	29	0.50
Philodromus sp. 2	48	60	81	189	3.23
Suemus sp. ‡	3			3	0.05
Thanatus sp.	1	2		3	0.05
PHOLCIDAE					
Smeringopus sp.		1		1	0.02
PISAURIDAE					
Rothus vittatus Simon, 1898	1		6	7	0.12
SALTICIDAE					
Heliophanus charlesi Wesołowska, 2003 †	14	8	3	25	0.43
Heliophanus pistaciae Wesołowska, 2003 †	1230	860	1028	3118	53.36
Heliophanus trepidus Simon, 1910	6	2		8	0.14
Mogrus sp. ?			1	1	0.02
Myrmarachne sp.		5	1	6	0.10
Natta horizontalis Karsch, 1879	8	3	4	15	0.26
Pellenes sp.	2	4	5	11	0.19
Phintella sp.	1	1	4	6	0.10
Phlegra sp.	4	7	8	19	0.33
Pseudicius sp. 1 †	3		3	6	0.10
Pseudicius sp. 2	5	3	5	13	0.22
Pseudicius sp. 3			3	3	0.05
Salticidae sp. (undetermined genus)		2		2	0.03
Thyene inflata (Gerstaecker, 1873)	78	53	89	220	3.77
Tusitala barbata Peckham & Peckham,1902	4		2	6	0.10
SEGESTRIIDAE					
Ariadna sp.			1	1	0.02
TETRAGNATHIDAE					
Tetragnatha sp. imm.			1	1	0.02
THERIDIIDAE					
Enoplognatha sp.	1		1	2	0.03
Euryopis sp.	15	77	52	144	2.46
Latrodectus geometricus C L Koch, 1841		1	3	3	0.05
Theridion sp. 1	73	44	36	153	2.62
Theridion sp. 2	2		4	6	0.10
THOMISIDAE					
Diaea puncta Karsch, 1884	1		2	3	0.05
Heriaeus sp. ‡	1			1	0.02
Misumenops rubrodecoratus Millot, 1942	4	2	7	13	0.22
Monaeses austrinus Simon, 1910			1	1	0.02
Monaeses quadrituberculatus Lawrence, 1927	2			2	0.03
Oxytate sp. ‡	1			1	0.02
Runcinia depressa Simon, 1906	1		1	2	0.03
Thomisus kalaharinus Lawrence, 1936	2		2	4	0.07

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Table 2 (*continued*)

Family/species	GVN 1	GVN 19	REM	Total	% of total
Thomisus machadoi Comellini, 1959	1			1	0.02
Thomisus stenningi Pocock, 1900	4	3	2	9	0.15
Xysticus sp.	1		5	6	0.10
ULOBORIDAE					
Uloborus plumipes Lucas, 1846 ?			3	3	0.05
Uloboridae sp.			1	1	0.02
Total number of spiders	2055	1548	2240	5843	~100.00
Total number of species	64	47	69	88	–
Species richness	0.736	0.540	0.784	–	–

† indicates a new species.
‡ indicates a possible new species.
? indicates a tentative identification.

ber no differences between orchards were found (GLM, $P > 0.11$). In October, there were significantly more spiders in REM than in GVN 1 and GVN 19 (GLM, $P = 0.011$), and in November and December no differences were found (GLM, $P > 0.10$).

In 2002 (Fig. 2), a similar situation prevailed. Again significant differences were found between orchards (LME, *F*-test, $P = 0.015$). In particular, there were significantly more spiders throughout the season in GVN 1 and REM than in GVN 19 (*t*-tests, $P < 0.02$). The differences varied between months. In January, there were significantly more spiders in GVN 1 and REM than in GVN 19 (GLM, $P = 0.012$). In February and March no significant differences were found (GLM, $P > 0.63$). In April, there were significantly more spiders in REM and GVN 19 than in GVN 1 (GLM, $P = 0.02$). In May and July no significant differences were found (GLM, $P > 0.26$). In September and October, there were significantly more spiders in REM and GVN 1 than in GVN 19 (GLM, $P < 0.0008$). In November there were significantly more spiders in GVN 1 than in GVN 19 and REM (GLM, $P < 0.00001$), and in December, no difference between orchards was found (GLM, $P = 0.22$).

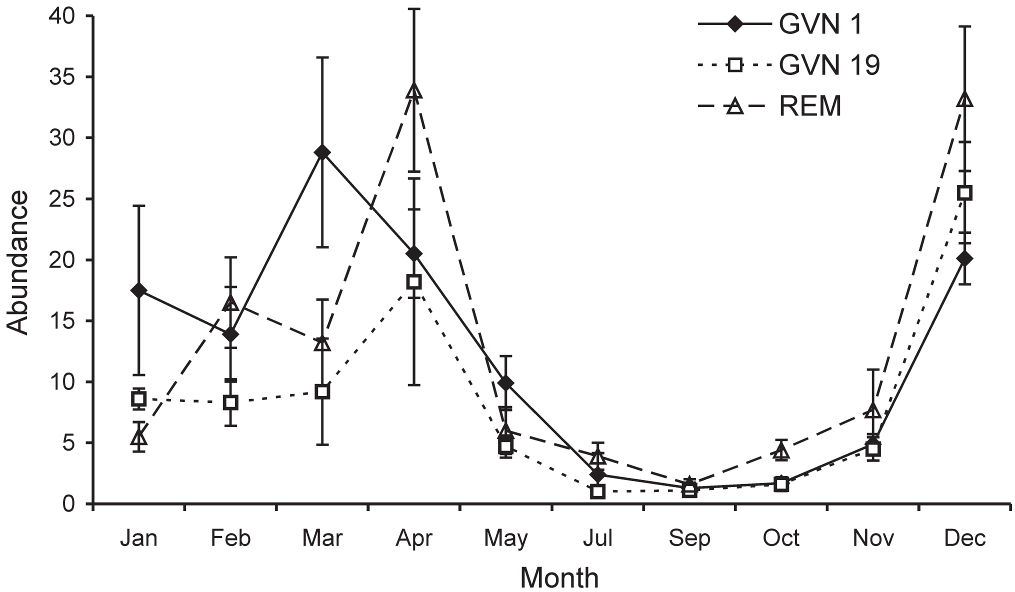

Fig. 1. Seasonal abundances (mean ± SE) of spiders in three pistachio orchards in 2001.

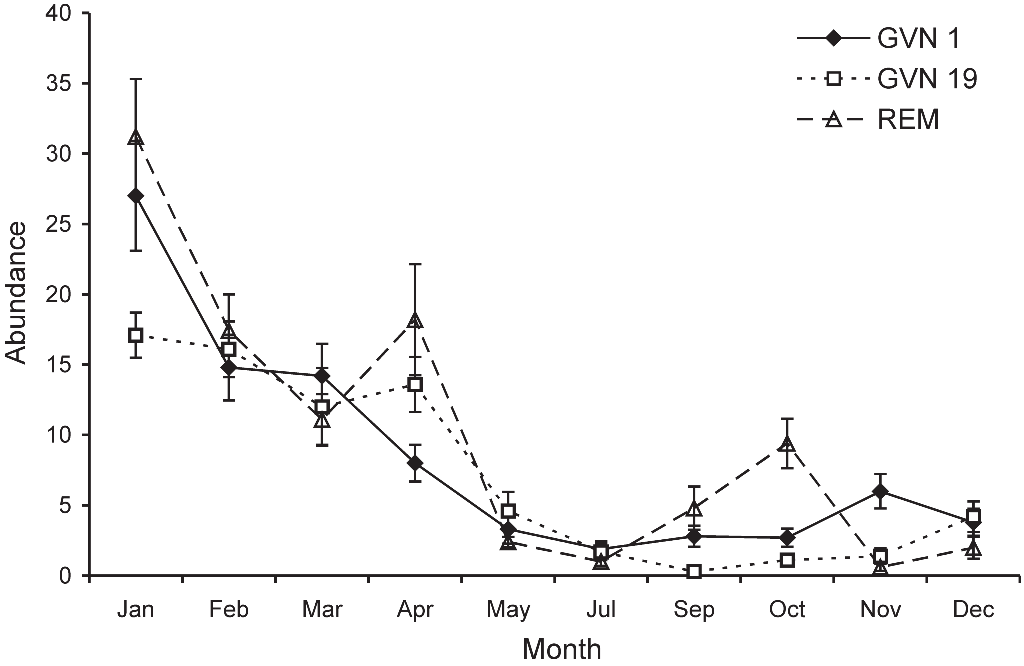

Fig. 2: Seasonal abundances (mean ± SE) of spiders in three pistachio orchards in 2002.

Diversity

Species diversity was highest in REM (69 spp.), followed by GVN 1 (64 spp.) and GVN 19 (47 spp.) (Table 2). In addition to being the most abundant family, the Salticidae was also the most diverse, with 15 species. This family was the most diverse in all three orchards. Other diverse families included the Gnaphosidae and Thomisidae (11 spp., 12.5% each), and Linyphiidae (10 spp., 11.4%).

Species richness (Table 2) was greatest in REM (0.784), and only slightly lower in GVN 1 (0.727). This could be expected, as REM is only a year older than GVN 1. Species richness was considerably lower in 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 (0.752) than between GVN 19 and GVN 1 (0.649) and between GVN 19 and REM (0.672), indicating that older pistachio orchards have comparable community compositions.

Discussion

Spider abundance and diversity recorded in the present study are in agreement with results reported by Van den Berg et al. (1992) for citrus and Dippenaar-Schoeman et al. (2001a) for macadamia in South Africa, where spiders represented a diverse and abundant group of generalist predators. Together these surveys suggest that salticids may dominate the spider fauna in orchard crops in the subtropical to semi-arid regions of southern Africa. In southern Europe and the United States, jumping spiders were also found to be common on apples (Samu et al. 1997; Wisniewska & Prokopy 1997; Bajwa & Aliniazee 2001) and in vineyards (Costello & Daane 1997; Nobre & Meierrose 2000).

The density of canopy spiders is typically correlated with an increase in the density of branches (Rinaldi & Ruiz 2002), which is related to the age of the trees, as well as the cultivars sampled. Orchard age thus seems to influence the establishment of particular spider species, and may result in an increase in the abundance of rare families. However, disturbance effects in the orchards, such as chemical applications, harvesting, ground cover mowing, may cause temporary local extinctions of rare species.

There was a strong dominance of wandering spiders in this study. However, considerably more web-builders were found in the pistachio orchards than in architecturally similar macadamia orchards (Dippenaar-Schoeman et al. 2001a), but this may simply reflect differences in sampling procedures. In the present study the trees were shaken and searched, which uncovered many sedentary web-builders, whereas Dippenaar-Schoeman et al. (2001a) only sprayed the trees and collected spiders that fell on sheeting under the trees.

Even if web-builders are less abundant than hunters, they often form a substantial proportion of the species in orchards (Dondale 1956; Dondale et al. 1979; Dippenaar-Schoeman et al. 2001a). Webs have additional benefits in biological control, since they add to the mortality of some pests in that they become trapped, although not necessarily fed on by the spiders (Van den Berg et al. 1992; Riechert 1999; Sunderland 1999). 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 these factors increase the likelihood of finding suitable control agents for pests (Marc & Canard 1997).

The higher diversity of spiders collected in GVN 1 and REM compared to GVN 19 can most likely be attributed to the differences in orchard age. It is of importance to note that the results of the present study only reflect the current situation in the pistachio orchards, and that the community composition is likely to change with time as the orchards mature and age. Such changes have been demonstrated in studies on spider succession in orchards by Bogya et al. (2000) and Pekár (2003), in which spider abundance decreased while diversity increased with orchard age. The lower diversity in GVN 19 was consistent across most families, but it was particularly noticeable in the Thomisidae, of which only two species were collected, compared to 10 species in GVN 1 and seven species in REM.

Smaller orchards, particularly those bordering natural habitats, will probably be colonised more rapidly from such areas than larger orchards. This probably also influenced the abundance and diversity of spiders in REM, since it is a smaller and 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. Although the two GVN orchards were the same size, GVN 1 had a much greater abundance and diversity of spiders, again reflecting the influence that orchard age has on spider communities.

The prominence of *H. pistaciae* in pistachio orchards at GVN, on Remhoogte and on other farms in the area, and in other orchards at GVN (figs, walnuts and pecan nuts), strongly supports its classification as an agrobiont species, i.e. a species that reaches high levels of dominance in agroecosystems (Samu & Szinetár 2002). Two other species, *C. furculatum* and *N. subfusca,* also reached high levels of relative abundance on occasion and were also collected throughout the year, and may also be called agrobionts.

Although only a single full season (2001/02) was sampled, spider populations reached a major peak in December/January, and a smaller secondary peak in March/April. Spider populations therefore reach their peak during the crucial period of nut kernel formation, and are most abundant during the period when nuts are attacked by pests. This suggests that spiders are likely to encounter pests at this time, and may play a role in their control.

When using spiders in a biological control programme, an important factor to consider is that 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 (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. In addition, different developmental stages of spider species and their prey will occur in different ratios throughout the year, and this may further affect the efficiency of a spider species in controlling a particular pest.

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References

Amalin D M, Peña J E, McSorley R, Browning H W & Crane J H 2001. Comparison of different sampling methods and effect of pesticide application on spider populations in lime orchards in south Florida. *Environmental Entomology* **30**: 1021–1027.

Bajwa W I & Aliniazee M T 2001. Spider fauna in an apple ecosystem of western Oregon and its field susceptibility to chemical and microbial insecticides. *Journal of Economic Entomology* **94**: 68–75.

Bogya S, Marko V & Szinetar C 2000. Effect of pest management systems on foliage- and grass-dwelling spider communities in an apple orchard in Hungary. *International Journal of Pest Management* **46**: 241–250.

Carroll D P 1980. Biological notes on the spiders of some citrus groves in central and southern California. *Entomological News* **91**: 147–154.

Costello M J & Daane K M 1997. Comparison of sampling methods used to estimate spider (Araneae) species abundance and composition in grape vineyards. *Environmental Entomology* **26**: 142–149.

Costello M J & Daane K M 1999. Abundance of spiders and insect predators on grapes in central California. *Journal of Arachnology* **27**: 531–538.

Crawley M J 2002. *Statistical computing. An introduction to data analysis using S-Plus.* John Wiley & Sons, Chichester, Hampshire.

Dippenaar-Schoeman A S 1976. An ecological study of a spider population in strawberries with special reference to the role of *Pardosa crassipalpis* Purcell (Araneae: Lycosidae) in control of *Tetranychus cinnebarinus* (Boisduval). MSc thesis, Rand Afrikaans University, Johannesburg.

Dippenaar-Schoeman A S 1977. The biology of *Pardosa crassipalpis* Purcell (Araneae: Lycosidae). *Journal of the Entomological Society of Southern Africa* **40**: 225–236.

Dippenaar-Schoeman A S 1979. Spider communities in strawberry beds: seasonal changes in numbers and species composition. *Phytophylactica* **11**: 1–4.

Dippenaar-Schoeman A S 1998. Spiders as predators of citrus pests. In: *Citrus pests in the Republic of South Africa,* 2nd edition, 24–25 (Eds E C G. Bedford, M A Van den Berg & E A De Villiers). ARC-Institute for Tropical and Subtropical Crops, Nelspruit.

Dippenaar-Schoeman A S, Van den Berg A M & Van den Berg A 1999. Spiders in South African cotton fields: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* **5**: 93–103.

Dippenaar-Schoeman A S, Van den Berg A M, Van den Berg M A & Foord S H 2005. Spiders in avocado orchards in the Mpumalanga Lowveld of South Africa: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* **11**: 8–16

Dippenaar-Schoeman A S, Van den Berg M A, Van den Berg A M & Van den Berg A 2001a. Spiders in macadamia orchards in the Mpumulanga Lowveld of South Africa: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* **7**: 39–46.

Dippenaar-Schoeman A S, Van den Berg M A & Van den Berg A M 2001b. Salticid spiders in macadamia orchards in the Mpumulanga Lowveld of South Africa (Arachnida: Araneae). *African Plant Protection* **7**: 47–51.

Dondale C D 1956. Annotated list of spiders (Araneae) from apple trees in Nova Scotia. *Canadian Entomologist* **88**: 697–700.

Dondale C D, Parent B & Pitre D 1979. A 6-year study of spiders (Araneae) in a Quebec apple orchard. *Canadian Entomologist* **111**: 377–380.

Green J 1996. Spiders in biological control – an Australian perspective. In: *Proceedings of the 13th International Congress of Arachnology* (Ed. V Manhert). *Revue Suisse de Zoologie,* hors série, 245–253.

Haddad C R, Louw S v d M & Dippenaar-Schoeman A S 2004a. An assessment of the biological control potential of *Heliophanus pistaciae* (Araneae: Salticidae) on *Nysius natalensis* (Hemiptera: Lygaeidae), a pest of pistachio nuts. *Biological Control* **31**: 83–90.

Haddad C R, Louw S v d M & Dippenaar-Schoeman A S 2004b. Spiders (Araneae) in ground covers of pistachio orchards in South Africa. *African Plant Protection* **10**: 97–107.

Hoffman M T 1996. Orange River Nama Karoo. In: *Vegetation of South Africa, Lesotho and Swaziland*, 1st edition, 71–72 (Eds A B Low & A G Rebelo). Department of Environmental Affairs and Tourism, Pretoria.

Knight A L, Turner J E & Brachula B 1997. Predation on eggs of codling moth (Lepidoptera: Tortricidae) in mating disrupted and conventional orchards in Washington. *Journal of the Entomological Society of British Columbia* **94**: 67–74.

Liao H-T, Harris M K, Gilstrap F E, Dean D A, Agnew C W, Michels G J & Mansour F 1984. Natural enemies and other factors affecting seasonal abundance of the blackmargined aphid on pecan. *Southwestern Entomologist* **9**: 404–420.

Louw S v d M & Fourie D V 2004. Patterns over time: implications of insect phytophagy on pistachio development in South Africa. In: *Proceedings, 2nd Australian New Crops Conference,* 177–186. CD-ROM version.

Magurran A E 1988. *Ecological diversity and its measurement.* Princeton University Press, New Jersey.

Marc P & Canard A 1997. Maintaining spider diversity in agroecosystems as a tool in pest control. *Agriculture, Ecosystems and Environment* **62**: 229–235.

Marshall S D, Walker S E & Rypstra A L 2000. A test for a differential colonization and competitive ability in two generalist predators. *Ecology* **81**: 3341–3349.

Nobre T & Meierrose C 2000. The species composition, within-plant distribution, and possible predatory role of spiders (Araneae) in a vineyard in southern Portugal. In: *Proceedings of the 18th European Colloquium of Arachnology* (Eds P. Gajdoš & S. Pekár). *Ekológia* (Bratislava) **19**: 193–200.

Nyffeler M & Benz G 1987. Spiders in natural pest control: a review. *Journal of Applied Entomology* **103**: 321–339.

Pekár S 2003. Change in the community of epigeal spiders and harvestmen (Araneae, Opiliones) with the age of an apple orchard. *Plant Soil and Environment* **49**: 81–88.

R Development Core Team 2004. *R: A language and environment for statistical computing.* R Foundation for Statistical Computing Vienna, Austria. http://www.R-project.org

Riechert S E 1999. The hows and whys of successful pest suppression by spiders: insights from case studies. *Journal of Arachnology* **27**: 387–396.

Riechert S E & Lawrence K 1997. Test for predation effects of single versus multiple species of generalist predators: spiders and their insect prey. *Entomologia Experimentalis et Applicata* **84**: 147–155.

Rinaldi I M P & Ruiz G R S 2002. Comunidades de aranhas (Araneae) em cultivos de seringueira (*Hevea brasiliensis* Muell. Arg.) no Estado de São Paulo. *Revista Brasiliera de Zoologia* **19**: 781–788.

Samu F, Rácz V, Erdélyi C & Balázs K 1997. Spiders of the foliage and herbaceous layer of an IPM apple orchard in Kecskemét-Szarkás, Hungary. *Biological Agriculture & Horticulture* **15**: 131–140.

Samu F & Szinetár C 2002. On the nature of agrobiont spiders. *Journal of Arachnology* **30**: 389–402.

Specht H B & Dondale C D 1960. Spider predators in New Jersey apple orchards. *Journal of Economic Entomology* **53**: 810–814.

Sunderland K D 1999. Mechanisms underlying the effects of spiders on pest populations. *Journal of Arachnology* **27**: 308–316.

Swart V R 2002. Insect-fungal ecology on selected new crops in South Africa. MSc thesis, University of the Free State, Bloemfontein.

Van den Berg A M & Dippenaar-Schoeman A S 1991. Spiders, predacious insects and mites on South African cotton. *Phytophylactica* **23**: 85–86.

Van den Berg M A, Deacon V E, Fourie C J & Anderson S H 1987. Predators of the citrus psylla, *Trioza erytreae* (Hemiptera: Triozidae), in the Lowveld and Rustenburg areas of Transvaal. *Phytophylactica* **19**: 285–289.

Van den Berg M A, Dippenaar-Schoeman A S, Deacon V E & Anderson S H 1992. Interactions between the citrus psylla, *Trioza erytreae* (Hemiptera: Triozidae), and spiders in an unsprayed citrus orchard in the Transvaal Lowveld. *Entomophaga* **37**: 599–608.

Van den Berg M A, Steyn M A & Greenland J 1999. Hemiptera occurring on macadamia in the Mpumalanga Lowveld of South Africa. *African Plant Protection* **5**: 89–**92.**

Wesołowska W 2003. New data on African *Heliophanus* species with descriptions of new species (Araneae: Salticidae). *Genus* **14**: 249–294.

Wilby A & Thomas M B 2002. Are the ecological concepts of assembly and function of biodiversity useful frameworks for understanding natural pest control *Agricultural and Forest Entomology* **4**: 237–243.

Wisniewska J & Prokopy R J 1997. Pesticide effect on faunal composition, abundance, and body length of spiders (Araneae) in apple orchards. *Environmental Entomology* **26**: 763–776.

Yee W L, Phillips P A, Rodgers J L & Faber B A 2001. Phenology of arthropod pests and associated natural predators on avocado leaves, fruit, and in leaf litter in southern California. *Environmental Entomology* **30**: 892–898.

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